CISMaRT
CANADIAN NETWORK FOR INNOVATIVE SHIPBUILDING, MARINE RESEARCH AND TRAINING | RÉSEAU CANADIEN POUR L'INNOVATION DANS LA CONSTRUCTION NAVALE, LA RECHERCHE MARINE ET LA FORMATION

Transport Canada   Transports Canada

Report on

The CISMaRT/Transport Canada Workshop on

Ship Noise Mitigation Technologies for a Quieter Ocean

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Table of Contents

Acknowledgements

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Executive Summary

- Underwater noise is known to have negative effects on marine life. With busy waterways, such as the coast of British Columbia and the Gulf of St. Lawrence, Canada is seeking ways to address the challenge of protecting marine life without unduly impacting commercial activities in these waters.
- An important element is to apply technological measures in the design, construction and operation of ships, especially large and fast ships, to address this challenge. A workshop was held to better define the problem and understand the gaps in mitigation technologies for underwater noise from ships.
- The workshop was organized and hosted jointly by CISMaRT and Transport Canada. It was held at the Four Points by Sheraton Halifax in November 28 and 29, 2018. There were about 70 attendees including representatives from engineering companies, shipping companies, classification societies, research organizations, academia and various government agencies. Most of the participants were engineers, naval architects or scientists.
- The workshop comprised a short course on underwater noise from ships, invited presentations from leading figures with special expertise in some aspects of underwater noise from ships, and breakout sessions. The presentations set the scene for the issues surrounding the problem on underwater noise from ships, and most specifically on ship noise mitigation technologies.
- Two breakout brainstorming sessions involved seven groups drawn from the workshop participants. The first session was concerned general aspects of ship noise and the second focused on the mitigation measures that can be incorporated into ships, either in the design stage or during retrofit. The basis for the latter session was a matrix developed prior to the workshop, which included a list of mitigation technologies currently available together with their key characteristics.
- From the results of the breakout sessions and the general discussions that followed each breakout session, it is clear that many uncertainties still remain and much work remains to resolve the challenges. In this regard the deliberations yielded a long list of possible projects that could be undertaken to address the challenges and the gaps.
- The results of the workshop will provide useful input to the planning of a second workshop to be held on January 29 – February 1, 2019 at the premises of the IMO, London, UK.

1 Introduction

This report describes the proceedings of a workshop titled "**Ship Noise Mitigation Technologies for a Quieter Ocean**" which was organized and hosted jointly by CISMaRT[1] and Transport Canada on November 28-29, 2018 in Halifax, NS. The background to the issue of the effects of underwater radiated noise (URN) from ships on marine life is outlined in the paragraphs below. Section 2 summarizes the short course on underwater noises. Sections 3 and 4 provide the summary of the other workshop sessions and outcomes.

1.1 Background

It has been noted by various authorities that the volume and intensity of URN has grown significantly over the last several decades[2]. There are broadly two underlying reasons for this. First, the volume of shipping has grown substantially since the 1970s and this is a manifestation of the growth in international trade. Between 80% and 90% of international trade is transported by sea and this has increased more than four-fold since 1970. The main ship types engaged in this trade are tankers, bulk carriers and containerships. The second associated reason for the increase in noise is the general increase in the size and speed of commercial ships.

Researchers and investigators have noted that the increase in URN has had a negative influence on several aspects of marine life in regions of the ocean where there is close proximity between ships, particularly large and fast ships, and marine life. Several conferences, workshops and symposia have been held to discuss the issues and have suggested possible ways ahead to mitigate the negative effects of the increase in URN. One significant resulting initiative was the development of broad non-mandatory guidelines[3] under the auspices of the International Maritime Organization (IMO). In addition, several large-scale and smaller research programs have been undertaken to better identify the gaps in relevant knowledge and associated technologies. Several countries have been involved in this work and major initiatives were led by European

[1] **C**anadian network for **I**nnovative **S**hipbuilding, **Ma**rine **R**esearch and **T**raining (CISMaRT) is a collaborative venture between industry, government and academia which fosters marine technology research relevant to Canada. CISMaRT focuses on projects in four themes – SMART, GREEN, SAFE and IMPLEMENT. Further details can be found at *cismart.ca*

[2] For example, see "50 Years of Review of Maritime Transport, 1968-2018: Reflecting on the Past, Exploring the Future", UNCTAD, 2018.

[3] Guidelines for the Reduction of Underwater Noise From Commercial Shipping to Address Adverse Impacts on Marine Life, MEPC.1/Circ. 833, 7 April 2014, International Maritime Organization, London, UK.

countries, much of them funded by European Union agencies. The principal examples of the latter are the AQUO[4] project and its sister project, SONIC[5]. Other smaller initiatives have explored related subject areas. Despite these efforts, uncertainties remain. This is a reflection of the vast scope of the scientific and technological challenges associated with the effect of ship URN on marine life.

The motivation for this workshop in particular, and the broad initiative in general, has been documented in various papers and presentations. In Canada, this issue is part of a broader concern with the health of the oceans and waterways that surround Canada. The subject of this workshop is associated with the effect of URN on marine life. For the background on the issue, see the presentation[6] by Michelle Sanders of Transport Canada.

The workshop discussed in this report can be regarded as a precursor to another workshop to be hosted by Transport Canada, titled "Quieting Ships to Protect the Marine Environment", on January 30 – February 1, 2019 and held at IMO premises in London, United Kingdom. Both workshops have the common aim of sharing knowledge and advancing work on quiet ship designs and technologies to help protect the marine environment. For the sake of clarity, the workshop that is the subject of this report is identified as "the Halifax workshop" and the forthcoming workshop as "the London workshop".

The Halifax workshop and the London workshop are focussed on one particular aspect concerning the engineering of ship noise mitigation measures to reduce URN levels. With an objective to achieve significant reductions in noise levels, it is clear that an international effort is required to put effective requirements in place. In this regard Canada wishes to raise the profile of this issue in international circles and the two workshops are designed to contribute to this goal.

1.2 The Halifax Workshop

The workshop was attended by nearly 70 delegates with an interest in underwater noise caused by shipping and its mitigation technologies through ship design. The delegates included representatives from various broad sectors of the marine industry, government, research community and academia. More specifically,

[4] A key deliverable of the AQUO project is: AQUO (Achieve QUieter Oceans by shipping noise footprint reduction), FP7 - Collaborative Project No. 314227, WP 5: Practical Guidelines, Task T5.1, Comprehensive Listing of Possible Improvement Solutions and Mitigation Measures.
[5] Suppression of Underwater Noise Induced by Cavitation, FP7-Collaborative Project No. 314394 -SONIC Final Report.
[6] Presentation can be found at http://cismart.ca/2018-workshop/. Link to this presentation, and others presented on November 28, 2018, is on the last line of the page.

participants included naval architects and engineers from engineering companies, shipping companies, classification societies, research organizations, academia and various government agencies. The marine science community was represented by those with expertise in subjects such as the effects of underwater noise on marine life, underwater noise measurement and the influence of operational measures to help mitigate noise. An approximate breakdown, by skill and by sector, is as follows:

By Skill	
Naval architects/engineers	41
Scientists	7
Environmental scientist/engineers	14
Non-technical	6

By Sector	
Academia	11
Class society	3
Consultancy	16
Government	14
Manufacturer	3
Operator	10
Research agency (including government agencies such as NRC, DRDC)	11

A complete list of those who registered for the work shop is provided in Appendix A. The agenda for the workshop is given in Appendix B.

The workshop was organized in three distinct parts, each lasting half a working day, and was preceded by two opening statements. The workshop was opened by Wei Qiu of Memorial University and Michelle Sanders of Transport Canada. Wei Qiu started proceedings by welcoming all to the workshop and making participants aware of various administrative issues.

Michelle Sanders added her welcome and laid out the reasons for supporting the work of the two workshops and provided a context for the initiative. Michelle noted that Canada is surrounded by three oceans and has busy waterways as a major trading nation. In regard to the latter, the current main locations of interest are the Port of Vancouver and the Gulf of St. Lawrence. Action is needed in these regions because of the crowded nature of these waterways – populated with certain species of whale which are forced to coexist with commercial shipping, ferry services, etc. This issue is one of several to be addressed under the Ocean Protection Plan, which is the largest investment ever made to protect Canada's coasts and waterways. A few initiatives are already underway related to URN from shipping. These include noise measurements programs, research projects such as analysis of measurements and development of analysis tools, and interaction with related international initiatives. This workshop and the London workshop are integral to the overall program.

The Halifax workshop was organized in three parts as follows:

1. Short course on underwater noise from ships
2. Presentations, breakout brainstorming session and discussion on general aspects of underwater noise from ships
3. Presentations, breakout brainstorming session and specific aspects of underwater noise from ships with a focus on noise mitigation technologies

The short course on underwater noise from ships was given by Michael Bahtiarian, a Principal Consultant with Acentech Inc.[7], an acoustics engineer with extensive experience in the subject including the design of quiet ships. The key features of the course are summarized in Section 2 of the report immediately following this Section. The primary objective of the course was to familiarize the audience with the basic elements of underwater noise technology, including terminology, units, the various sources of noise, and engineering strategies for minimizing URN. The course provided useful background for subsequent discussions held during Parts 2 and 3 of the workshop.

The second and third parts, described in Sections 3 and 4, each included presentations, a breakout brainstorming session and a general discussion period. The breakout sessions were designed to elicit information from the participants to establish a good understanding of the main questions and challenges in each of the areas relevant to URN from ships. The second part (Section 3) addressed general aspects while the third part (Section 4) was concentrated on ship noise mitigation technologies. Participants were invited to also propose potential projects designed to address the identified challenges and gaps.

As described in Sections 3 and 4, the approach adopted for the breakout sessions was to pose a number of questions for the breakout groups to consider and then to present a summary of each of the deliberations to the entire workshop. The key points made during the presentations, in the breakouts groups and in the general discussion are summarized.

Concluding remarks about the workshop are presented in Section 5.

[7] Acentech is headquartered in Cambridge, MA and offers consulting services in architectural acoustics, audio-visual design, noise and vibration control, security systems, and information technology design.

2 Short Course on Underwater Noise from Ships

The topics covered in the course were:

- Fundamentals of underwater sound
- Ship noise predictions
- Noise control treatments
- Acceptance criteria
- Ship case study

The section on fundamentals of underwater sound, representing almost half the course, introduced the basic physics of sound, the associated terminology and units used in quantifying sound. A description of relevant frequency ranges followed together with how they are represented mathematically. Comparisons of how sound behaves in air and water were made. The important topic of measuring underwater sound was outlined. Typical sound levels were presented to give the audience an appreciation of the kinds of sound that underwater sea life is subjected to. A description was provided of the sound levels experienced in the marine environment and included ambient sound and underwater radiated noise from shipping. A chart was shown indicating typical frequency ranges for sound that is anthropogenically-generated and the frequency ranges important to various sea mammals. A comparison of URN generated by different ship types was presented.

The next broad topic covered was the types of noise generated by ships. The main sources are the propeller, machinery, sea-connected systems and airborne transmission. Details of the noise generation mechanisms were provided along with how noise is transmitted through the air, fluids and ship structure.

The next topic concerned the subject of noise measurement. A typical field set-up was described. Various North American sound range facilities for making dedicated measurements were listed. Various existing standards for noise measurements were summarized.

The focus of the next section was how noise is treated in ship design. This included a description of the quiet ship design process. In a qualitative sense, contributions to overall noise from several sources onboard ships were given. Also indicated were the paths of noise from these sources transmitting to the surrounding sea. The analysis methods at the disposal of designers were discussed. These ranged from largely empirical methodologies used as cookbook approaches to advanced numerical methods such as Statistical Energy Analysis. Some of the commercially available software packages were described. Also presented were typical comparisons between predicted and measured URN levels.

The next broad topic covered was the technology available to reduce noise levels, including how propellers can be made less noisy, damping and insulation treatments, isolation systems, and general good design practice to avoid “noise shorts”. Also shown was an indication of how effective these approaches are in noise reduction.

The final topic covered was on limiting criteria published by various organizations and agencies. Included in the latter are classification societies.

3 Session on General Aspects of Ship Underwater Noise

This section presents a summary of activities during the session on the afternoon of November 28, 2018. This includes a number of presentations, breakout group meetings, presentations by groups and, finally, the general discussions.

3.1 Presentations

The current state-of-the-art of underwater noise from ships was given in a series of presentations by recognised experts in various aspects. Four invited presentations were given; a brief summary of each presentation is as follows.

The first presentation in this session was given by Eric Baudin of Bureau Veritas, Paris, France. It was titled "*Overview of the AQUO, SONIC and related projects - Main findings and next steps*". The AQUO and SONIC projects were major EU-funded initiatives, lasting three years and concluded in 2015. As a joint effort, the initiatives involved the participation of some 25 organizations, including mainly universities, industrial research organizations, shipyards, classification societies, and manufacturers. The broad aim was to provide support to those responsible for setting policy on URN from ships, to propose design solutions and mitigation measures, and to develop practical guidelines to reduce shipping noise. The main deliverables are two sets of guidelines.[8] The presentation also summarized other initiatives in Europe. An example of such an initiative is the so-called i^3 project (named after the lead organization – institute interdisciplinaire de l'innovation) which was intended to take the work undertaken thus far (e.g., AQUO and SONIC) to the next stages. This included the holding of three workshops and one conference, and the drafting of a position paper[9]. As an outcome from this work, it was found that many unknowns, such as the cumulative effects of noise and long-term effects, remain while it was clear that there was a significant impact of URN on certain species. Another important finding was that more work needs to be done in coordinating various initiatives being undertaken in several parts of the world, sharing data and findings, and encouraging dialogue internationally between stakeholders.

The next presentation was given by Lee Kindberg of Maersk Line, the world's largest containership operator in terms of numbers of ship. Its fleet includes some of the

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[8] AQUO, "Underwater Noise Footprint of Shipping: The "Practical Guide", WP 5: Guidelines to Reduce Ship Noise Footprint, FP7 – Collaborative Project No. 314227, 2015. SONIC," Suppression of UW Noise Induced by Cavitation", SONIC Deliverable 5.4, FP7- Grant Agreement No. 314394, 2015

[9] Institute interdisciplinaire de l'innovation et al., "Rackets in the Oceans – Why Underwater Noise Matters, How to Measure it, and How to Manage it", 2017.

world's largest containerships, some of which approach 400m in length. A key message from the presentation concerned the role of innovation in ship design in terms of energy efficiency and ultimately how modern versions of these ships will produce significantly less CO_2 than ships in the existing fleet. The company has undertaken a number of full-scale experiments on Maersk G-Class vessels examining various energy-saving devices. Examples of the latter include refined bulbous bow designs, new propeller designs, propeller boss cap fins, and other devices. The presentation also discussed the primary factors that contribute to underwater noise and the relationship between the energy-saving devices and the URN levels. Based on measurements undertaken by the Scripps Institute of Oceanography, an estimated 6 – 8 dB reduction was attained depending on the frequency range. A key conclusion from this work is the positive synergy that exists between energy savings and noise reduction. A caveat noted was that this work is only the first step towards a full understanding of underwater noise generation and ways to reduce resulting impacts on marine mammals. The presentation posed questions regarding optimum solutions that account for all the elements relevant to ship operations, the environment and efficiency.

The third presentation was given by Krista Trounce of the Vancouver Fraser Port Authority (VFPA) and provided an overview of the ECHO program which started in 2014. The purpose of the program was to better understand and reduce the cumulative impacts of commercial vessel activity on at-risk whales in waters adjacent to the southern coast of British Columbia. As part of this program an extensive measurement program was initiated and in the last three years noise measurements from over 5,100 vessel transits have been made. Sufficient data has been accumulated to allow the development of a vessel ranking system. It was found that ship noise levels depend on a number of ship parameters, such as ship type, gross tonnage, draught, etc. Work is planned to use the gathered data to better understand the relationship between URN and ship parameters. The VFPA EcoAction program was described wherein discounts for port fees are applied in a three-tier system designated Gold, Silver and Bronze. A rating is applied depending on the action taken to implement noise mitigation measures in the ship design concerned. Also discussed were operational measures to reduce noise levels such as reducing ship speed. Sufficient data has been gathered to yield data on URN reduction as a function of speed reduction for several ship types. Further analysis work is planned for the near term, including refining vessel correlations models.

The final presentation was made by Holly Neatby of Defence Research and Development Canada - Atlantic Research Centre on propellers and noise. In commercial shipping, large ships generate high levels of noise and much of the noise originates from the propeller, especially if the propeller is cavitating. The presentation provided a comprehensive list of sources of noise generated by propellers and factors affecting the level of noise. Included were also discussions of flow noise and noise from cavitation and various methodologies for the predictions of URN level. The advantages and disadvantages of model-scale experimental testing, full-scale ship measurements and numerical methods were outlined. This was followed by an important discussion of noise mitigation approaches under the categories of operations, hull design and propeller design. As with most sources of URN from ships, strategies are available for the effective reduction noise levels by design and by changes in operational practice.

3.2 Breakout Session

The short course and specialized presentations provided an excellent primer on underwater noise from ships and useful information for the breakout sessions.

A structured approach to the breakout sessions was employed. First, breakout teams were formed so that each team had a mix of backgrounds useful for considering issues surrounding underwater noise from ships. Second, a number of questions were provided for consideration by the breakout teams (See Appendix C for the composition of teams and the questionnaire in Appendix D). While it was not practicable for all questions to be addressed, either because of limitations of time or because of the lack of a particular expertise in the team, the answers taken as a total provided valuable insights into relevant issues. After the breakout session each breakout team provided a summary of their findings to the workshop. In the remainder of this section, a summary of key responses from the breakout sessions are given in terms of the questions (shown below in *italics*).

Questions were also provided encouraging participants to identify projects for investigating various gaps and challenges. These have been collected and presented in Section 4.3.

1. *Marine life varies from location to location in the world's oceans. Is it reasonable to suppose that the level of noise mitigation required will similarly vary? Is there sufficient data available to quantify the required level of mitigation? If not, please outline the kind/s of project/s that could address the shortcoming.*

One breakout team suggested that the best strategy for overall ship URN reduction is to require small reductions for all ships so that, in aggregate, a general reduction in overall noise levels occurs. Also recommended was to target "low hanging fruit" first and to target especially vulnerable areas. As suggested in the latter, the drive for fuel efficiency and crew comfort may also well reduce URN. A better definition of the problem is needed from the marine science community and an approach should be made to local authorities to specify noise reduction requirements.

2. *Measurements of underwater noise from shipping traffic have been made. Most measurements have been opportunistic although some data has been gathered in dedicated trials. The measured noise is generally representative of total noise and hence it is a challenge to identify the contribution from individual sources of noise. Are further dedicated measurement programs required to understand this situation better? If yes, please outline the basic features of such a measurement program.*

Further to the issue of identifying individual sources of noise, the other variable to be considered is operating condition. Examples include top speed, accelerating, turning, etc. The mission profile of a ship is also considered to be relevant. Note that the influence of operational condition on URN levels was a recurring theme in the workshop and was raised as such in the answers to some other questions.

The use of hydrophones on each side of a shipping channel was recommended as a means of reducing uncertainties in measurements. Dedicated trials were recommended by one breakout group to systematically consider noise as a function of speed and maneuvers.

Noise measurements usually record the total noise signature from ships. It is considered important to be able to identify individual sources of noise, e.g., propellers and main engines, to help target the main sources of noise.

Onboard measurement systems need to be considered and include vibration and pressure sensors in the vicinity of the propellers. One group suggested that a portable data logger could be taken aboard with the pilot when approaching and leaving port.

Another idea was to monitor URN from ships and apply penalties for those that violate limits.

3. *A key component of any assessment of underwater noise levels is the measuring procedures and techniques adopted. Various standards making bodies (ANSI, ISO, ITTC etc.) and classification societies (ABS, BV, DNV GL, etc.) have developed requirements in this regard. Are there efforts to harmonize these requirements? Should there be? What are the primary challenges given the wide variety of ship types? Please suggest projects to address these challenges.*

There was general support for harmonization of requirements, such as measurement procedures and techniques. Some degree of harmonization was occurring among classification societies but the focus in this case is more on criteria rather than measurement procedures and techniques. It was noted that for comparisons to be made the data collecting methods should be harmonized.

There is also a need to establish sensible limits for given ship types, operations and propulsion systems. The current challenge is that requirements to limit noise are voluntary and there is a considerable degree of uncertainty in setting limits and applying them.

4. *In general, which is preferable to a ship operator – noise mitigation by operational measures or by building in low-noise features in the design? What factors are important in making this comparison? Is there sufficient information available to make tradeoff studies?*

The answer depends on several factors, including operational flexibility, cost impacts, and impacts on other efficiencies. Ideally the aim is to minimize cost while maximizing efficiency. Related questions raised in discussions include:

a. Should noise measurements be part of sea trials?
b. Is there a role for noise plans similar to the IMO requirements for Ship Energy Efficiency Management Plans?

In regard to trade-off studies it was noted there is not enough data to for these studies. The suggestion is to start with existing data, identify shortcomings and improve from there.

5. *The general consensus is that that propellers on large commercial ships are the greatest source of URN in the ocean. Noise from propellers on naval ships is a key design parameter. How applicable is this technology to larger commercial ships? And how accessible is naval technology?*

The technology used in naval ships to reduce URN is, according to several breakout groups, relevant to commercial ships, particularly propellers. In addition, a number of specific observations were made as follows:

a. Skewed propeller designs may be considered.
b. Some speculated that propellers made of composite materials might perform better than propellers made of traditional materials.
c. The importance was noted on the quality of manufacturing naval ship propellers for minimizing URN. Careful machining, especially of the leading edge, helps reduce cavitation.
d. As a strategy, the use of two large tunnels just forward of the propellers was suggested to improve intake flow.
e. It was suggested that a reduction in turbulence in the flow upstream of the propeller would also help.
f. Design of propellers should routinely include assessments of vibration and cavitation.

6. *Which three or four simple ship design parameters, or combinations of parameters, are the best indicators of likely high levels of URN. For example, it has been suggested that the EEDI (Energy Efficiency Design Index, a measure of CO_2 emissions per ship's capacity mile) could be used as a surrogate for ship URN. Are you aware of any studies?*

Opinions on the use of EEDI as a surrogate of URN were mixed. Nevertheless, it was considered to be an idea worth further studies and one participant noted that their organization was about to embark on such a study in due course.

There were several suggestions for parameters that might act as surrogates for URN levels, including those as follows either on their own or in combination:

a. Vibration levels measured on shafts and hull (presumably in the vicinity of the propeller)
b. Ship type
c. Ship speed
d. Propulsion type
e. Installed power
f. Propeller diameter
g. Propeller rpm

7. *Is there a significant role for wind-assisted propulsion technologies (e.g. Flettner rotor, sails) to reduce noise levels indirectly?*

This question generated relatively little discussion. The general consensus was the use of wind-assisted should be encouraged. A distinction was made between wind used for generating power and wind that directly propels the ship. The former, of course, offers little, if any, advantage in regard to URN.

One ferry operator suggested Flettner rotors are of interest. Another participant noted that anecdotal evidence from Sweden suggested that benefits were in one case less than expected.

8. *The implementation of URN mitigation technologies has associated co-benefits. Examples may include reduced noise and vibration levels onboard ship, and decreased fuel consumption. Has this been systematically studied? If yes, please identify. Please also suggest projects that would investigate this aspect of URN mitigation technology.*

Some consider that co-benefits of noise reductions have not been clearly demonstrated and it seems that this subject has not been systematically studied. A number of points were made regarding related data, including:

a. High quality data is needed.
b. Gathered data needs to be pooled.
c. Appropriate analytics is required.
d. A standardized approach to data acquisition would be an advantage together with QC and QA requirements.
e. IP was raised as an issue, but it was also noted that data can be made anonymous.
f. Extract trends in the data which can be used to support quieter operations.
g. Social engineering approaches should be explored, e.g., using "nudges" to motivate desired behavior, i.e., lower noise emissions.

9. *What broad long-term trends in commercial shipping are likely to have an impact on URN levels? Examples might include reduced world trade, increase in fuel costs, increase in ship size, transition to LNG as a fuel, etc.*

The only clear trend, other than the ones mentioned in the question, is that the growth in size of ships, at least certain types of ships, is likely to lead to higher levels of URN.

10. *In a recent study, 10 priority research questions related to marine vessel acoustic science were identified. In regard to vessel attributes the following two issues were raised:*

a. What attributes of ships are the most effective indicators of URN?

b. What are the tradeoffs in noise exposure between ship high speed/short time exposure and low speed/long time exposure?

Answers to the second question could provide valuable input into developing URN mitigation strategies and also indicate which issues should be subject to further research.

There were some other points made during general discussions following breakout brainstorming sessions which are not captured above, including:

a. Monitoring systems are low cost nowadays and should be used more widely.
b. There are good reasons for promoting harmonization, especially since shipyards would require this. It was suggested that IMO would be the right body to push for this although, it was noted, the IMO may have limited influence over bodies such as the ISO.
c. Some species in the sea are sensitive to particle motion rather than URN. But it is only important within about 50m of the ship or in shallow water.

4 Session on Ship Underwater Noise Mitigation Technologies

This section presents a summary of activities during the final session of the workshop which was held during the morning of November 29, 2018. This session focussed on technologies for ship underwater noise mitigation and central to the discussions were the findings summarized in a report[10] of work undertaken by VARD Marine in Ottawa for Transport Canada. In preparation for this workshop, the report was circulated to the participants some weeks before the workshop accompanied by a request to participants to review the report. The conclusions were summarized in a presentation (described below) during this session. In the breakout sessions after the presentation, seven breakout teams considered a number of questions related to the report. The primary objective of this session was to establish any gaps in the report, provide additional information, to suggest projects to address gaps, and to generally contribute to the advancement of the state of the art.

As indicated above, the session opened with a single presentation and was followed by breakout group brainstorming sessions. This was followed by presentations by the breakout groups to all workshop participants and a general discussion. The discussions of the breakout groups are summarized in Section 4.2.

Participants were asked to identify possible projects to address gaps and challenges related to the questions. Suggested projects are listed in Section 4.3.

4.1 Presentation

A presentation of the aforementioned report was given by Andrew Kendrick of VARD Marine Inc., Ottawa. The presentation opened with a number of general observations, including the motivation for Transport Canada to take a lead in addressing the threat posed by high levels of URN and the slow pace of the process of developing and eventually approving international regulations for shipping.

The presentation went on to discuss the contents of the report and the key element in terms of a matrix listing technological measures to reduce underwater radiated noise from ships. The matrix presents all commonly known measures together with key features of each measure. These features include:

[10] Ship Underwater Radiated Noise, Report 368-000-01, Rev 1, 09 November 2018, VARD Marine Inc., Ottawa, ON. This report was circulated in its draft form.

- Advantages/benefits
- Disadvantages/challenges
- Technological Readiness Level (TRL)
- Cost estimates
- Applicability (vessel type, as well as new build or refit measures)
- Effectiveness

4.2 Breakout Session

Unlike the subject matter in previous session on general aspects of URN, the session under discussion here was more focussed. The subject matter is confined to technologies that can be implemented to reduce URN levels either during the design phase or once the ship is in service. Operational measures are not within the scope to be considered.

The same structured approach to the breakout session employed for the previous breakout session was used in this session, i.e., seven breakout groups considered ten questions and proposed answers. Each group presented their findings to the workshop. The key points made in response to the questions are summarized below. Also included are key points made during the general discussion when presentations were made by the breakout groups. The break out groups are listed in Appendix C and the questions for breakout groups are in Appendix E. The questions are repeated below in *italics*.

Specific to the Report

1. *Are there other broad categories of noise mitigation technology that should be included? If "Yes", please list.*

The consensus of the breakout groups was that the report covered comprehensively the main ship noise mitigation technologies. A few other candidates for inclusion are suggested as follows:

a. Articulated paddle wheels
b. Ducted propellers
c. Noise attenuation devices such as Helmholtz resonators might be a candidate
d. Active noise cancellation was mentioned a number of times although it was recognized that this was a low TRL technology.

Some related suggestions/comments were made:

a. A suggestion was made to keep the matrix in Appendix A of the VARD Report as a "live document".
b. Active monitoring systems such that noise-making systems could be turned off when needed.

c. Bubbler systems installed for reducing drag may also help mask sound.
d. Systems could be used to monitor propeller outflow and cavitation levels, propeller rpm and pitch.
e. Above systems could be integrated into an AIS data logger.
f. Monitoring systems to trigger maintenance actions particularly related to propeller URN performance.
g. A "factory test" category could include tests for noise mitigation measures where practicable to ensure measurements matches what has been modelled.
h. Cold ironing was suggested as a means of reducing noise at ports
i. Adaptive management.

2. The Matrix (Appendix A of the VARD Report) lists for each noise mitigation technology a number of key features such as TRL, Cost Estimation etc. Are there other features not mentioned that could be usefully added? If "Yes", please list.

The following specific suggestions for features that could be added to the matrix in Appendix A of the VARD Report:

a. Details about ship types that each noise mitigation technology is applicable to.
b. Limitations for each of the mitigation technologies and associated risks, if any.
c. For wind-related technologies the effectiveness in relation to relative wind direction.
d. Cost estimation information should be provided for the prediction URN table

Additional comments:

a. There is not enough low-TRL work being done that could lead to new noise mitigation technologies.
b. The term "enhanced efficiency" (See Section 4.4 of the VARD Report) should be defined more specifically. Does it refer to fuel consumption, for example?
c. It would be useful to provide graphics and references, where applicable, of the technologies discussed in the VARD Report.
d. "Applicability" may be expanded to include circumstances in which the technology will not work effectively.
e. Are the dB values quoted in the VARD report for individual treatments?

3. Under "Propeller Noise" are there treatments and techniques, other than those listed, that have the potential to reduce noise significantly?

The following were mentioned as possible additions to the report:

a. The role of propeller manufacturing quality and tolerance, e.g., high-quality machining of propeller blade by CNC machining to final form and finish without hand grinding

b. Addition of riblets
c. Composite propellers
d. Propellers made using additive manufacturing
e. Propeller surface treatments/coatings
f. Noise cancelling technology

Noise Mitigation Technologies

4. *A co-benefit of reducing noise may be an improved noise environment onboard the ship. Do we know how much? Are you aware of work that addresses this issue? If yes, please identify. Please suggest projects that would help establish quantitative benefits*

The consensus was that a co-benefit of URN reduction would likely result in reduced noise onboard ship, the process is not well understood and difficult to quantify.

Another related comment made was that a similar relationship may exist between the award of a Comfort Class[11] and URN.

5. *What are the main co-benefits (other than the one noted in Q4 above, of introducing noise reducing measures in the design of large ships? Please identify two or three projects that would lead to a better understanding of co-benefits.*

There was a general agreement that the main co-benefits of reduced URN are energy efficiency, less noise on board, and higher levels of habitability.

In regard to energy efficiency, related benefits also include:

a. Less CO2 emissions
b. Lower fuel costs
c. Less human fatigue
d. Less structural fatigue
e. Greater crew and passenger comfort
f. Possibly less wear on propellers because of lower levels of cavitation

6. *In large commercial ships the design of propellers is optimized for thrust. Do you estimate that there is a significant penalty in modifying such designs to also reduce URN? If yes, please estimate ballpark percentages for doing so.*

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[11] "Comfort Class" is a voluntary notation offered by DNV GL and is applied to ships where habitability on board ship is particularly important. Measured noise and vibration levels are required to meet set criteria. There are also requirements for certain properties of air climate in spaces on board ship.

The following comments were offered:

a. Penalty is expected with measures such as increased blade area.
b. One group suggested that low noise propellers are typically 1-3% less efficient, and another group quoted "a few %".
c. Two other groups suggested that an estimate would be premature or that the penalty would have to be estimated on a case-by-case basis.

As an aside one group noted that a Joint Industry Project (JIP) has been initiated by MARIN to develop a new propeller design, dubbed the Wageningen F Series, which will have a number of superior performance characteristics including a low noise signature.

7. *The propeller of large ships is generally the most dominant source of noise. Do we understand how operating conditions (e.g. loading condition, maneuvering) affect the level of noise?*

The breakout groups indicated that our knowledge on how operating conditions influence URN vary from "not known" to "partially known"

Particular comments include:

a. Influence of maneuvering and steering on URN is not known, especially when maneuvering or steering to compensate for cross winds/currents.
b. Limited knowledge on the effect of sea state on URN
c. Bulk carriers – what are differences in noise levels when unloaded versus loaded?
d. Cavitation tests are only done at one or two load conditions at steady speed. Not much data exists for other load conditions or during maneuvering.
e. Not fully known for actual operations and maneuvering (may be possible to assess using CFD to estimate drag and other wake properties, but would need to relate these to URN through transfer functions.)

A group asked why CPP could not be used on cargo ships.

8. *Various methods are used for predicting noise level ranging from simple formulae to advanced numerical analysis tools. Please identify the kinds of tools useful for assessing the effectiveness of noise mitigation measures.*

There was limited discussion on this subject in the breakout groups. It was observed that models exist for predicting URN. However, one group suggested that the level of uncertainty is a key variable in using any of the available tools. The use of these tools usually represents a compromise between effectiveness, cost and time available to exercise the tools.

Statistical Energy Analysis (SEA) is increasingly being used and has been found to be an effective analysis tool, especially for high frequencies.

Among other specialist tools mentioned are cavitation volume velocity methods and simplified physics models.

Systematic work is required comparing predictions and measurements from, say, sound ranges.

9. *Please identify up to three projects that would potentially add significantly to our understanding to the subject of underwater noise from ships. (In this context the size of project can be very approximately characterized as costing, say, US$200K)*

See Section 4.3 below where all projects suggested by breakout groups are summarized.

There were some other points made during general discussions which are not captured above, which include:

a. In regard to the matrix in the VARD report it was suggested to use "+" to signify a positive outcome and "-" a negative outcome for the sake of consistency.
b. Also in regard to the VARD report (Appendix A, Page 1) in the low noise reduction category, i.e., 0-3 dB, it was noted that "0" does not represent a reduction. This should be amended.
c. Again in regard to the report, a request was made to further develop the "Cost Estimation" column to provide more details on cost recovery and payback period. In terms of cost a further request was that capital costs, operating costs and maintenance costs should be identified separately.
d. A question was asked about how to address any attempt to discredit the issue of URN at the London workshop if countered. It was suggested that experts with detailed knowledge of the effects of URN on marine mammals should be present to address such comments.
e. The need for a large cavitation tunnel in Canada was noted.

4.3 Suggested Projects

Participants were asked to list possible projects on both days to address gaps and challenges identified during breakout sessions. These are listed below[12] and presented under 12 categories designated by capital letters; projects are listed numerically under each category.

The titles are the "raw" versions as drafted in the breakout sessions. In the breakout group discussions, it is not possible to develop well-thought-out titles and descriptions for projects; and it is only possible to express a general idea.

[12] The suggested projects have been arranged in categories by M. Bahtiarian.

Nevertheless, the list of topics was considered worthy of investigation and have the potential to address the identified gaps and challenges. The suggested project list will also help focus deliberations for the London workshop.

The wide range of subjects and issues is a broad reflection of the high level of uncertainties in many elements of the subject. In a general and qualitative sense, the design measures that can be taken to mitigate URN are reasonably well understood not least because of the experience gained in the design of naval, research and other types of ships in which quiet operations are desirable. Nevertheless in the absence of experience of applying some of these technologies to large commercial ships, some uncertainties remain.

A. Ship noise measurements, signature analysis and interpretation, machinery vibration, internal noise, propeller pressure pulses

1. Program to establish noise measurement opportunities for designers and owners (and share data). Also need expertise to conduct signature analysis and interpretation.
2. Sea trial data on specific vessels together with related measurements of vibrations, internal noise, pressure pulses from propeller, separating propeller/engine noise.
3. Experiments measuring URN on propellers with manufacturing defects and damage.
4. Noise measurements with different technologies.
5. Characterizing uncertainties in many parameters. Effect of modifications, environmental conditions variability.
6. More baselining – context, vessel condition.

B. Ship self-noise monitoring with cavitation inception indication, collect data with other data sets

1. Program for operators to monitor noise from their own systems together with data on operating conditions. How are such projects activated?
2. Portable data measurement system that can be rapidly installed on a ship.
3. Onboard monitoring system (pressure sensors, accelerometers) to ID cavitation inception – correlating this with actual noise levels
4. Onboard sound/vibration monitoring with acoustic module/interface – collecting other data.
5. Onboard monitoring on five ships for 3-6 months.

C. Research into variation of URN with regard to fouling, damage and manufacturing deflects

1. Measurement program to further study the variation of underwater noise with regard to fouling, damage and manufacturing defects. Can such data be made public?

D. Development of propeller noise/cavitation prediction tools

1. Develop lower-order cavitation prediction tools.
2. Develop high-fidelity models and tools for predicting cavitation, including model and full-scale comparisons, and correlations between cavitation and noise levels.
3. Cavitation collapse delay – efficient propeller.
4. Effectiveness of propeller design strategies for URN in oblique flow.
5. Beneficial hydroelastic blade distortion.

E. Quantification of benefits (i.e. financially) and via fuel consumption of reduced URN

1. Quantifying benefits/co-benefits (financially where possible) especially fuel consumption/efficiencies and URN

F. Research and development of design for vibration isolation of large 2-stroke diesel engines

1. For large 2-stroke diesel engines, experiments on vibration isolation/damping. Current systems don't work.

G. Evaluate Haro Straights data for impact of certain noise control technologies

1. With respect to the Haro Strait, identify which technologies have high impact on noise mitigation.

H. Compile relevant data from new ship builds with respect to URN

1. Collect relevant design data in future ships designs more purposefully.
2. Identify other data sets, scopes and limits.

I. Research and development on whether noise correlates with energy efficiency and maintenance

1. Can energy management tools be expanded to address noise management issues? Does noise correlate well with energy efficiency and maintenance?

J. Case study on existing ship design with focus on mitigation and modelling

1. Case study of existing ship design.
2. Evaluate different options for mitigation.
3. Use modeling tools.

K. Research & development into active noise cancellation (panels above propeller & other)

1. Active noise cancellation panels above propellers.

L. Ship noise predictions to evaluate combined mitigation treatments to gain the most benefit

1. Combined mitigation treatments – what can be combined to achieve most benefit?

5 Concluding Remarks

This report describes the Halifax workshop on the subject of technologies for mitigating underwater radiated noise from ships. The first half-day was devoted to a short course on underwater noise from ships. This formed the backdrop for the subsequent sessions, which comprised presentations from experts on various aspects of the subject, and breakout group brainstorming sessions. The report summarized the main findings from these sessions and includes an assessment of the current state-of-the-art and the issues that need to be addressed in order to take the general topic of ship URN mitigation technologies to subsequent stages. Also included are suggestions for projects to address the gaps and challenges identified as part of the workshop deliberations. All this taken together should provide information useful for the next event, the London workshop.

A significant body of knowledge has been developed on technologies for reducing the level of underwater noise emitted from ships. The design community has experience in applying the knowledge in designing navy, research and other types of ships which are required to be as quiet as practicable. At the same time, it is recognized that much of the underwater radiated noise emitted in shipping is from large commercial ships which, while having some similarities to smaller naval and research vessels, also have important differences. Not all the technology is fully scalable.

The workshop showed that many noise-reducing technologies are mature as indicated by the high TRL numbers shown in Appendix A of the VARD Report. However, these high TRL numbers are associated with quieting technologies applied to specific ship types, such as navy and research vessels. The requirements to limit noise signatures are motivated by the necessity to perform their mission rather than to reduce URN levels to protect marine life. These ships are typically much smaller than many modern commercial ships. The largest containerships can approach 400m in length and are designed for speeds of about 25 knots. Hence, while quieting technologies may have high TRL numbers for present applications, lower numbers should apply when the application is to modern large commercial ships, the source of high noise levels in the world's oceans.

The workshop also identified some technologies that were developed for application in non-marine industries where the technology may have a high TRL number. Examples include noise-cancelling technology and additive manufacturing techniques. These may very well eventually prove to be effective as means for reducing noise levels from ships. Again, considerable work is required to demonstrate that the technology can be adapted for the URN problem.

Another challenge is associated with what criteria should apply in terms of limiting sound levels and the frequency ranges that should apply. While some work has been done in terms of assessing the damage caused to marine mammals from URN, it does not appear to be sufficiently precise to develop limiting criteria that strike the right balance between the needs of marine mammal life and cost of designing sufficiently quiet ships. Presumably the limiting criteria will need to take account of which waterways are to be protected and to what extent. It is well known that URN can be minimized by design measures or by operational actions or some combination thereof. Without fairly precise limiting criteria, it is difficult for shipowners and operators to apply cost effective strategies to limit URN.

Many relevant parameters of the overall problem remain undefined. As a consequence, many of the projects suggested during the workshop were aimed at reducing the uncertainties which principally concern the following:

1. The influence on noise levels of the various parameters that characterize ships and their operations
2. The application of newer technologies that hold the promise of effective noise control in ships
3. A focus of high precision propeller manufacturing processes and improved propeller designs by investigating the application of novel design features
4. Dedicated field measurements of noise from ships to address uncertainties noted immediately above
5. A better understanding of the co-benefits of noise reductions with a focus on energy efficiencies. The marine industry is already committed to the latter because of current regulatory and economic pressures.

Appendix A Workshop Participants

First Name	Last Name	Title	Organization
Chanwoo	Bae	Engineering Manager	BC Ferries
Michael	Bahtiarian	Principal Consultant	Acentech
Roger	Basu	Dr/Facilitator	Roger Basu & Associates Inc.
Eric	Baudin	Head of Test & Measurements	Bureau Veritas
David	Belisle	Manager, Vessel Performance	Algoma Central Corporation
David	Benoit	Captain	DND
James	Bonnell	Director, Business Development	Dominis Engineering Ltd
Anna	Bryns	Naval Architect	Bruns - Naval Architect
Scott	Carr	CEO	JASCO Applied Sciences (Canada) Ltd.
Clement	Chion	Professor	University of Quebec in Outaouais
Elena	Corin	Director of Sales	Albion Marine Solutions Ltd.
Daniel	Cote	Sr. Environmental Advisor	Transport Desgagnes
Jim	Covill	Lead Technical Specialist	Lloyd's Register ATG
Allan	Dale	Director, Industry Partnership	UPEI - Faculty of Sustainable Design Engineering
Vince	den Hertog	Vice President, Engineering	Robert Allan Ltd.

First Name	Last Name	Title	Organization
Caroline	Denis	Manager, Environmental Programs	Canada Steamship Lines
Gordon	Deveau	Deputy Director	NSERC Atlantic Regional Office
Zuomin	Dong	Professor	University of Victoria
Patrick	Fortier-Denis	Ingenieur	Innovation Maritime
Abigail	Fyfe	Research & Development Officer	Transport Canada Innovation Centre
Jason	Gedamke	Ocean Acoustics Program Manager	NOAA Fisheries
Sara	German	Policy Advisor	Transport Canada
Bodo	Gospodnetic	President	Dominis Engineering Ltd.
Jason	Gu	Professor	Dalhousie University
Kathy	Heise	Research Associate	Coastal Ocean Research Institute
Mira	Hube	Director, Environment	Algoma Central Corporation
Mohammed	Islam	Senior Research Officer	National Research Council Canada
Rajeev	Jaiman	Associate Professor	University of British Columbia
Michael	Jasny	Director, Marine Mammals	NRDC
Jasmin	Jelovica	Assistant Professor	University of British Columbia
Andrew	Kendrick	Vice President	Vard Marine
Lee	Kindberg	Director, Environment & Sustainability	Maersk

First Name	Last Name	Title	Organization
Ryan	Klomp	Director, Multi-Modal RD&D	Transport Canada Innovation Centre
Rory	Macdonald	President	Lengkeek Vessel Engineering Inc.
John	MacKay	Chief Scientist/Physical Sciences (Acting)	Defence R&D Canada
Donald	MacPherson	Technical Director	HydroComp. Inc.
Liz	McCrary	Marketing Communications Manager	HydroComp, Inc.
Dan	McGreer	Principal Engineer	Vard Marine
Brian	McShane	Senior Innovation Officer	ISED Canada
Sue	Molloy	CEO	Glas Ocean
David	Molyneux	Associate Professor/Director of OERC	Memorial University of Newfoundland
Lorenzo	Moro	Assistant Professor	Memorial University of Newfoundland
Holly	Neatby	Defence Scientist	Defence Research & Development Canada
Charlie	Nisbet	Engineering Director	BMT
Mark	Oakes	Chief Technical Officer	Alion Science and Technology
Dan	Oldford	Sr. Engineer	ABS
Neil	Pegg	Program Manager, Naval Platforms	Defence Research & Development Canada
Melissa	Perera	Biologist	US Coast Guard
Greg	Peterson	Director Engineering Service	BC Ferries

First Name	Last Name	Title	Organization
Wei	Qiu	Department Head, ONAE	Memorial University of Newfoundland
Bruce	Quinton	Deputy Head, Assistant Professor	Memorial University of Newfoundland
Francoise	Quintus	Environmental Affairs Analyst	St. Lawrence Shipoperators
Janice	Ray	Advisor, Environmental Affairs	Canada Nova Scotia Offshore Petroleum Board
Francine	Richard	Special Advisor, Environmental Policy	Transport Canada
Brendan	Rideout	Defence Scientist	DRDC Atlantic
Braden	Rostad	Mechanical Engineer	US Coast Guard
Michelle	Sanders	Director, Clean Water Policy	Transport Canada
Dong	Seo	Research Officer	National Research Council
Mo	Shamma	Research Associate	Nova Scotia Community College
Sonia	Simard	Director, Legislative & Environmental Affairs	Shipping Federation of Canada
Jaideep	Sirkar	Naval Architect	US Coast Guard
Desiree	Stockermans	Operations Manager	Ocean Sonics
Tabitha	Takeda	A/Chief Marine RD&D	Transport Canada Innovation Centre
Krista	Trounce	Project Manager - ECHO Program	Vancouver Fraser Port Authority
Karin	de Vries	Customer Solutions Engineer	Wärtsilä Canada Inc.
David	Whitehouse	Business Development and Innovation Manager	Lloyd's Register

First Name	Last Name	Title	Organization
Fraser	Winsor	Senior Research Officer	National Research Council
Mark	Wood	President	Ocean Sonics
Jinshan	Xu	Physical Scientist	Bedford Institute of Oceanography

Appendix B Workshop Agenda

CISMaRT/Transport Canada Workshop on Ship Noise Mitigation Technologies November 28-29, 2018 Admiral's Room, Four Points by Sheraton, Halifax, Nova Scotia Wednesday, November 28, 2018		
07:30 – 08:00	Registration and Breakfast	
08:00 – 08:30	Scope of the Workshop on ship noise mitigation technologies *Canada's vision and plan on marine noise reduction* Michelle Sanders, Transport Canada	
08:30 – 12:00	**Short Course on Underwater Noise from Ships** Course Instructor: Michael Bahtiarian, Acentech	
08:30 – 09:30	Fundamentals of underwater sound	• Basic introduction of noise (physical description, nomenclature, typical sound levels, etc.) • Shipboard noise sources and paths • Noise measurements • Sources of noise on ships (propeller, machinery, hull, etc.)
09:30 – 10:30	Ship noise predictions	• Airborne noise • Structureborne noise • Methods for predicting noise levels • Analysis methods (CFD, SEA, FEA, etc.) • Comparisons of measured and predicted noise levels
10:30 – 10:50	**Coffee Break**	
10:50 – 11:30	Noise control treatments	• URN reduction methods • Hull design • Propeller design • Noise control treatments • Isolation systems • Acoustic enclosures • Damping treatments • Shipbuilding QA/QC
11:30 – 12:00	Acceptance criteria Vessel case study	• Description of damaging levels of noise on sea life • Existing criteria • Case study
12:00 – 13:00	**Lunch at Navigator Room –** Screening of Video: *"Sonic Sea – Shipping"*	• Group photo will be taken shortly before lunch.

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13:00 – 13:10	**Overview of the afternoon session**	
13:10 – 13:35	*Overview of the AQUO, SONIC and related projects – main findings and next steps* Eric Baudin, Bureau Veritas	
13:35 – 14:00	*Underwater noise from ships – an operator's perspective* Lee Kindberg, Maersk	
14:00 – 14:25	*The ECHO program – understanding the underwater noise environment off the coast of southern BC* Krista Trounce, Port of Vancouver	
14:25 – 14:50	*Propeller noise and its mitigation* Holly Neatby, DRDC Atlantic	
14:50 - 15:10	**Coffee Break**	
15:10 – 15:50	Breakout session	• Rooms: Explorer, Admiral's, Compass
15:50 – 16:50	Breakout presentations and general discussion	• Including recommendations for future projects
16:50 – 17:00	Closing remarks and preview of next day	

CISMaRT/Transport Canada Workshop on Ship Noise Mitigation Technologies
November 28-29, 2018
Admiral's Room, Four Points by Sheraton, Halifax, Nova Scotia

Thursday, November 29, 2018

07:30 – 08:00	Breakfast	
08:00 – 08:10	Overview of the final session	
08:10 – 09:15	*Technologies to mitigate underwater noise from ships* Andrew Kendrick, VARD Marine	
09:15 – 10:15	Breakout session	• Rooms: Explorer, Admiral's, Compass
10:15 – 10:35	**Coffee Break**	
10:35 – 11:50	Breakout presentations and general discussion	• Including recommendations for future projects
11:50 – 12:00	Closing remarks	

Appendix C Breakout Teams for November 28 & 29 Sessions

First Name	Last Name
GROUP 1 (at Admiral's Room)	
Chanwoo	Bae
David	Belisle
Allan	Dale
Vince	den Hertog
Gordon	Deveau
Brian	McShane
Janice	Ray
Braden	Rostad
Dong	Seo

First Name	Last Name
GROUP 2 (at Admiral's Room)	
Elena	Corin
Zuomin	Dong
Patrick	Fortier-Denis
Sara	German
Dan	McGreer
David	Molyneux
Mo	Shamma
Tabitha	Takeda
Mira	Hube

GROUP 3 (at Compass Room - A)	
Eric	Baudin
Clement	Chion
Caroline	Denis
Abigail	Fyfe
Bodo	Gospodnetic
Jason	Gu
Sue	Molloy
Sonia	Simard
Krista	Trounce

GROUP 4 (at Compass Room - B)	
Jon	Mikkelsen
Kathy	Heise
Jasmin	Jelovica
Andrew	Kendrick
Lee	Kindberg
Charlie	Nisbet
Dan	Oldford
Greg	Peterson
Fraser	Winsor

GROUP 5 (at Compass Room - C)	
Michael	Bahtiarian
James	Bonnell
Daniel	Cote
Jim	Covill
Mohammed	Islam
Holly	Neatby
Jaideep	Sirkar
Desiree	Stockerman
Jianshan	Xu
Liz	McCrary

GROUP 6 (at Navigator Room)	
Anna	Bryns
Lee	Kindberg
Rory	Macdonald
John	MacKay
Lorenzo	Moro
Mark	Oakes
Neil	Pegg
Francoise	Quintus
Tarachand	Satsangi
Mark	Wood

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GROUP 7 (at Explorer Room)

First Name	**Last Name**
David	Benoit
Scott	Carr
Karin	de Vries
Jason	Gedamke
Ryan	Klomp
Donald	MacPherson
Melissa	Perera
Bruce	Quinton
Michelle	Sanders

Appendix D Breakout Session Questionnaire November 28, 2018

Breakout Session on Ship Noise Mitigation Technologies – General Aspects

This is the first of two breakout sessions. It focuses on general aspects of ship noise surrounding ship noise mitigation technologies. The second breakout session concentrates on specific aspects, namely noise mitigation technologies summarized in a report authored by VARD Marine Ltd. dated October 31, 2018.

In the present breakout session, general aspects of underwater radiated noise (URN) from ships are considered. All inputs are important, whether directly or indirectly, to implementing noise mitigating technologies and strategies.

This breakout discussion report should be submitted to the workshop facilitator at the end of the brainstorming session. Please write legibly since this report will be used as input to the final workshop report.

1. Marine life varies from location to location in the world's oceans. Is it reasonable to suppose that the level of noise mitigation required will similarly vary? Is there sufficient data available to quantify the required level of mitigation? If not, please outline the kind/s of project/s that could address the shortcoming.

2. Measurements of underwater noise from shipping traffic have been made. Most measurements have been opportunistic although some data has been gathered in dedicated trials. The measured noise is generally representative of total noise and hence it is a challenge to identify the contribution from individual sources of noise. Are further dedicated measurement programs required to understand this situation better? If yes, please outline the basic features of such a measurement program.

3. A key component of any assessment of underwater noise levels is the measuring procedures and techniques adopted. Various standard making bodies (ANSI, ISO, ITTC etc.) and classification societies (ABS, BV, DNV GL, etc.) have developed requirements in this regard. Are there efforts to harmonize these requirements? Should there be? What are the primary challenges given the wide variety of ship types? Please suggest projects to address these challenges.

4. In general, which is preferable to a ship operator – noise mitigation by operational measures or by building in low-noise features in the design? What factors are important in making this comparison? Is there sufficient information available to make tradeoff studies?

5. The general consensus is that that propellers on large commercial ships are the greatest source of URN in the ocean. Noise from propellers on naval ships is a key design parameter. How applicable is this technology to larger commercial ships? And how accessible is naval technology?

6. Which three or four simple ship design parameters, or combinations of parameters, are the best indicators of likely high levels of URN. For example, it has been suggested that the EEDI (Energy Efficiency Design Index, a measure of CO_2 emissions per ship's capacity mile) could be used as a surrogate for ship URN. Are you aware of any studies?

7. Is there a significant role for wind-assisted propulsion technologies (e.g. Flettner rotor, sails) to reduce noise levels indirectly?

8. The implementation of URN mitigation technologies has associated co-benefits. Examples may include reduced noise and vibration levels onboard ship, and decreased fuel consumption. Has this been systematically studied? If yes, please identify. Please also suggest projects that would investigate this aspect of URN mitigation technology.

9. What broad long-term trends in commercial shipping are likely to have an impact on URN levels? Examples might include reduced world trade, increase in fuel costs, increase in ship size, transition to LNG as a fuel, etc.

10. In a recent study, 10 priority research questions related to marine vessel acoustic science were identified. In regard to vessel attributes the following two issues were raised:
    a. What attributes of ships are the most effective indicators of URN?
    b. What are the tradeoffs in noise exposure between ship high speed/short time exposure and low speed/long time exposure?

    Answers to the second question could provide valuable input into developing URN mitigation strategies. What type of research might be conducted to address the questions raised?

Appendix E Breakout Session Questionnaire November 29, 2018

Group No. _________

Breakout Session on Ship Noise Mitigation Technologies – Specific Aspects

The available methods for minimizing underwater noise from ships are summarized in the draft report by VARD Marine Ltd. dated 31 October 2018 (referred to as "the Report" in the remainder of this questionnaire). The purpose of this questionnaire is to guide the discussion on the subject of noise mitigation technologies using the Report as a baseline.

Several questions are posed in broadly two categories:

1. Questions specific to the report
2. Broader questions related to the subject of noise mitigation technologies but not necessarily related to the report

This report should be submitted to the workshop facilitator at the end of the brainstorming session. Please write legibly since this report will be used as input t a workshop report.

Specific to the Report

1. Are there other broad categories of noise mitigation technology that should be included? If "Yes", please list.

2. The Matrix (Appendix A of the Report) lists for each noise mitigation technology a number of key features such as TRL, Cost Estimation etc. Are there other features not mentioned that could be usefully added? If "Yes", please list.

3. Under "Propeller Noise" are there treatments and techniques, other than those listed, that have the potential to reduce noise significantly?

Noise Mitigation Technologies

4. A co-benefit of reducing noise may be an improved noise environment onboard the ship. Do we know how much? Are you aware of work that addresses this issue? If yes, please identify. Please suggest projects that would help establish quantitative benefits

5. What are the main co-benefits (other than the one noted in Q4 above, of introducing noise reducing measures in the design of large ships? Please identify two or three projects that would lead to a better understanding of co-benefits.

6. In large commercial ships the design of propellers is optimized for thrust. Do you estimate that there is a significant penalty in modifying such designs to also reduce URN? If yes, please estimate ballpark percentages for doing so.

7. The propeller of large ships is generally the most dominant source of noise. Do we understand how operating conditions (e.g. loading condition, maneuvering) affect the level of noise?

8. Various methods are used for predicting noise level ranging from simple formulae to advanced numerical analysis tools. Please identify the kinds of tools useful for assessing the effectiveness of noise mitigation measures.

9. Please identify up to three projects that would potentially add significantly to our understanding to the subject of underwater noise from ships. (In this context the size of project can be very approximately characterized as costing, say, US$200K)