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ORCA Benchmark Underwater Radiated Noise Simulation (BURNSi) Measurement Trial Report

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Reference Document

DRDC-RDDC-2021-D009

February 2021

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Abstract

A research project is currently being undertaken by Transport Canada (TC) to better understand the impact of marine vessel generated noise on marine life on the West Coast of Canada. In support of the research project, Defence Research and Development Canada (DRDC) – Atlantic Research Centre carried out a set of trials in July 2019 and measured both onboard vibrations and off board underwater noise levels generated by an ORCA-class training ship available from the Royal Canadian Navy (RCN) on the West Coast. The measurements showed onboard vibration levels can be used to predict the underwater radiated noise from the vessel and that it is possible to monitor propeller cavitation. As a result of this trial, the Netherlands Defence Materiel Organization (DMO) proposed an international workshop, the Benchmark Underwater Radiated Noise Simulation (BURNSi) workshop. Participants of the workshop would be provided with the necessary onboard data, drawings and structural models and they would then perform blind predictions of the ship's underwater radiated noise to validate their prediction model as a spinoff. The participants would then gather to compare predictions and the previously measured noise levels. As the previous trial did not gather all the necessary information to support such a workshop, DRDC carried out additional trials on the same ship in pursuit of characterizing structure and airborne noise contribution from main machinery noise sources; identifying flanking paths by measuring vibration levels on all presumed flanking paths (e.g., cooling water, lube oil, propeller shaft); evaluating the impact of machinery mounts (when applicable) on structure-borne noise transfer; and measuring ship foundation mechanical impedance. This Reference Document outlines the work that was done, the completed list of runs performed and other measurements made, and some preliminary results.

Significance to Defence and Security

The data from these trials will be used to support the underwater noise prediction capability of both research organizations and other participants in the planned BURNSi workshop, and will increase our confidence in our ability to predict the underwater noise of naval platforms.

Résumé

Un projet de recherche est actuellement entrepris par Transports Canada (TC) pour mieux comprendre l'impact du bruit généré par les navires sur la vie marine sur la côte ouest du Canada. À l'appui du projet de recherche, Recherche et développement pour la défense Canada (RDDC) – Centre de recherches de l'Atlantique a réalisé une série d'essais en juillet 2019 et a mesuré les vibrations à bord et les niveaux de bruit sous-marin hors bord générés par un navire-école de classe ORCA disponible auprès de la Marine royale canadienne (MRC) sur la côte ouest. Les mesures ont montré que les niveaux de vibration à bord peuvent être utilisés pour prédire le bruit sous-marin rayonné du navire et qu'il est possible de surveiller la cavitation de l'hélice. À la suite de cet essai, l'Organisation néerlandaise du matériel de défense (OGD) a proposé un atelier international, l'atelier Benchmark Underwater Radiated Noise Simulation (BURNSi). Les participants à l'atelier recevraient les données de bord, les dessins et les modèles structurels nécessaires, puis ils effectueraient des prédictions aveugles du bruit rayonné sous-marin du navire pour valider leur modèle de prévision en tant que retombée. Les participants se réunissaient ensuite pour comparer les prévisions et les niveaux de bruit mesurés précédemment. Comme l'essai précédent n'a pas rassemblé toutes les informations nécessaires pour soutenir un tel atelier, RDDC a effectué des essais supplémentaires sur le même navire afin de caractériser la structure et la contribution au bruit aérien provenant des principales sources de bruit des machines; identifier les trajectoires flanquantes en mesurant les niveaux de vibration sur toutes les trajectoires flanquantes présumées (par exemple eau de refroidissement, huile de lubrification, arbre d'hélice); évaluer l'impact des supports de machines (le cas échéant) sur le transfert du bruit véhiculé par la structure; et mesurer l'impédance mécanique des fondations du navire. Ce document de référence décrit le travail effectué, la liste complète des analyses effectuées et des autres mesures effectuées, ainsi que quelques résultats préliminaires.

Importance pour la défense et la sécurité

Les données de ces essais seront utilisées pour soutenir la capacité de prévision du bruit sous-marin des organismes de recherche et d'autres participants à l'atelier BURNSi prévu, et augmenteront notre confiance dans notre capacité à prédire le bruit sous-marin des plates-formes navales.

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1 Introduction

Transport Canada (TC) is working on projects to better understand the impact of marine vessel generated noise on marine life on the West Coast of Canada, in particular, the Southern Resident Killer Whale population. In support of these projects [1] [2], Defence Research and Development Canada (DRDC) – Atlantic Research Centre carried out a set of trials in July 2019 and measured both onboard vibrations and off board underwater noise levels generated by the Royal Canadian Navy (RCN) ORCA-class training ship, Patrol Craft, Training (PCT) MOOSE available on the West Coast [3]. The measurements showed onboard vibration levels can be used to predict the underwater radiated noise from the vessel (due to machinery or propeller noise) and that it is possible to monitor propeller cavitation [4] [5].

As a result of this trial, the Netherlands Defence Materiel Organization (DMO) proposed an international workshop, the Benchmark Underwater Radiated Noise Simulation (BURNSi) workshop [6] in which participants would be provided with the necessary onboard data and structural models and they would then perform blind predictions of the ship's underwater radiated noise. The participants would then gather to compare predictions and the previously measured noise levels. As the previous trial did not gather all the necessary information to support such a workshop, DRDC performed additional trials on PCT MOOSE in February 2020, at the RCN's Patricia Bay (Pat Bay) acoustic range near Victoria, Canada. The objectives of this trial included:

- Determining structure-borne and airborne noise contributions from main machinery noise sources;
- Identifying flanking paths by measuring vibration levels on presumed flanking paths (e.g., cooling water, lube oil);
- Evaluating the impact of machinery mounts (when applicable) on structure-borne noise transfer;
- Measuring ship foundation mechanical impedances; and
- Measuring/determining the ship foundation transfer functions of the main machinery by means of shaker tests.

DRDC acted as the primary organizer and project manager of the trial and also performed the onboard measurements with the support of the Netherlands DMO and the Netherlands research organization TNO, as well as the German defence research organization Bundeswehr Technical Centre for Ships and Naval Weapons, Maritime Technology and Research (WTD71). Fleet Maintenance Facility (FMF) Cape Breton staff also provided support by operating the acoustic range and providing additional equipment.

The ship measured was the ORCA-class training vessel, PCT MOOSE (see Figure 1). PCT MOOSE has a length of 33 m, a beam of 8.34 m, a draft of 2.6 m, and a displacement of 210 tons. It is a twin-screw vessel driven by two 2500HP Caterpillar diesels with a maximum speed of 20 knots.

Figure 1: PCT MOOSE.

Overall, the trials were successful with the majority of the high-priority objectives met. The trials team performed some of the experiments at the jetty, followed by about two days of dynamic runs (with the accompanying acoustic range measurements), then two days moored on the static range. This Reference Document outlines the work that was done, the completed list of runs performed and other measurements made, and some preliminary results. Further documentation based on a detailed analysis of the results will be discussed in future publications.

2 Trial Description

2.1 Trials Team

Due to the international component of this trial, there was quite a large trials team. Table 1 shows the personnel involved and their affiliation.

Table 1: Scientific trials team.

Name	Role	Affiliation
Layton Gilroy	Chief Scientist	DRDC
Esen Cintosun	Acoustic Scientist	DRDC
Jasper Dupuis	Computer Scientist	DRDC
Alan Polvi	Technologist	DRDC
Paul Saville	Scientist	RCN, Navy Innovation
Hans Hasenpflug	Acoustic Scientist	DMO
Casper Bosschaart	Acoustic Scientist	DMO/TNO
Wouter Buul	Acoustic Scientist	DMO
Stefan Schal	Range Specialist	WTD71

Pat Bay range staff (part of Fleet Maintenance Facility Cape Breton) were available the entire week to support both the dynamic and static rangings, as well as for discussions on range performance with the DMO and WTD71 representatives.

2.2 Overview

The trial took place February 2–7, 2020 around the Pat Bay acoustic range located near Sidney, British Columbia. The trial consisted of an installation and jetty-side measurement phase, dynamic and static acoustic rangings at Pat Bay and other underway measurements outside of the range area. The ship was temporarily fitted with a limited set of accelerometers and other sensors, a GPS tracking system, a data acquisition system, and an attached computer. DRDC staff performed the installation of the equipment and supervised the data acquisition and performance of the measurements (with support from the Dutch and German participants) while Fleet Maintenance Facility (FMF) Cape Breton staff operated the acoustic range equipment and recorded the associated acoustic data. Both DRDC staff and the international participants attended the range house at various times to gain and share experience in range operations. The original trials plan was generally followed, but changes to the planned schedule occurred as the trial unfolded. A general overview of each day is shown below:

Sunday, Feb 2, 2020: DRDC (including Saville) and DMO staff joined the ship at 0800 and equipment was installed successfully finishing about 1400. Input mobility measurements were then performed at selected sites. Measurements ceased around 1630 and trials staff returned to hotel. Weather was quite nice, sunny and about 5°C with low winds.

Monday, Feb 3, 2020: Staff joined the ship about 0800 and immediately started with "dead ship" transfer mobility tests. These tests mean that the ship was completely dead with no machinery running. Note that shore power was not available which meant that the trials equipment were running on UPS. Three sets of these tests were performed limited largely by the fact the ship could only maintain dead ship for a limited time (roughly one hour at most). At approximately 1300, MOOSE sailed for dynamic ranging tests starting about 1400. The team completed most of Dynamic Trials Part 1 (see original trials plan [3]), finishing about 1700 and returned to jetty. Weather was generally quite nice, partly sunny, very low sea state. Measurements were only fouled a couple of times on the range due to passing vessels.

Tuesday, Feb 4, 2020: Staff joined the ship at 0800 and the ship proceeded directly to the dynamic range. A second set of dynamic ranging runs (Part 1) was performed with accelerometer measurements focussed on the port engine and diesel generator (DG) set. At approximately 1500, various accelerometer placements were planned for straight-line dynamic runs (varying speed from 3 to 15 knots, no ranging) to examine the various equipment inputs (primarily propulsion diesels and DG sets). Unfortunately, due largely to unanticipated difficulties with the accelerometer attachments, the configuration changes did not go well and only three configurations were measured and no flanking path measurements were made. Weather was overcast with light rain, but little wind.

Note that mid-afternoon the ship had a medical emergency and had to deliver a crewman to an ambulance ashore. Despite our offer to cease operations for the day, the ship insisted on continuing the trials.

Wednesday, Feb 5, 2020: The ship sailed at 0800 for the static range with four DRDC staff on board. A conductivity, temperature, depth (CTD) probe was deployed at the centre of the dynamic range and the centre of the static range. The ship moored successfully on the static range (a four-point mooring) using two Zodiacs, finishing at approximately 1000. The DRDC hydrophone was deployed over the starboard side of the ship roughly 8 m from the stern to a depth of about 8 m (in a water depth of about 16 m). DRDC attempted to perform an ambient noise measurement around 1100, but there appeared to be some issue with noise on the static range hydrophones (it is unclear whether this issue was resolved). Measurements started with a measurement of DG1 around 1110. Static Trial Part 1 was completed (Runs 2, 3, 6, and 8 from the plan). The Emergency Fire Pump (Run 7) was not able to be started and was not measured (but the unit was repaired later that day). The day's tests were completed with a shaker test run about 1630 and then the trials team were taken off the ship by Zodiac. Weather was overcast with light rain, but little wind.

Thursday, Feb 6, 2020: Sea state was very calm, with a steady light rain, and temperatures about 5–7°C. Staff arrived at jetty at 0800 and were transferred to the ship by Zodiac (two trips were required). The first test performed was to static range the Emergency Fire Pump. The shaker was then installed and measurements were made from 200 Hz to 2 kHz in 50 Hz steps (15 s per tone) for three shaker locations. A frequency sweep was also done at all locations. The first shaker location was on a frame near the gearbox (port side outboard), the second was on the outboard forward mount of DG1. The third shaker location was on the outboard port side diesel mount. The team then performed the loudspeaker measurements. Two loudspeakers were positioned in the engine room. Runs 13 (fouled), 14, and 15 were done with the first speaker (14 was stepped sine and 15 was swept sine). Run 16 was a swept sine using the second speaker. The range noted that both the shakers and speakers were clearly detectable via the range hydrophones. These runs were completed by 1500 and the ship then proceeded to unmoor from the static range.

Note that we are unsure of the performance of the hydrophone deployed over the side of the ship as the embarked DRDC staff were not sufficiently familiar with the equipment to easily see if the measurements are making sense. This will have to be addressed during the data analysis phase. During the speaker trials, staff also noticed an issue with the two Netherlands (NLD) microphones which did not appear to be recording properly. The issue was resolved but it called into question the (non-critical) microphone measurements made during the dynamic ranging trials.

Friday, February 7, 2020: DRDC and NLD staff boarded the ship at about 0800. The ship indicated they were concerned about incoming rough weather for their transit back to Canadian Forces Base (CFB) Esquimalt and asked whether the trials could finish earlier than planned. DRDC then performed a CTD measurement at the centre of the dynamic range, then proceeded to complete two of the straight-line, varying-speed dynamic runs to complete the assessment of the machinery and flanking paths missed on Tuesday. Range staff were available, so the ship performed two ranging runs at 5 knots (one a keel run) to allow them to verify the operation of their software. The measurements were completed by about 1100 and the ship then proceeded to berth and DRDC began the removal and packing of our equipment (including data backups and data transfer to our partners). Packing and removal of our equipment was completed by 1300, allowing the ship a timely departure to minimize risk on their return to Esquimalt.

2.3 Onboard Data Acquisition

DRDC installed a twenty (20) channel data acquisition system (DAQ) in the main engine room of the ship. The channel allocation varied from test to test but included accelerometers at various locations in the engine room or steering gear compartment, microphone input from the engine room, and tachometers for the two main shafts. Depending on the test, an electromechanical shaker, loudspeaker, or instrumented hammer was used to provide excitation to the structure of the ship while ship noise was measured with microphones, a sound level meter, and a hydrophone deployed over the side of the ship.

No fixed wiring was installed as the sensor fit varied from test to test. Instead, a large number of accelerometer mounting blocks (roughly 19 mm steel cubes) were glued at points of interest throughout the engine room and steering gear compartment. The various accelerometer fits are explained in Annex A. For each test, accelerometers were placed at the required mounts and temporary wiring was run back to the DAQ. This wiring was positioned to avoid problems for ship staff as much as possible but, regardless, ship staff were made aware of the wiring as a potential hazard. As with the previous trial, it was necessary to run wiring from the engine room to the steering gear compartment, so the connecting hatch was propped open for the duration of the trial (with the understanding that, in an emergency situation, the wires could be cut).

The computer controlling the DAQ was installed in the ship's classroom. To communicate, an Ethernet cable was run from the engine room, up through the aft emergency escape hatch then through the starboard door into the classroom. Both the hatch and the door were propped open during the tests. A GPS antenna was mounted on the bridge roof and the cable was also run into the classroom through the starboard door.

Range staff also installed their own GPS system for broadcast to the range house during ranging runs.

3 Trial Outcomes

As noted above, there were several main sets of tests consisting of jetty-side input and transfer mobility measurements, dynamic runs over the sound range, separate “unranged” dynamic runs to evaluate engine vibrations, a static ranging, and further measurements of shaker- and speaker-induced noise on the static range. These will be discussed in more detail below.

3.1 Input Mobility

Upon completion of the equipment and DAQ installation, input or cross mobility or impedance measurements were started supporting Static Trials Part 3 from the trials plan. The instrumented impact hammer was connected into TNO’s DAQ and several locations were struck while the ship was in the “dead ship” state (all equipment fully powered down). TNO also installed their own accelerometers for each installation to measure cross- or transfer impedance as well. The complete test set-up will be outlined in a future TNO report. The locations struck are summarized in Table 2 and in more detail in Annex B.

Table 2: Impact testing summary.

Count	UTC Time	Machinery Tested	Strike Location	Above/ Below Mount	Hammer Head
1	21:50:01	DG1 (Port)	7	Below	Teflon
2	21:54:54	DG1 (Port)	7	Below	Rubber
3	21:57:17	DG1 (Port)	7	Below	Steel
4	22:01:54	DG1 (Port)	6	Below	Steel
5	22:03:48	DG1 (Port)	6	Below	Rubber
6	22:08:22	DG1 (Port)	3	Above	Rubber+Mass
7	22:10:49	DG1 (Port)	2	Above	Rubber+Mass
8	22:15:57	DG1 (Port)	3	Above	Steel
9	22:17:37	DG1 (Port)	2	Above	Steel
10	22:32:27	DG1 (Port)	3	Above	Rubber+Mass
11	22:34:19	DG1 (Port)	3	Above	Rubber+Mass
12	22:38:53	DG1 (Port)	7	FP	Rubber+Mass
13	22:42:44	DG1 (Port)	7	FP	Steel
14	23:22:19	DG2 (Centre)	6	Below	Steel
15	23:25:02	DG2 (Centre)	6	Below	Rubber+Mass
16	23:26:37	DG2 (Centre)	7	Below	Rubber+Mass
17	23:31:17	DG2 (Centre)	7	Below	Steel
18	23:33:33	DG2 (Centre)	3	Above	Steel
19	23:35:53	DG2 (Centre)	2	Above	Steel

Count	UTC Time	Machinery Tested	Strike Location	Above/ Below Mount	Hammer Head
20	0:12:45	PPD	5	Below	Steel
21	0:15:34	PPD	8	Below	Steel
22	0:17:10	PPD	8	Below	Rubber+Mass
23	0:19:00	PPD	5	Below	Rubber+Mass
24	16:59:28	DG1 (Port)	3	Above	Rubber+Mass
25	17:01:01	DG1 (Port)	2	Above	Rubber+Mass
26	17:04:56	DG1 (Port)	3	Above	Steel
27	17:06:00	DG1 (Port)	2	Above	Steel
28	17:09:53	DG1 (Port)	7	Below	Steel
29	17:11:36	DG1 (Port)	7	Below	Rubber+Mass
30	17:52:40	PPD	1	Above	Rubber+Mass
31	17:54:38	PPD	4	Above	Rubber+Mass
32	17:56:11	PPD	1	Above	Steel+Mass
33	17:57:56	PPD	4	Above	Steel+Mass
34	18:01:18	PPD	1	Above	Big Hammer
35	18:07:37	PPD—Flanking Path	N/A	Above	Big Hammer
36	18:09:59	PPD—Flanking Path	N/A	Above	Big Hammer
37	18:42:42	PPD—Flanking Path Hose	N/A	N/A	Big Hammer
38	18:45:19	PPD—Flanking Path Hose	N/A	N/A	Big Hammer
39	18:47:08	PPD—Foundation	N/A	N/A	Big Hammer
40	18:48:53	PPD—Foundation	N/A	N/A	Big Hammer
41	19:00:44	PPD—Leaf Spring	N/A	N/A	Big Hammer

As can be seen, the centre and port DG sets were tested as well as the port propulsion diesel (PPD). A Bruel & Kjaer (B&K) Model 8206-002 hammer (100 g head mass) with a variety of heads was used for Runs 1 through 33 while the larger B&K Model 8210-51454 hammer (12 lb, 5450 g head mass) was used for the remaining. The Strike Location is the spot around the machine that was struck as per the diagrams in Annex B. This is not applicable to the flanking path runs which also have the strike locations indicated in Annex B. Typically, the strikes were made either above or below the relevant engine mount unless otherwise indicated (e.g., FP indicates foundation plate). Runs 1 through 23 were performed on February 2, while the remainder were performed on February 3. Times throughout are given as Coordinated Universal Time (UTC). The times are noted in every run table to facilitate locating the appropriate data set.

3.2 Dynamic Ranging

Dynamic ranging of the ship was generally performed as per the "Dynamic Trials Part 1" in Reference 3. The accelerometers were in the baseline configuration (Configuration 1) as outlined in Annex A. Note that this configuration focuses on the propulsion diesels, with no sensors on the DG sets. In particular, the port propulsion diesel was more heavily instrumented than the starboard and any results are assumed to be reasonably symmetric (this will be checked comparing similar accelerometer locations). The ship was in Machinery State “A” using DG3 (machinery states are defined in Reference 3). The first set of dynamic runs, performed on the first day of sea trials, is shown in Table 3.

Table 3: Dynamic trials, Day 1.

Run No.	Run Plan Number	CPA Time (UTC)	Nominal Speed (Knots)	GPS Speed (Knots)	Trolling	Mach State	Direction	Track Error (m)
1	41	2150	3	3.3	ON	A	W	4
2	41	2236	3	2.5	ON	A	E	N/A
3	42	2247	5	5.4	ON	A	W	1
4	42	2253	5	5.1	ON	A	E	9
5	43	2301	7	7.3	ON	A	W	5
6	43	2312	7	7.0	ON	A	E	4
7	44	2319	9	9.0	OFF	A	W	1
8	44	2327	9	8.7	OFF	A	E	3
9	45	2333	11	10.5	OFF	A	W	5
10	45	2337	11	10.2	OFF	A	E	2
11	46	2345	13	13.0	OFF	A	W	6
12	46	2349	13	12.6	OFF	A	E	10
13	47	2354	15	15.0	OFF	A	W	2
14	47	2359	15	14.9	OFF	A	E	4
15	48	0004	17	17.0	OFF	A	W	10
16	48	0008	17	17.1	OFF	A	E	10
17	49	0027	19	18.9	OFF	A	W	15
18	49	0031	19	19.2	OFF	A	E	9
19	48R	0036	17	17.1	OFF	A	W	15
20	48R	0041	17	17.0	OFF	A	E	6
21	46R	0047	13	12.4	OFF	B	W	4
22	41R		3	3.0	ON	B	E	N/A

Note that the “Run Number” was incremented to match range measurements and that in the original specification, the “Run Plan Number” was assigned as a pair of East/West runs. The ship has two speed-dependent clutch settings indicated by the “trolling” column. Actual speed according to GPS is given, as staff perceived that the log speed (speed through the water) indicated on the ship’s bridge was not reliable. The track error is the ship estimate of how far off they were from the ideal range centreline at the closest point of approach (CPA). Note that Run 22 was aborted due to a range data recording error.

During the second day of dynamic trials, the runs as set out in Dynamic Trials Part 1 were repeated to generate additional statistics. These are shown in Table 4 as Runs 23 through 41 with Runs 42 to 45 providing additional data for 13 knots.

Table 4: Dynamic trials, Day 2.

Run No.	Run Plan Number	CPA Time (UTC)	Nominal Speed (Knots)	GPS Speed (Knots)	Trolling	Mach State	Direction	Track Error (m)
23	41	1632	3	3.5	ON	A	W	3
24	41	1645	3	3.1	ON	A	E	7
25	42	1654	5	5.2	ON	A	W	7
26	42	1702	5	5.0	ON	A	E	13
27	43	1708	7	7.4	ON	A	W	2
28	43	1713	7	6.6	ON	A	E	14
29	44	1721	9	8.8	OFF	A	W	3
30	44	1727	9	8.6	OFF	A	E	1
31	45	1737	11	10.4	OFF	A	W	6
32	45	1739	11	10.3	OFF	A	E	5
33	46	1744	13	12.8	OFF	A	W	1
34	46	1749	13	12.7	OFF	A	E	3
35	47	1754	15	15.0	OFF	A	W	4
36	47	1759	15	14.9	OFF	A	E	15
37	47	1803	15	14.9	OFF	A	W	10
38	48	1807	17	17.1	OFF	A	E	5
39	48	1812	17	17.2	OFF	A	W	0
40	49	1817	19	18.8	OFF	A	E	15
41	49	1829	19	18.9	OFF	A	W	7
42	46	1835	13	12.7	OFF	A	E	6
43	46	1840	13	12.7	OFF	A	W	0
44	46	1845	13	12.9	OFF	A	E	3
45	46	1851	13	12.8	OFF	A	W	0
46	Keel (N)	1911	5	5.3	ON	A	E	3
47	Keel (N)	1924	5	4.8	ON	A	W	20
48	Keel (N)	1933	5	5.0	ON	A	E	9
49	Keel (N)	2039	5	5.2	ON	A	W	0
50	Keel (N)	2045	7	7.1	ON	A	E	13
51	Keel (N)	2054	7	7.1	ON	A	W	3
52	Keel (S)	2124	5	5.0	ON	A	E	5

To support investigations into keel versus beam acoustic measurements, additional runs directly over one of the hydrophones were made at two speeds (Runs 46 through 52). All except for Run 52 were performed over the North hydrophone, while Run 52 was done over the South hydrophone as a checkpoint. Unfortunately, due to ship tracking issues, the runs indicated by gray boxes did not have successful acoustic recordings made by the range.

Upon completion of these runs, the ship then performed additional “off-range” dynamic runs not listed in the trials plan. Due to the fact that limited numbers of accelerometer channels were available, these additional dynamic runs were carried out to determine the structure-borne noise level of all mounting and flanking paths of the port propulsion diesel. The intent was to investigate changes to vibrations resulting from changing the machinery state, but with no requirement for concurrent acoustic measurements. Three accelerometer configurations were used (changing the nine machinery-based accelerometers) to measure the vibrations under two DG configurations. These accelerometer configurations are shown in Annex A. The runs consisted of the ship sailing a straight line starting at 3 knots. When the ship speed was constant, a 30-second accelerometer measurement was made. Ship speed was then increased to 5 knots and, when constant, another measurement was made. This was done for speeds of 3 through 15 knots in 2-knot increments. The first set of runs (with accelerometer Configuration No. 1) were performed with DG2 and DG3 operating while the next two sets (accelerometer Configurations No. 2 and No. 3) were performed with only DG3 operating. Table 5 shows the runs with the relevant accelerometer configuration, diesel generator configuration, and time stamps.

Table 5: Dynamic runs, sea trials.

Count	Run Number	Nominal Speed (Knots)	Accel. Config.	DG Config.	COMEX Time (UTC)
1	103	3	1	2+3	2245
2	105	5	1	2+3	2250
3	107	7	1	2+3	2254
4	109	9	1	2+3	2258
5	111	11	1	2+3	2301
6	113	13	1	2+3	2306
7	115	15	1	2+3	2312
8	203	3	2	3	2344
9	205	5	2	3	2347
10	207	7	2	3	2349
11	209	9	2	3	2354
12	211	11	2	3	2356
13	213	13	2	3	2359
14	215	15	2	3	2402
15	303	3	3	3	0111
16	305	5	3	3	0113
17	307	7	3	3	0115
18	309	9	3	3	0117
19	311	11	3	3	0120
20	313	13	3	3	0121
21	315	15	3	3	0123

3.3 Static Trials

On February 5, the ship sailed to moor at the static range after performing a CTD measurement at the approximate midpoint of the dynamic range. This was completed by 1000. DRDC performed a CTD measurement on the static range and deployed a hydrophone over the starboard side of the ship about 8 m from the stern at a depth of 8 m (in 16 m of water). The hydrophone cable was fed into the classroom and hooked into the DAQ.

After performing a “dead ship” ambient noise measurement, the Static Trials Part 1 (as per the trials plan) were commenced with the ship being powered by DG1. Table 6 shows the runs performed.

Table 6: Static trials Part 1, Day 1.

Count	Run Number	COMEX Time (UTC)	Machinery Config.	Accel. Config.
1	A1	1844	Ambient	4
2	1.1	1906	DG1	4
3	1.2	1907	DG1	4
4	1.3	1908	DG1	4
5	2.1	1935	DG1	5
6	2.2	1936	DG1	5
7	2.3	1937	DG1	5
8	3.1	2023	DG2	6
9	3.2	2032	DG2	6
10	3.3	2034	DG2	6
11	4.1	2130	DG2+BW	7
12	4.2	2131	DG2+BW	7
13	4.3	2132	DG2+BW	7
14	4.4	2137	DG2	7
15	4.5	2138	DG2	7
16	4.6	2139	DG2	7
17	5.1	2205	DG2+MFP	8
18	5.2	2206	DG2+MFP	8
19	5.3	2207	DG2+MFP	8
20	6.1	2230	DG2+SGP2	8
21	6.2	2231	DG2+SGP2	8
22	6.3	2232	DG2+SGP2	8

The run number corresponds to the trials plan with the “.1” added to indicate repeats (the first listed run, A1, is the ambient noise measurement). The machinery configuration was changed by changing the operating DG as well as adding additional significant noise sources including the Black Water pump (BW), the main fire pump (MFP), and the steering gear pump (SGP). These latter changes supported Static Trails Part 4 from the original trials plan. Accelerometer configurations were changed to ensure that most points on each DG or other machinery mounts were measured. These configurations are listed in Annex A. Note that the propulsion diesels were not running during these trials.

On February 6, the basic static runs were completed by performing runs with the emergency fire pump (EFP) as shown in Table 7 (with the Configuration 9 described in Annex A).

Table 7: Static trials Part 1, Day 2.

Count	Run Number	COMEX Time (UTC)	Machinery Config.	Accel. Config.
1	7.1	1712	DG2+EFP	9
2	7.2		DG2+EFP	9
3	7.3		DG2+EFP	9

The equipment configuration was then changed to Configuration 10 (Annex A) to support Static Trials Part 2, which involve the use of a piezoelectric shaker to apply known loads to particular spots on the ship structure. These locations are shown in Annex D. Shaker runs were performed with the ship "dead" (i.e., no equipment on board running). Scientific power was provided through the use of a portable generator located on the ship's upper deck, maintaining the uninterruptible power supplies (UPS) attached to the computers and DAQ. The radiated noise was measured by both the onboard hydrophone and the range hydrophones. Table 8 shows the shaker runs performed.

Table 8: Shaker runs.

Run Number	Range Run Number	COMEX Time (UTC)	Shaker Location	Signal Type	Accel. Config.
1101		1748	Frame near gearbox	Tones	10
1102	9	1759	Frame near gearbox	Tones	10
1201	10	1847	DG1, outboard fwd mount	Tones	10
1202	11	1909	DG1, outboard fwd mount	Swept Sine	10
1301	12	2114	PPD, outboard fwd mount	Tones	10
1302	13	2129	PPD, outboard fwd mount	Swept Sine	10

The first run was aborted as the range was fouled (although the onboard hydrophone measurement may still be useful). Three shaker locations were used and two types of signals were tried. The "Tones" signal involved a manual sweep from 200 to 2000 Hz with 50 Hz spacing running 15 s per tone. The "Swept Sine" signal was an automatic sweep from 200 Hz to 2000 Hz over 5 minutes. In Run 1301, the manual sweep was changed to 100 to 500 Hz at 25 Hz spacing followed by 500 to 2000 Hz at 50 Hz spacing with the same time interval per tone. In Run 1302, the lower frequency was changed to 100 Hz.

A loudspeaker was then set up at one of two locations and similar trials were performed, using either stepped tones or swept sine excitation. The two speaker locations were 1) centred between the port and starboard propulsion diesels and 2) between DG2 and DG3 (the starboard and central DGs). The precise speaker locations are shown in Annex C and the runs shown in Table 9.

Table 9: Speaker and balloon runs.

Run Number	Range Run Number	COMEX Time (UTC)	Speaker/ Balloon Test	Signal Type	Accel. Config.
2101	13	215701	Speaker, 1	Tones	10
2102	14	221149	Speaker, 1	Tones	10
2103	15	221951	Speaker, 1	Swept Sine	10
3101	N/R	222905	Balloon, 1	Impulse	10
3102	N/R	222927	Balloon, 2	Impulse	10
3103	N/R	222945	Balloon, 3	Impulse	10
3104	N/R	223000	Balloon, 4	Impulse	10
2201	16	223044	Speaker, 2	Swept Sine	10

Run 2101 was aborted by the range (due to fouling), but included a manual sweep up to 200–750 Hz at steps of 25 Hz. Run 2102 was a manual sweep from 750 to 2000 Hz at 50 Hz steps (15 s intervals) while Runs 2103 and 2104 were automatic sweeps from 100 to 2000 Hz over 5 minutes.

Finally, runs were performed to evaluate the reverberation characteristics of the machinery room space. To accomplish this, standard party balloons were popped and the resulting noise and vibration were recorded. Balloons were popped at four locations, shown in Annex C.

After completion, sound range staff indicated that the tones produced were clearly detectable above ambient for both the shaker and speaker runs.

3.4 Dynamic Trials—Part 2

On February 7, additional dynamic runs (shown in Table 10) were performed to support the Dynamic Trials Part 2 portion of the trial plan. This involved two sets of sea trial runs (straight lines at ever increasing speeds) as described above. These runs were performed to examine noise flanking paths for the port propulsion diesel (Configuration 11) and gathering more data from the port propulsion diesel (Configuration 12).

Table 10: Second dynamic sea trial runs.

Count	Run Number	Nominal Speed (Knots)	Accel. Config.	DG Config.	COMEX Time (UTC)
1	403	3	11	3	1658
2	405	5	11	3	1700
3	407	7	11	3	1703
4	409	9	11	3	1705
5	411	11	11	3	1708
6	413	13	11	3	1711
7	415	15	11	3	1714
8	503	3	12	3	1737
9	505	5	12	3	1739
10	507	7	12	3	1742
11	509	9	12	3	1745
12	509a	9	12	3	1752
13	511	11	12	3	1755
14	513	13	12	3	1800
15	515	15	12	3	1803

To support range activities, two additional runs were performed over the dynamic range (see Table 11). Run 53 went directly over the North hydrophone while Run 54 went on the standard range track. DG3 was maintained as was accelerometer Configuration 12.

Table 11: Range support dynamic runs.

Run No.	Run Plan Number	CPA Time (UTC)	Nominal Speed (Knots)	GPS Speed (Knots)	Trolling	Mach State	Direction	Track Error (m)
53	Keel (N)	1828	5	5.2	ON	A	W	0
54	42	1842	5	5.1	ON	A	E	6

Upon completion of these runs, the ship returned to the jetty to facilitate the dismantling and unloading of the trials equipment, which was completed by approximately 1300, allowing the ship to sail for its home jetty.

3.5 Ambient Noise

Ambient noise measurements were made whenever possible during the trials. Due to limited range time, three ambient noise measurements were taken, one on the first day of dynamic trials and two more on the second. Figure 2 shows the ambient noise from the runs with the thinner lines representing the three measurements (a North and South hydrophone reading for each run). The heavier red line shows the average while the black line shows the average from the trial performed in July, 2019. Note that the horizontal axis is frequency in 1/3-octave (OTO) bands. There appear to be significant noise peaks around the 64 and 200 Hz 1/3-octave bands, which were somewhat present in the previous trials, as well as additional high frequency noise around 20 kHz. Note that the recent ambient levels are similar to the previous levels below 60 Hz, higher at 60 Hz, lower to 10 kHz and higher above 10 kHz.

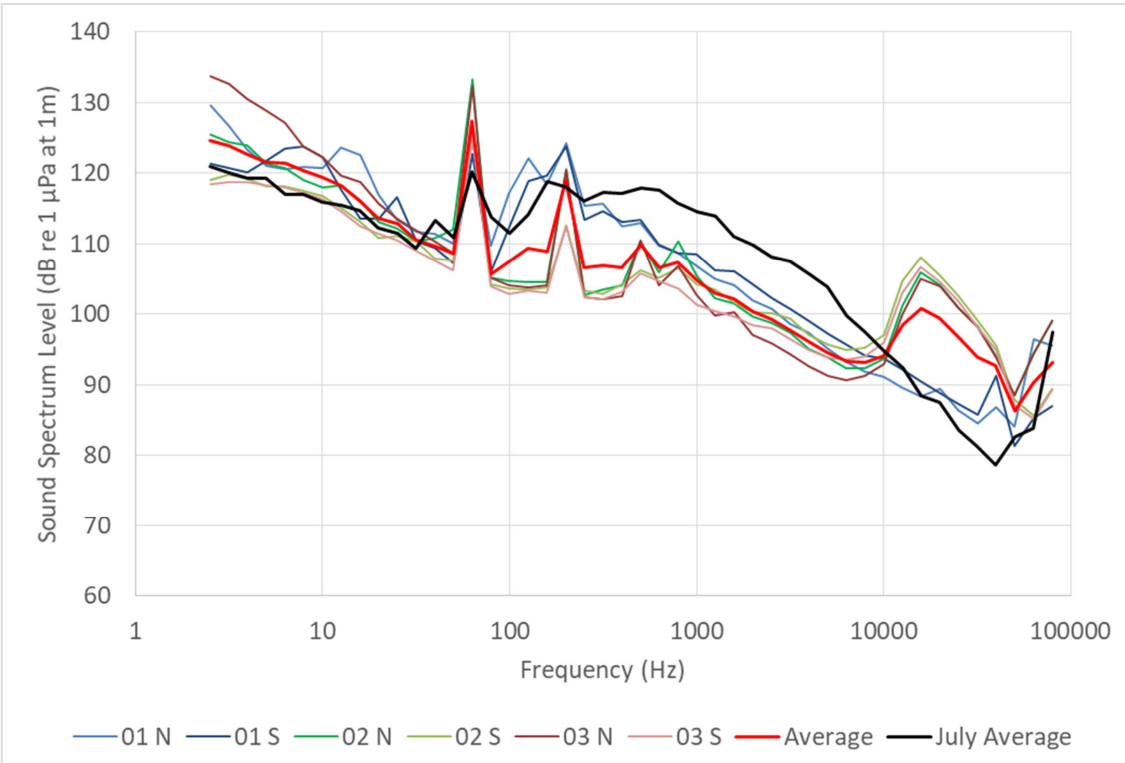

Figure 2: Ambient noise averages for trial.

3.6 CTD

In support of future environmental acoustic modelling (in particular, modelling of transmission loss), sound speed profiles were measured every night using a conductivity, temperature, depth (CTD) probe. From the CTD data, the sound speed profiles (sound speed versus depth) can be determined and are shown in Figure 3 (the legend shows the date and time (UTC)). As expected, over the reasonably short time frame with little variation in weather, the results are fairly consistent. Figure 4 shows a comparison between the average sound speed profiles measured during this trial with those measured in the July 2019 trial.

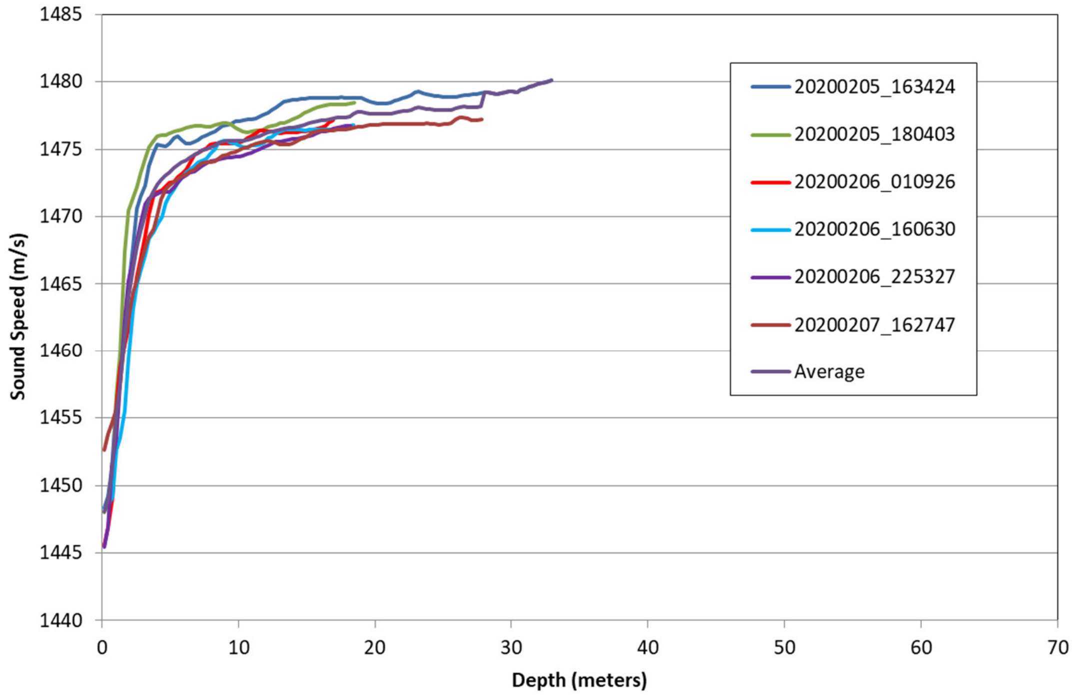

Figure 3: Sound speed profiles.

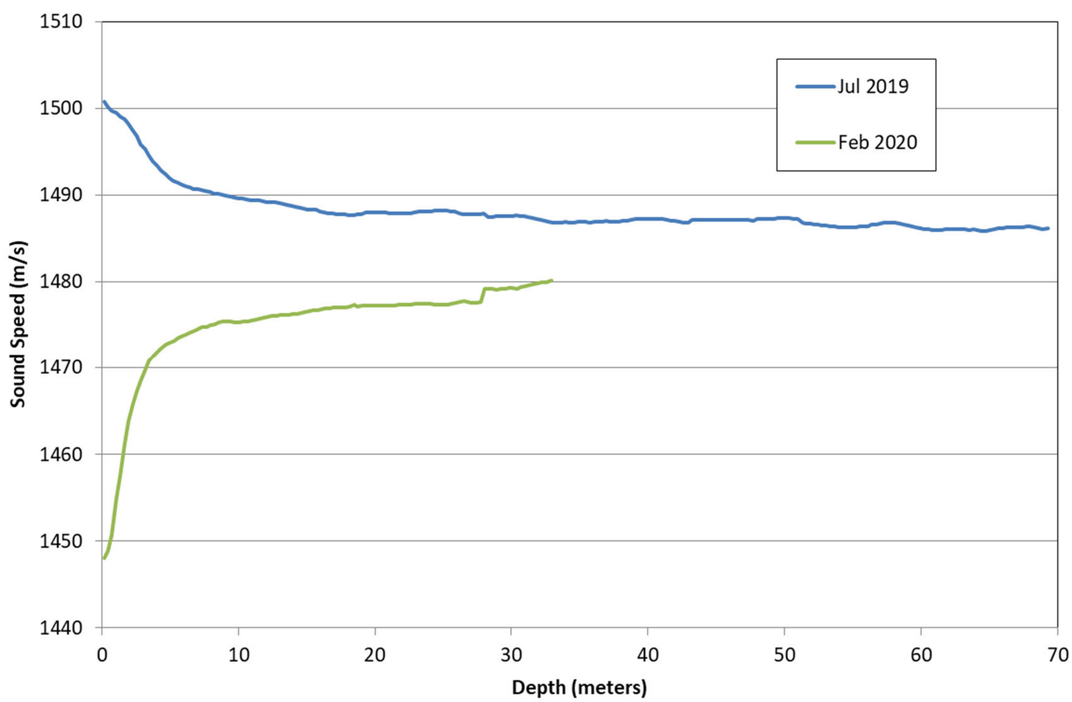

Figure 4: Sound speed profile comparison.

3.7 Onboard Accelerometer Data

As indicated above, during every run, static or dynamic, accelerometer and tachometer data were recorded at a sampling rate of 24 kHz along with the GPS position and time provided by the GPS system mounted on the bridge roof.

3.8 Airborne Noise

During the trial, the microphones (B&K Model 4192) were placed in the engine room to monitor airborne noise levels and these were recorded during the majority of the static and dynamic runs as shown in Table 12.

Table 12: Microphone test positions.

Run Count	Date	Test	Microphone Position
1	2020-02-02	Dynamic ranging	1 & 2
2	2020-02-04	Dynamic ranging	1 & 2
3	2020-02-04	Sea trial	3 & 4
4	2020-02-05	Static ranging	3 & 4
5	2020-02-06	Static ranging	3 & 4
6	2020-02-07	Sea trial	3 & 4

A portable B&K sound level meter (Model 2260) was also used to make point airborne noise measurements of the overall sound level (dBA) during several runs.

3.9 Noise Measurements

All offboard noise measurements were made by FMF range staff and the data were collected at the conclusion of the trial. For the dynamic runs, acoustic measurements were made at two hydrophones separated by 200 m between which the ship sailed. The data recording started 100 m before the closest point of approach (CPA) and terminated 100 m after CPA (where CPA is defined using the stern of the ship—the location of the loudest noise source, i.e., the propellers). For the static rangings, there were also two hydrophones located 200 m apart between which the ship was moored. In these tests, sound levels are typically recorded for 30 s. Time series data, as well as narrow band (NB) Fast Fourier Transforms (FFTs) and 1/3-octave band representations of the data were supplied by the range. A full analysis of the acoustic results will be published separately.

4 Conclusions and Recommendations

In support of the Transport Canada project on understanding noise issues with respect to local resident whale populations, a trial was performed to measure both onboard vibrations and offboard underwater noise of the Royal Canadian Navy ORCA-Class training vessel, PCT MOOSE. The objectives of this trial included determining structure-borne and airborne noise contributions from main machinery noise sources; identifying noise flanking paths by measuring vibration levels on presumed flanking paths; evaluating the impact of machinery mounts on structure-borne noise transfer; measuring ship foundation mechanical impedances; and measuring the ship foundation transfer functions of the main machinery by means of shaker tests.

There were several main sets of tests consisting of jetty-side input and transfer mobility measurements, dynamic runs over the Pat Bay acoustic sound range, separate “unranged” dynamic runs to evaluate engine vibrations, a static acoustic ranging, and further measurements of shaker- and speaker-induced noise on the static range. Ambient noise and sound velocity profile measurements were also made to support future range modelling efforts.

Overall, the majority of the trial objectives were met with only minor secondary objectives not achieved due to the limited time available. In general, weather was not an issue (as it often is for acoustic ranging work) and there were no issues with the ship machinery. Some trials time was lost due to a medical emergency and due to an early finish prompted by a forecast of difficult weather for the ship’s return journey home. The data gathered are expected to meet the requirements of the proposed BURNSi project and, together with the data gathered in the previous trial, will become a valuable resource for future ship noise and vibration work, both nationally and internationally.

A few observations and suggestions can be derived from the trial experience:

- The trials were arranged on very short notice from the other side of the country and limited trial days were available. As such, trials preparation and installation were rushed and the trial schedule was compressed. DRDC staff could have used more time to familiarize themselves with the equipment (e.g., the hydrophone) and avoided issues with accelerometer layout changes that arose during the trial. There was also insufficient time for data integrity checks and coordinating/rationalizing trial notebooks.
- Due to the relatively small size and high speed of the ORCA class, they are very maneuverable, which leads to quick changeovers between runs on the acoustic range. This allows for a lot of dynamic runs to be made in a very short time. As well, ship staff were very cooperative, accommodating our equipment intrusions, making machinery changes in a timely manner, and supporting staff transfers with boat operations.
- During the first accelerometer configuration change, it became obvious that using glued mounting blocks was a problem. Glue mounting was used as there were concerns about magnetic mounts moving and not providing a rigid enough connection. However, the accelerometers had to be threaded off and on to the blocks and this is very difficult with a 3 m integral accelerometer cable attached. This cost considerable time during configuration changes when the machinery changes could be made in seconds or minutes.

- In advance of the trial, there was concern that the shaker excitation used would not be detectable by the range hydrophones (one reason we added the extra ship hydrophone). As it turns out, the range was able to readily detect both the shaker- and speaker-induced noise.
- Overall, trials support was outstanding including the captain and crew of PCT MOOSE, range staff, the ORCA squadron office and, in particular, Paul Saville with the RCN Green Fleet Program.

References

[1] Memorandum Of Understanding Between Transport Canada (Represented by the Innovation Centre) and Department Of National Defence (Represented by Defence Research And Development Canada) Concerning The Environmental Effects Of The Operation Of Ships, DND Identification Number: 2019040001, July 2019.

[2] Technical Services Arrangement Number 01-2020 to the Memorandum Of Understanding Between Transport Canada (Represented by the Innovation Centre) and The Department of National Defence (Represented by Defence Research and Development Canada) on The Environmental Effects Of The Operation Of Ships, January 2020.

[3] Gilroy, L., ORCA underwater noise measurement trial plan, Defence Research and Development Canada, Reference Document, DRDC-RDDC-2020-D003, January 2020.

[4] Larsen, G., Results from off-board noise prediction study on an ORCA-class training vessel, Defence Research and Development Canada, Scientific Letter, DRDC-RDDC-2020-L045, March 2020.

[5] Larsen, G., Dupuis, J., Gilroy, L., Results from off-board noise prediction study in ORCA-class training vessel, Defence Research and Development Canada, Scientific Report, DRDC-RDDC-2021-R003, January 2021.

[6] Hasenpflug, H., BURNSi, Presentation at the 111th International Conference on Ship Signature Management, Centre for Ship Signature Management, Kiel, Germany, 25 September 2019.

Annex A Accelerometer Configurations

During the trial, the accelerometers were moved through various configurations depending on the test being conducted. As the number of data acquisition channels were limited, there were many more points of interest than channels available. Some channels were also required for shaft rpm and other sensors. As such, 15 channels were available for accelerometers for each test. The tables below outline the various configurations established for the tests. Table A.1 shows the initial configuration. Throughout the trials, unless otherwise indicated, the hull mounted accelerometers (Numbers 1 through 6) were always connected and the machinery accelerometers varied.

Table A.1: *Accelerometer Configuration 1 (baseline).*

Count	Channel Number	Location Marker	Axis	Hull/ Machinery	Location
1	K1	N/A	Z	H	Port prop outboard
2	A2	N/A	Z	H	Port prop inboard
3	C3	N/A	Z	H	Port SG aft of door
4	A0	N/A	Z	H	Port SG fwd of door
5	Q0	N/A	Z	H	Port aft gearbox
6	A3	N/A	Z	H	Port fwd of engine
7	A1	3.1	X	M	Port diesel
8	C0	3.2	Y	M	Port diesel
9	C1	3.3	Z	M	Port diesel
10	Q2	1.1	X	M	Port diesel
11	K0	1.3	Z	M	Port diesel
12	K2	4.3	Z	M	Stbd diesel
13	Q3	2.3	Z	M	Stbd diesel
14	C2	16.3	Z	M	Port gearbox upper
15	Q1	18.3	Z	M	Port gearbox lower

The channel number is the identifier for the data acquisition system, the location marker locates the accelerometer in the engine room (these were not used for the hull accelerometers), the axis indicator shows which direction is being measured (Z is vertical, X is fore/aft, and Y is port/starboard), the hull/machinery column indicates whether the accelerometer is on the hull or a piece of machinery, and the location is a description of the general location. Note that the location marker further denotes the axis orientation with ".1" representing "X" up to ".3" representing "Z." In many cases, including the hull mounted accelerometers, only the "Z" or vertical axis was measured. Note also that the hull accelerometers will be denoted by "H" plus their Count identifier, so H1 will be the port propeller outboard accelerometer.

Figures A.1 through A.5 show the Location Markers pictorially. The numbers in the blue ovals indicate accelerometers on the machinery side of the mount (above) while the pink ovals indicate accelerometers on the ship foundation side of the mount (below).

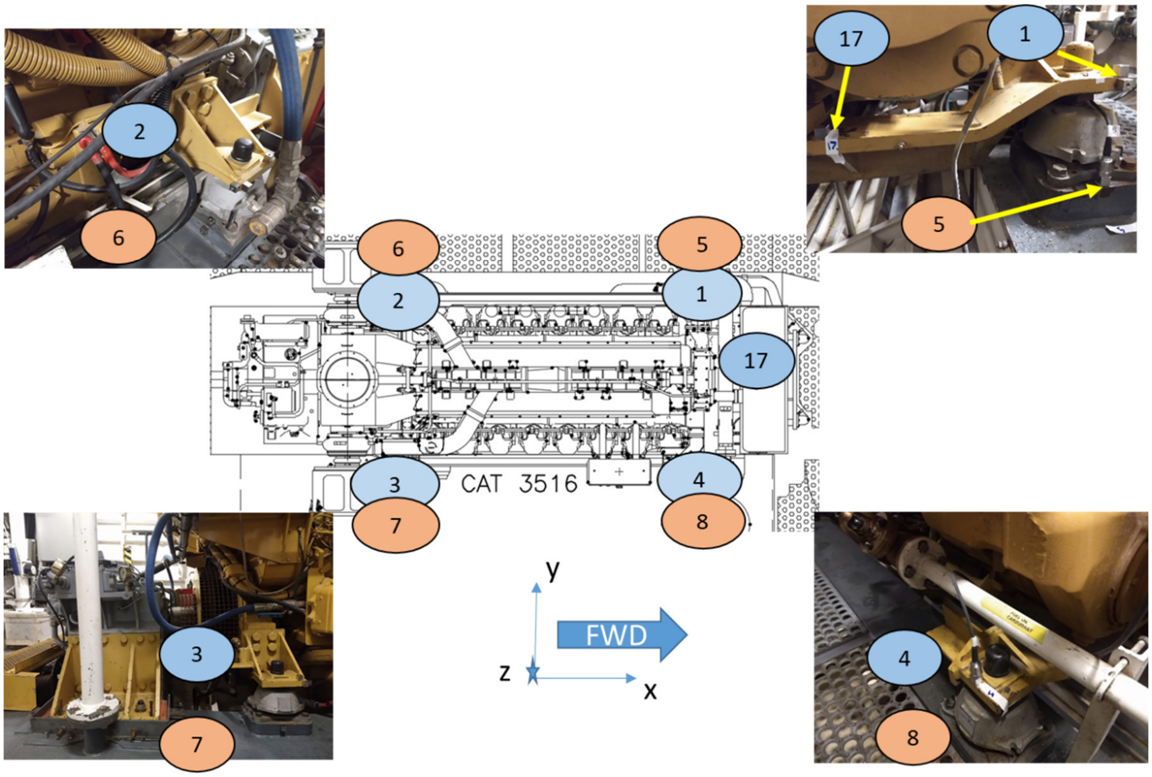

Figure A.1: *Port diesel accelerometer positions.*

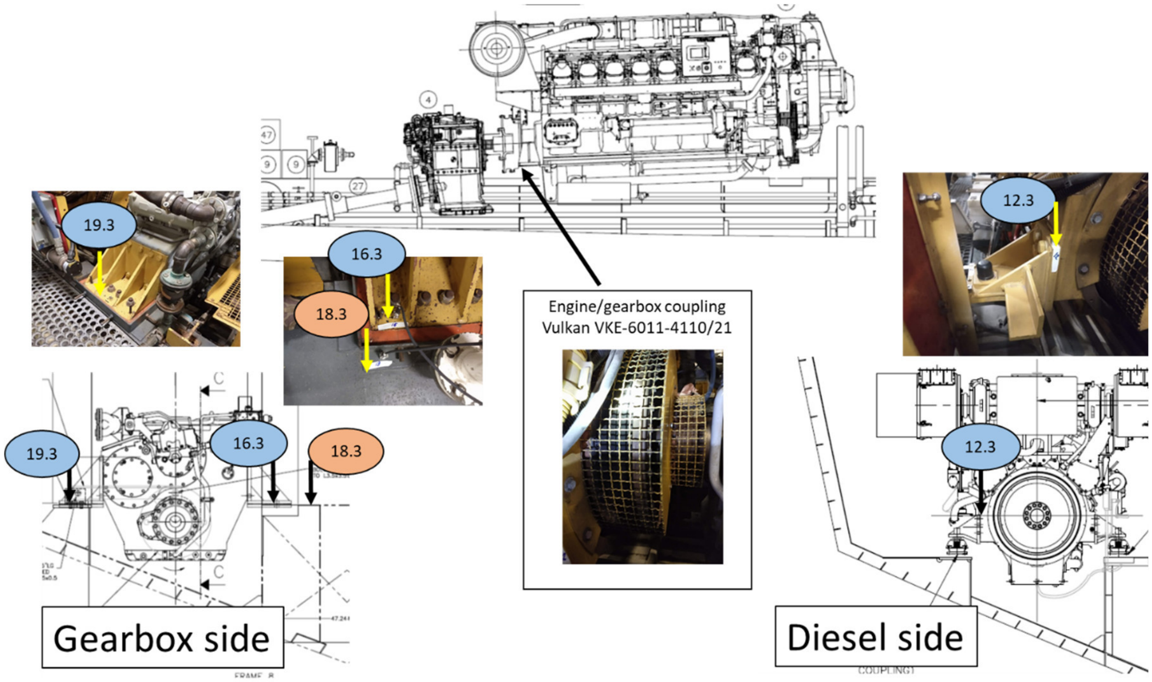

Figure A.2: *Port diesel shaft line accelerometer positions.*

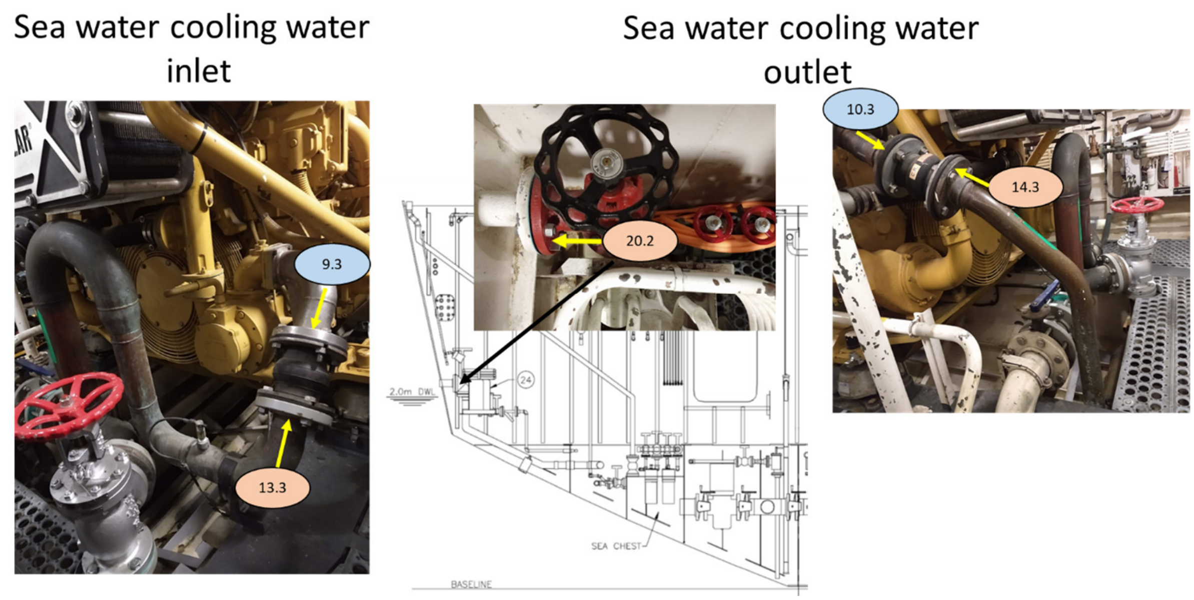

Figure A.3: Port diesel flanking paths accelerometer positions.

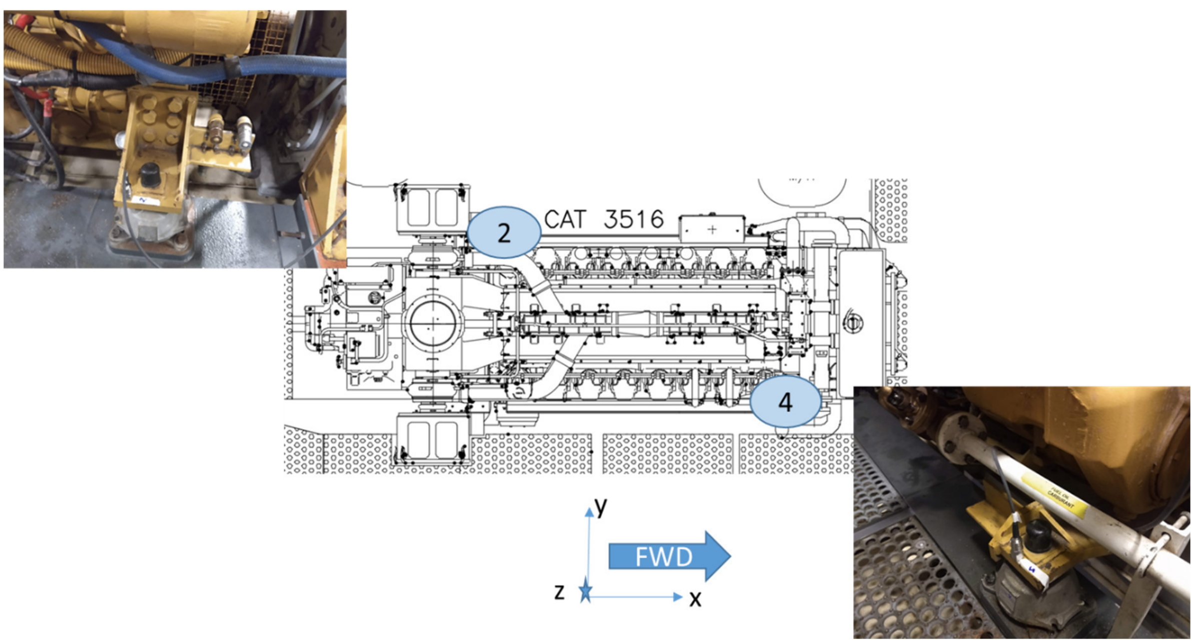

Figure A.4: Starboard diesel accelerometer positions.

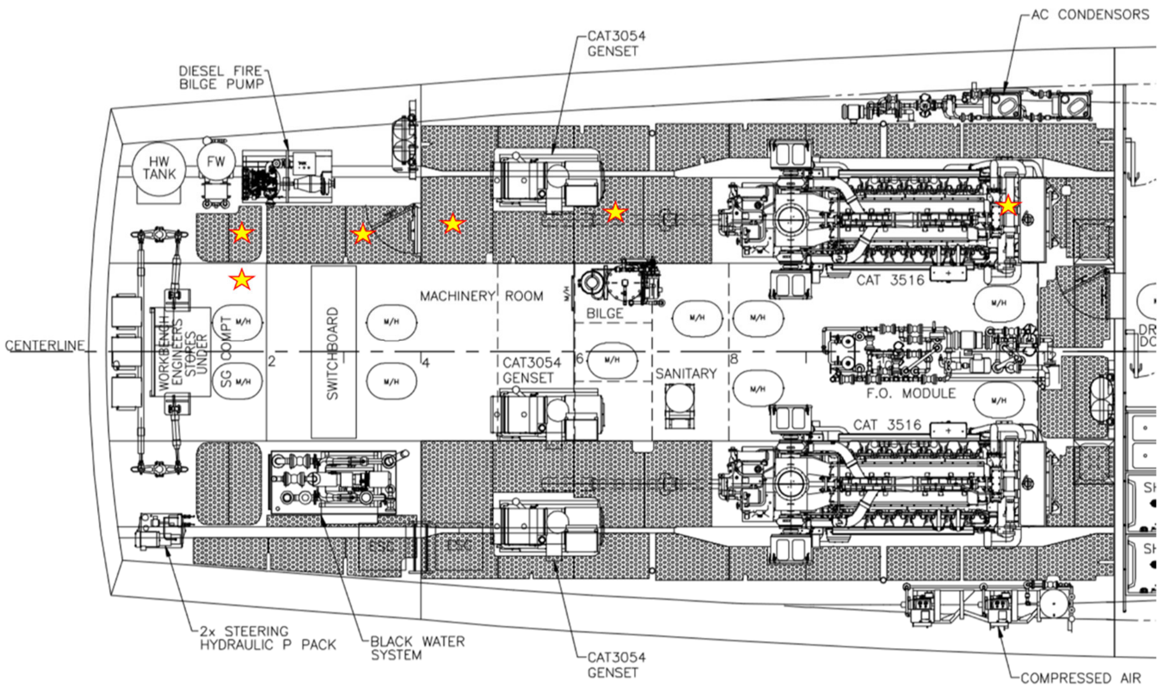

Figure A.5: *Hull mounted accelerometer positions (gold stars).*

The accelerometer configurations for the extra dynamic (non-ranged) runs performed on February 4 are shown in Table A.2.

Table A.2: *Sea trial machinery accelerometer Configurations 1 through 3.*

Count	Channel Number	Configuration 1 DG2 and DG3	Configuration 2 DG3	Configuration 3 DG3
7	A1	3.1	7.1	4.1
8	C0	3.2	7.2	2.2
9	C1	3.3		3.2
10	C2	16.3	12.3	8.3
11	Q1	18.3	2.3	2.3
12	Q2	1.1	5.1	5.2
13	Q3	1.2	10.3	4.3
14	K0	1.3	17.3	17
15	K2	4.3		9.3

The accelerometer configurations for the static trials are shown in Table A.3. Note that Configurations 4 and 5 apply to locations on DG1, while the remaining configurations apply to locations on DG2. For the location numbering system for the DG sets, see Figure A.6.

__Table A.3:__ Static trial Part 1 accelerometer configuration.

Count	**Channel ID**	**Config. 4**	**Config. 5**	**Config. 6**	**Config. 7**	**Config. 8**
1	V0	Hydrophone	Hydrophone	Hydrophone	Hydrophone	Hydrophone
2	V1	Stbd Tach	Stbd Tach	Stbd Tach	Stbd Tach	Stbd Tach
3	V2	Not Used	Not Used	Not Used	Not Used	Not Used
4	V3	Port Tach	Port Tach	Port Tach	Port Tach	Port Tach
5	A0	H4	H4	H4	H4	H4
6	A1	2.3	2.3	2.1	3.1	MFP
7	A2	H2	H2	H2	H2	H2
8	A3	H6	H6	H6	H6	H6
9	C0	7.2	5.3	2.2	3.2	EFP Fwd
10	C1	8.3	8.3	2.3	2.3	2.3
11	C2	3.2	6.2	3.3	3.3	3.3
12	C3	H3	H2	H2	H2	H2
13	Q0	H5	H6	H6	H6	H6
14	Q1	3.3	2.1	6.2	7.2	SGP
15	Q2	3.1	3.1	6.3	6.3	6.3
16	Q3	6.3	6.3	7.3	7.3	7.3
17	K0	7.3	1.3	5.3	5.3	5.3
18	K1	H1	H1	H1	H1	H1
19	K2	7.1	2.2	6.1	7.1	EFP Aft
20	K3	Unused	Unused	Unused	Unused	Unused

The numbering for the accelerometers attached to the DG sets is the same for every DG, requiring that the DG be identified to clarify which is being discussed. Figure A.6 shows a representative DG set (from above) and the orientation with respect to the ship. Accelerometers 1 through 4 (the blue ovals) indicate accelerometers on the machinery side of the mount (above) while 5 through 8 (the pink ovals) indicate accelerometers on the ship foundation side of the mount (below).

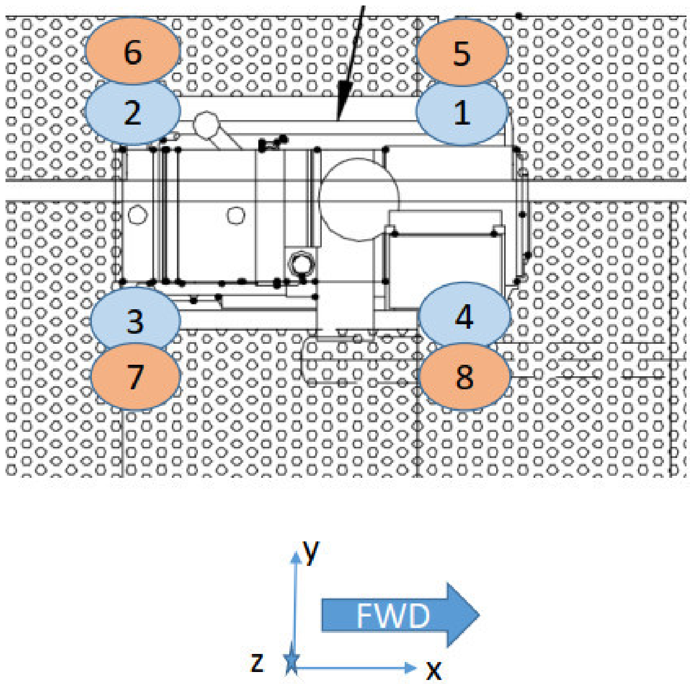

Figure A.6: *DG set accelerometer numbering.*

Table A.4 shows the accelerometer configuration for the final static run from Part 1, involving the emergency fire pump (EFP) listed as Configuration 9. The table also shows the configuration for the shaker trials including the force signal from the shaker (Shaker, F) as well as the acceleration at the shaker input (Shaker, a).

Table A.4: *Static trial Parts 1 and 2 accelerometer configurations.*

Count	Channel ID	Config. 9	Config. 10
1	V0	Hydrophone	Hydrophone
2	V1	Stbd Tach	Stbd Tach
3	V2	Not Used	Not Used
4	V3	Port Tach	Port Tach
5	A0	H4	H4
6	A1	8.3 PPD	8.3 PPD
7	A2	H2	H2
8	A3	H6	H6
9	C0	EFP Fwd	Shaker, F
10	C1	6.3 PPD	6.3 PPD
11	C2	6.3 DG1	6.3 DG1
12	C3	H2	H2

Count	Channel ID	Config. 9	Config. 10
13	Q0	H6	H6
14	Q1	18.3	18.3
15	Q2	5.3	5.3
16	Q3	7.3	7.3
17	K0	Unused	*
18	K1	H1	H1
19	K2	EFP Aft	Shaker, a
20	K3	Unused	Unused

The asterisk (*) indicates that a magnetic mount was used at location 5.3 after 19:24 UTC for comparison with the glue mounts used (Channel IDs 15 and 17).

Table A.5 shows the final two accelerometer configurations for the last two dynamic sea trial runs looking a noise flanking paths for the port propulsion diesel (Configuration 11) and gathering more data from the port propulsion diesel (Configuration 12). Note that Channel ID K0 was a magnetically-mounted accelerometer placed next to H6 (glued).

Table A.5: *Final accelerometer configurations.*

Count	Channel ID	Config. 11	Config. 12
1	V0	Hydrophone	Hydrophone
2	V1	Stbd Tach	Stbd Tach
3	V2	Not Used	Not Used
4	V3	Port Tach	Port Tach
5	A0	H4	H4
6	A1	13 axial	1.3
7	A2	H2	H2
8	A3	H6	H6
9	C0	19.3	2.3
10	C1	10 axial	3.3
11	C2	9 axial	4.3
12	C3	H2	H2
13	Q0	H6	H6
14	Q1	4.3	7.3
15	Q2	14 axial	8.3
16	Q3	8.3	18.3
17	K0	H6, M	5.3
18	K1	H1	H1
19	K2	20 axial	18.3
20	K3	Unused	Unused

Annex B Input Mobility Configurations

The hammers used in the mobility measurements were a smaller Bruel & Kjaer (B&K) Model 8206-002 hammer (100 g head mass) with and a larger B&K Model 8210-51454 sledge hammer (12 lb, 5450 g head mass). The smaller hammer had interchangeable Teflon, rubber, and steel heads as well as the possibility of adding additional mass.

Figures B.1 through B.6 show details of the locations used in the mobility tests with black stars indicating the strike locations.

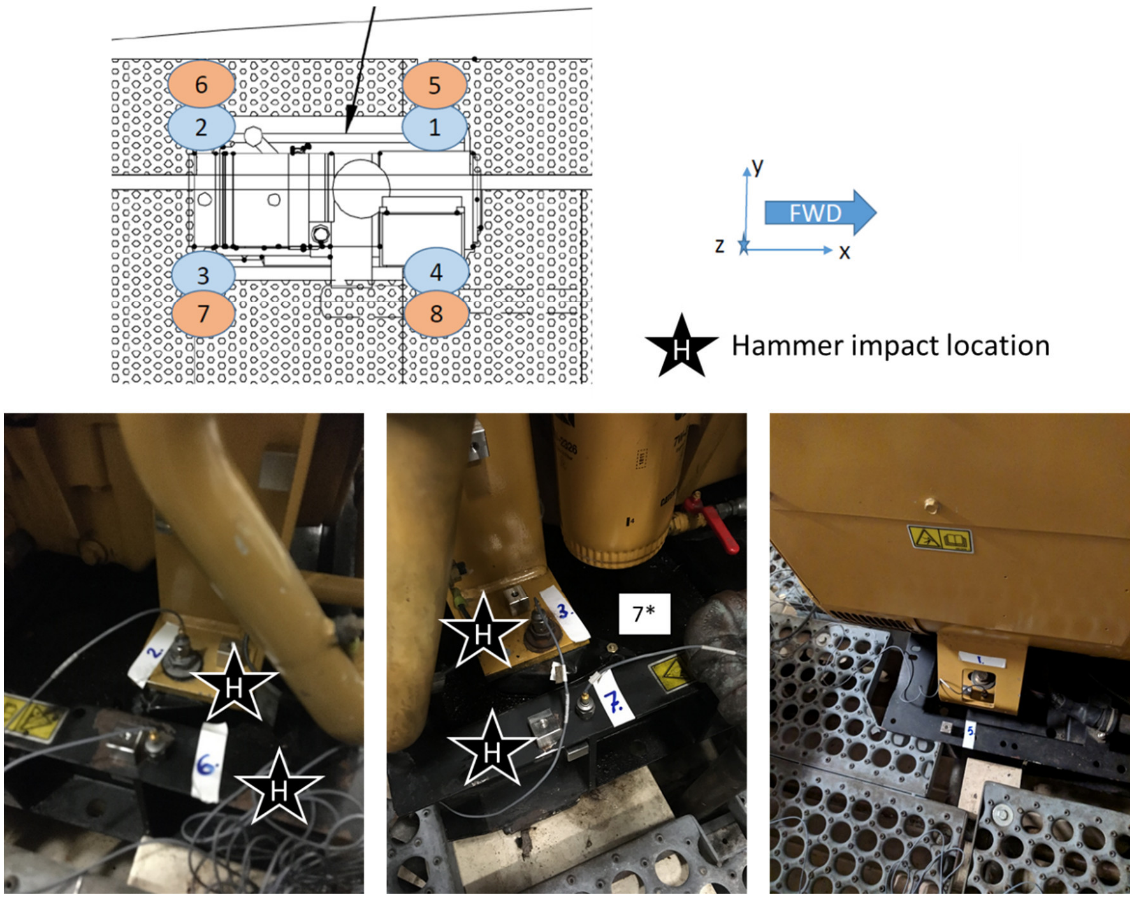

Figure B.1: *Hammer tests locations on DG1.*

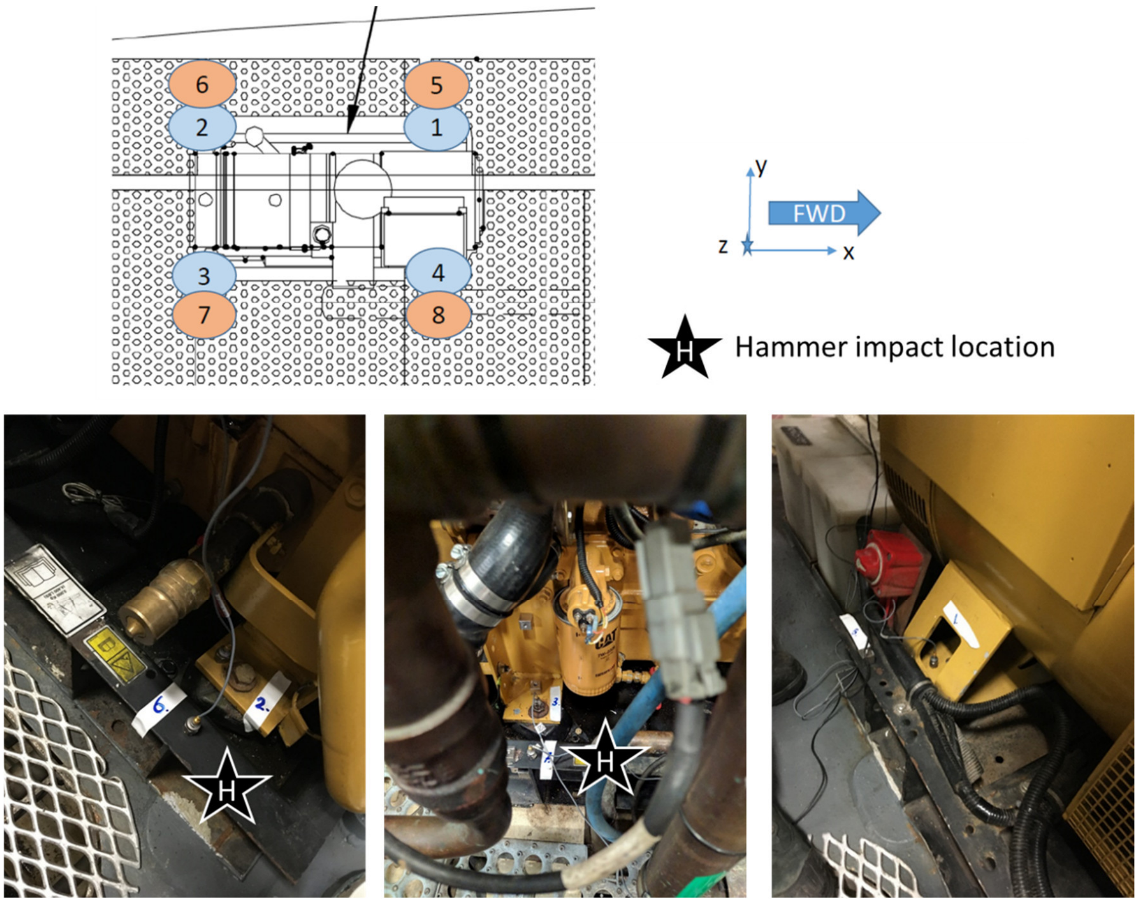

Figure B.2: *Hammer test locations on DG2.*

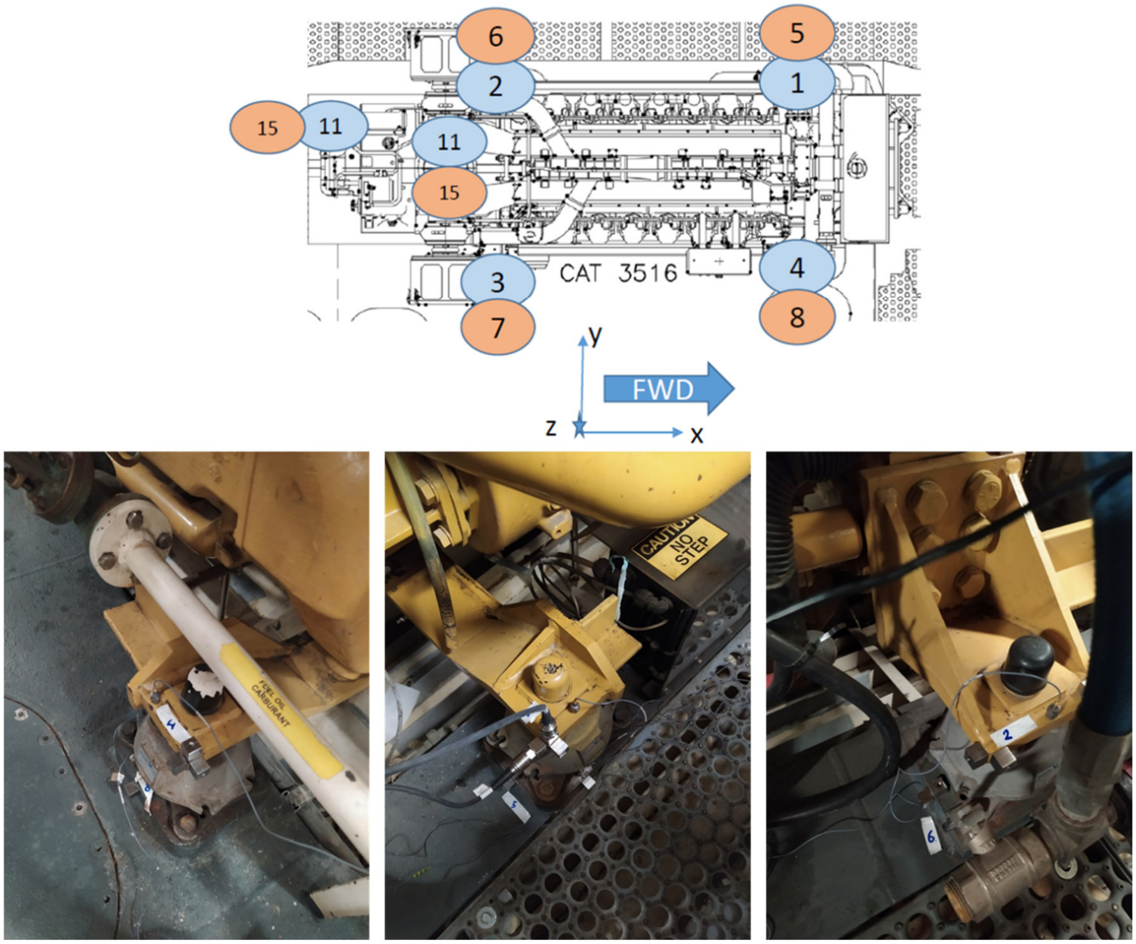

Figure B.3: *Hammer test locations on port propulsion diesel.*

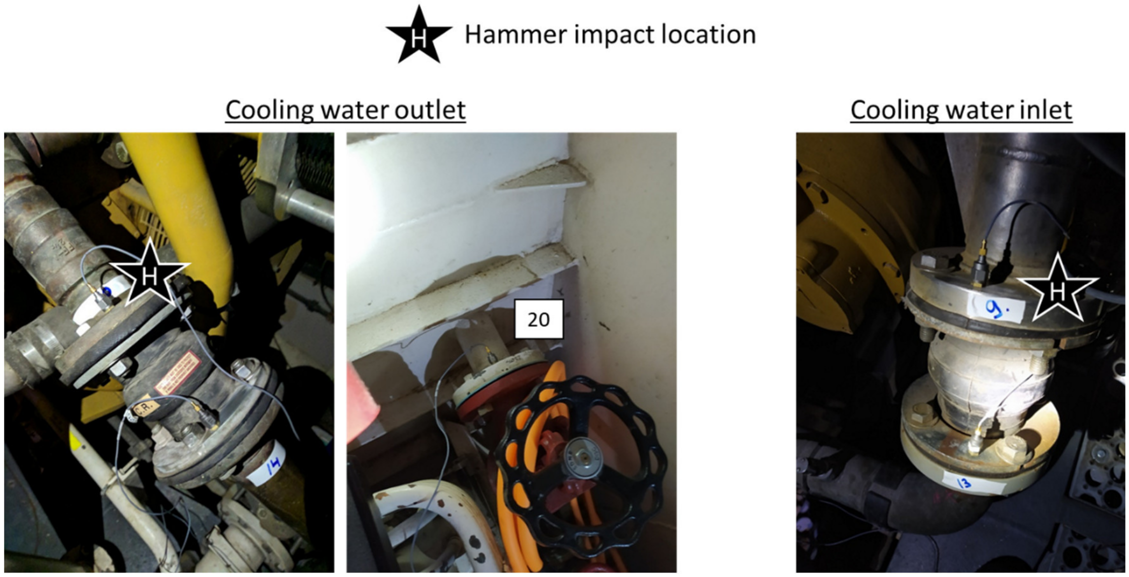

Figure B.4: *Hammer test locations—flanking paths*.

Figure B.5: *Hammer test locations—port propulsion diesel foundation*.

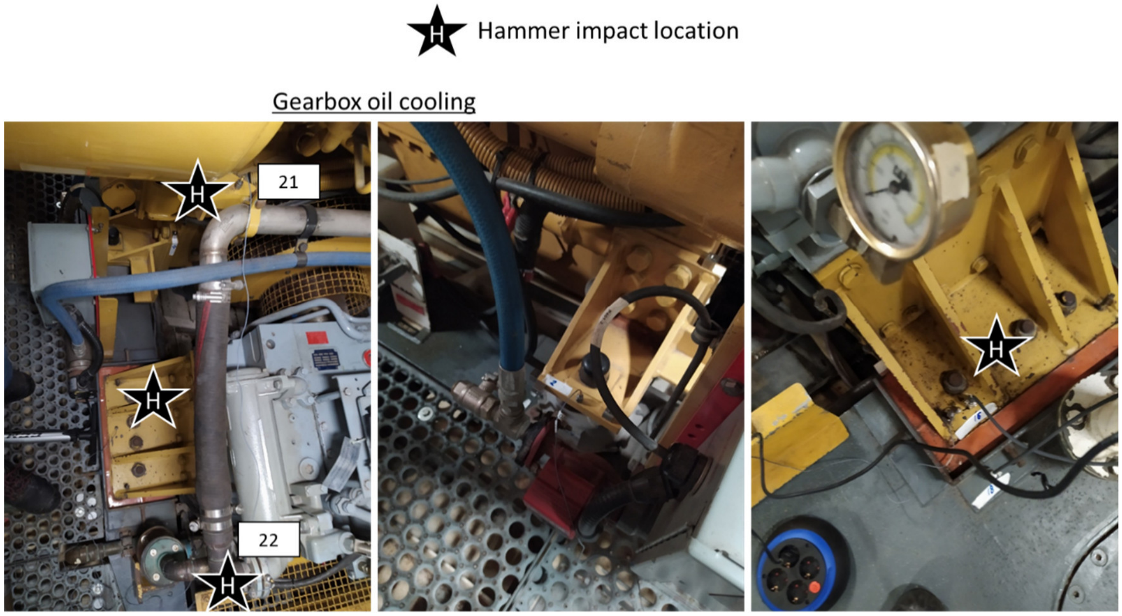

Figure B.6: *Hammer test locations—gearbox oil cooling.*

Annex C Microphone/Speaker Configurations

During the trial, microphones (B&K Model 4192) were placed in the engine room to monitor airborne noise levels. There were two microphones and four locations were selected. The microphones were suspended from the ceiling and the signals were measured concurrently with other data during each run. Figures C.1 and C.2 below show the four locations. The yellow circle indicates the microphone in the photographs and the yellow star shows their location in the plan view.

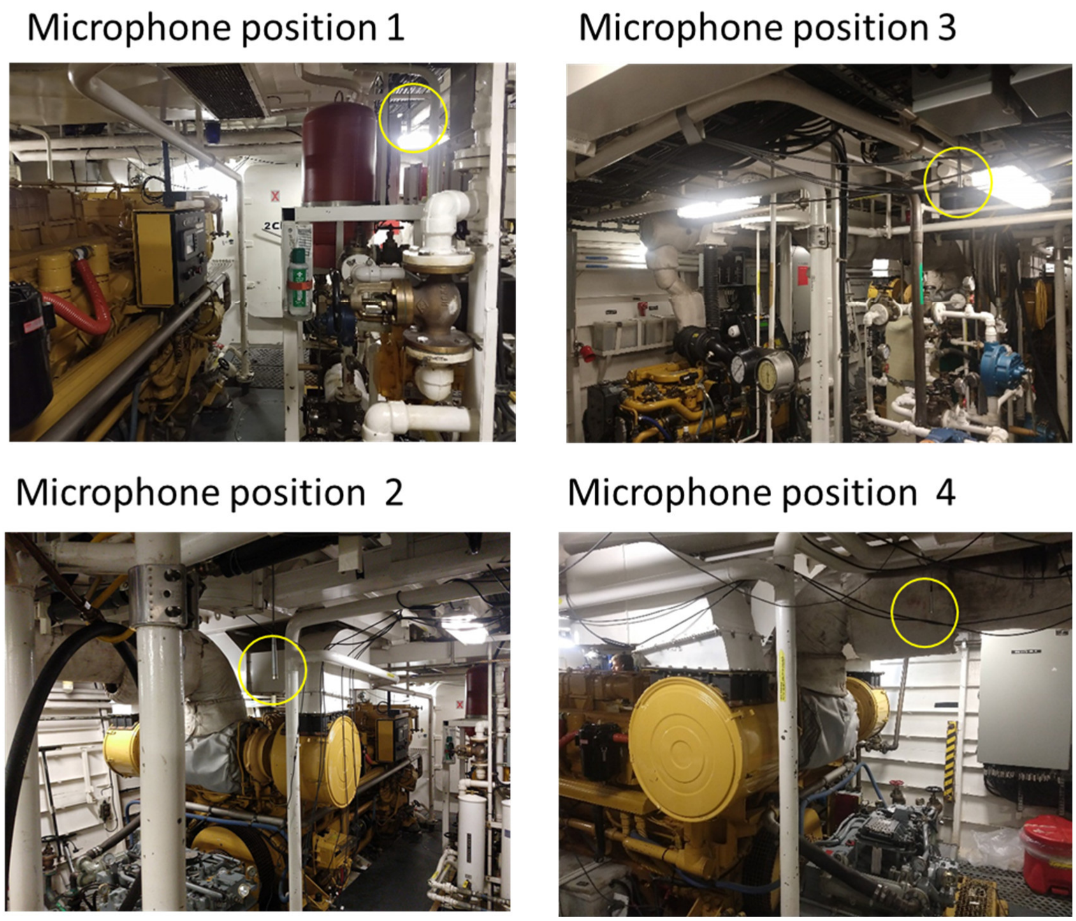

Figure C.1: *Microphone location photos.*

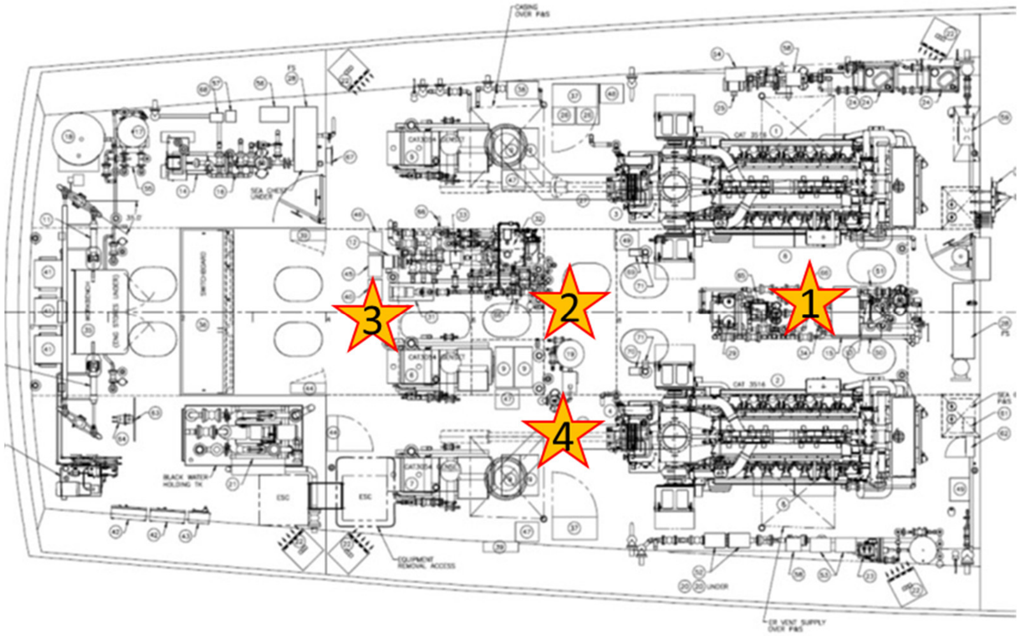

Figure C.2: *Microphone locations—plan view.*

A loudspeaker was set up at one of two locations shown in Figures C.3 and C.4. The two locations were 1) centred between the port and starboard propulsion diesels and 2) between DG2 and DG3 (the starboard and central DGs). Note that, in the photos, the speaker is the white rectangular object (indicated by the red arrow) on the tripod pedestal.

Figure C.3: *Speaker Position 1.*

Figure C.4: *Speaker Position 2.*

The popping of standard rubber balloons was used to perform reverberation experiments during the static trials. Four tests were done using the microphone locations from Figure C.2. However, the balloon pop tests were re-ordered slightly as shown in Figure C.5.

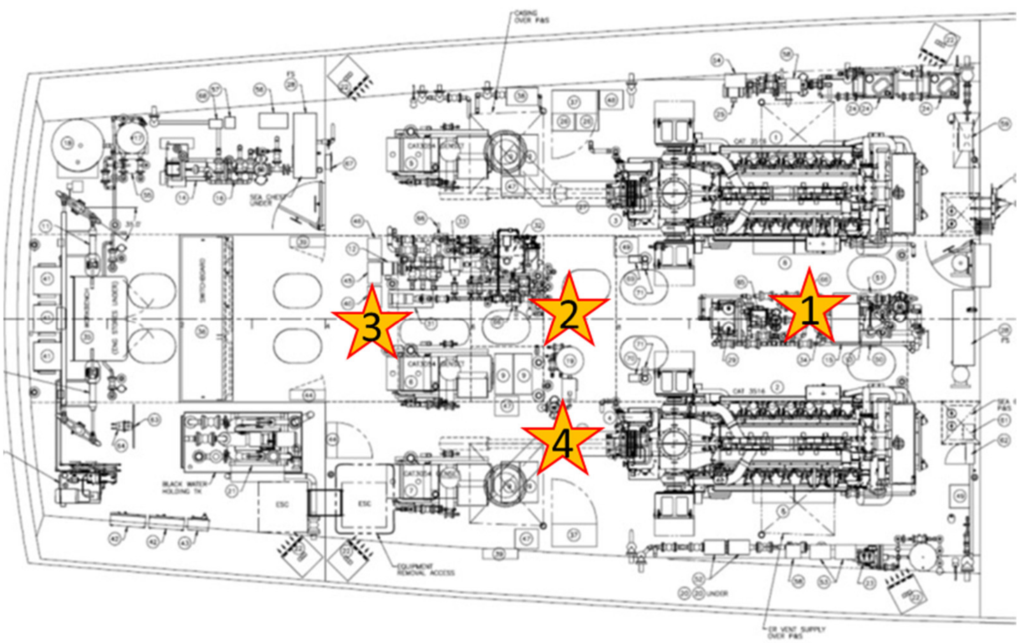

Figure C.5: *Balloon locations.*

Annex D Shaker Configurations

During the static trials, a piezomechanical shaker (Wilcoxon F4/F7) was used to provide controlled excitation of the ship structure. Three shaker locations were used and are shown below in Figures D.1 through D.3. The first is on a ship frame near the portside gearbox, the second is on the outboard forward mount of DG1, while the third in on the outboard forward mount of the port propulsion diesel.

Figure D.1: *Shaker Location 1.*

Figure D.2: *Shaker Location 2.*

Figure D.3: *Shaker Location 3.*

List of Symbols/Abbreviations/Acronyms/Initialisms

B&K	Bruel and Kjaer
BURNSi	Benchmark Underwater Radiated Noise Simulation
BW	Black Water pump
CFB	Canadian Forces Base
CPA	closest point of approach
CTD	conductivity, temperature, depth
DAQ	data acquisition system
DG	diesel generator
DMO	Defence Materiel Organization
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EFP	emergency fire pump
FFT	Fast Fourier Transform
FMF	Fleet Maintenance Facility
FP	fire pump
MFP	main fire pump
MRC	Marine royale canadienne
NB	narrow band
NDL	Netherlands
Pat Bay	Patricia Bay
PCT	Patrol Craft, Training
PPD	port propulsion diesel
RCN	Royal Canadian Navy
SGP	steering gear pump
TC	Transport Canada
UPS	uninterruptible power supplies
UTC	Coordinated Universal Time
WTD71	Bundeswehr Technical Centre for Ships and Naval Weapons, Maritime Technology and Research

DOCUMENT CONTROL DATA

*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.) DRDC – Atlantic Research Centre Defence Research and Development Canada 9 Grove Street P.O. Box 1012 Dartmouth, Nova Scotia B2Y 3Z7 Canada	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) CAN UNCLASSIFIED 2b. CONTROLLED GOODS NON-CONTROLLED GOODS DMC A

3. TITLE (The document title and sub-title as indicated on the title page.)

ORCA Benchmark Underwater Radiated Noise Simulation (BURNSi) Measurement Trial Report

4. AUTHORS (Last name, followed by initials – ranks, titles, etc., not to be used)

Gilroy, L.

5. DATE OF PUBLICATION (Month and year of publication of document.) February 2021	6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.) 45	6b. NO. OF REFS (Total references cited.) 6

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

Reference Document

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

DRDC – Atlantic Research Centre
Defence Research and Development Canada
9 Grove Street
P.O. Box 1012
Dartmouth, Nova Scotia B2Y 3Z7
Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) 01ec - Naval Signature Management	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC-RDDC-2021-D009	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

Naval Acoustic Signature Management; Acoustic Ranging; Transfer Function; Sea Trial; Accelerometers; Onboard Noise

13. ABSTRACT (When available in the document, the French version of the abstract must be included here.)

A research project is currently being undertaken by Transport Canada (TC) to better understand the impact of marine vessel generated noise on marine life on the West Coast of Canada. In support of the research project, Defence Research and Development Canada(DRDC) – Atlantic Research Centre carried out a set of trials in July 2019 and measured both onboard vibrations and off board underwater noise levels generated by an ORCA-class training ship available from the Royal Canadian Navy (RCN) on the West Coast. The measurements showed onboard vibration levels can be used to predict the underwater radiated noise from the vessel and that it is possible to monitor propeller cavitation. As a result of this trial, the Netherlands Defence Materiel Organization (DMO) proposed an international workshop, the Benchmark Underwater Radiated Noise Simulation (BURNSi) workshop. Participants of the workshop would be provided with the necessary onboard data, drawings and structural models and they would then perform blind predictions of the ship's underwater radiated noise to validate their prediction model as a spinoff. The participants would then gather to compare predictions and the previously measured noise levels. As the previous trial did not gather all the necessary information to support such a workshop, DRDC carried out additional trials on the same ship in pursuit of characterizing structure and airborne noise contribution from main machinery noise sources; identifying flanking paths by measuring vibration levels on all presumed flanking paths e.g., cooling water, lube oil, propeller shaft); evaluating the impact of machinery mounts (when applicable) on structure-borne noise transfer; and measuring ship foundation mechanical impedance. This Reference Document outlines the work that was done, the completed list of runs performed and other measurements made, and some preliminary results.

Un projet de recherche est actuellement entrepris par Transports Canada (TC) pour mieux comprendre l'impact du bruit généré par les navires sur la vie marine sur la côte ouest du Canada. À l'appui du projet de recherche, Recherche et développement pour la défense Canada (RDDC) – Centre de recherches de l'Atlantique a réalisé une série d'essais en juillet 2019 et a mesuré les vibrations à bord et les niveaux de bruit sous-marin hors bord générés par un navire-école de classe ORCA disponible auprès de la Marine royale canadienne (MRC) sur la côte ouest. Les mesures ont montré que les niveaux de vibration à bord peuvent être utilisés pour prédire le bruit sous-marin rayonné du navire et qu'il est possible de surveiller la cavitation de l'hélice. À la suite de cet essai, l'Organisation néerlandaise du matériel de défense (OGD) a proposé un atelier international, l'atelier Benchmark Underwater Radiated Noise Simulation (BURNSi). Les participants à l'atelier recevraient les données de bord, les dessins et les modèles structurels nécessaires, puis ils effectueraient des prédictions aveugles du bruit rayonné sous-marin du navire pour valider leur modèle de prévision en tant que retombée. Les participants se réunissaient ensuite pour comparer les prévisions et les niveaux de bruit mesurés précédemment. Comme l'essai précédent n'a pas rassemblé toutes les informations nécessaires pour soutenir un tel atelier, RDDC a effectué des essais supplémentaires sur le même navire afin de caractériser la structure et la contribution au bruit aérien provenant des principales sources de bruit des machines; identifier les trajectoires flanquantes en mesurant les niveaux de vibration sur toutes les trajectoires flanquantes présumées (par exemple eau de refroidissement, huile de lubrification, arbre d'hélice); évaluer l'impact des supports de machines (le cas échéant) sur le transfert du bruit véhiculé par la structure; et mesurer l'impédance mécanique des fondations du navire. Ce document de référence décrit le travail effectué, la liste complète des analyses effectuées et des autres mesures effectuées, ainsi que quelques résultats préliminaires.