UNCLASSIFIED / NON CLASSIFIÉ

TP 15504E

REPORT #481

Quieting Ships to Protect the Marine Environment
Workshop Final Report

April 19, 2019

Prepared for:
Transport Canada/Government of Canada
Place de Ville, Tower C - 26th Floor
330 rue Sparks Street
Ottawa ON K1A 0N5 - Canada

Transport Canada

Acentech Project No. 630964

Submitted by:
Michael Bahtiarian, INCE Bd. Cert.
Principal Consultant
mbahtiarian@acentech.com

ACENTECH Inc
33 Moulton Street
Cambridge, MA 02138

617 499 8000 | acentech.com

This report has been prepared for Transport Canada based on the proceedings of an International Technical Workshop held in London on January 30 to February 1, 2019. All ideas, thoughts and concepts reported herein are based on information gained from attendees during this workshop and the editorial presentation performed by the workshop chairman and author of this report,

Michael Bahtiarian, INCE Board Certified.

Transport Canada | Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 15504E	2. Project No. B1B8	3. Recipient's Catalogue No.
4. Title and Subtitle Quieting Ships to Protect the Marine Environment Workshop Final Report		5. Publication Date 19 April 2019
		6. Performing Organization Document No. Report #481 – Project No. 630964
7. Author(s) Michael Bahtiarian,		8. Transport Canada File No. RDIMS 17812977
9. Performing Organization Name and Address **ACENTECH Inc** 33 Moulton Street Cambridge, MA 02138		10. PWGSC File No.
		11. PWGSC or Transport Canada Contract No.
12. Sponsoring Agency Name and Address Transport Canada -Innovation Centre Place de Ville, Tower C 330 Sparks Street, 18th Floor Ottawa, Ontario K1A 0N5		13. Type of Publication and Period Covered Technical Report, 2018-2019
		14. Project Officer Amelie Laprade

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

In late January of 2019, Transport Canada hosted a technical workshop entitled "Quieting Ships to Protect the Marine Environment". Around 140 subject-matter experts from around the world gathered at this event for two and half days. The purpose of the workshop was to identify the state of knowledge on quiet ship technology, provide an opportunity for international collaboration, and exchange research ideas. This report highlights the recommendations and outcomes of the workshop

17. Key Words Marine – Underwater Noise	18. Distribution Statement Digital Copy

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages 71	23. Price Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 15504E	2. N° de l'étude	3. N° de catalogue du destinataire
4. Titre et sous-titre Rapport final de l'atelier sur la réduction du bruit des navires pour protéger le milieu marin		5. Date de la publication 19 avril 2019 6. N° de document de l'organisme exécutant Report #481 – Projet No. 630964
7. Auteur(s) Michael Bahtiarian,		8. N° de dossier - Transports Canada SGDDI 17812977
9. Nom et adresse de l'organisme exécutant ACENTECH Inc 33 Moulton Street Cambridge, MA 02138		10. N° de dossier - TPSGC - 11. N° de contrat - TPSGC ou Transports Canada
12. Nom et adresse de l'organisme parrain Transport Canada - Centre d'innovation Place de Ville, tour C 330, rue Sparks, 18e étage Ottawa (Ontario) K1A 0N5		13. Genre de publication et période visée Rapport Technique, 2018-2019 14. Agent de projet Amelie Laprade

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

16. Résumé

À la fin de janvier 2019, Transports Canada a organisé un atelier technique intitulé « Réduire le bruit des navires pour protéger les milieux marins ». Environ 140 experts à travers le monde se sont réunis lors de cet événement pendant deux jours et demi. L'objectif de l'atelier était d'identifier l'état des connaissances sur la technologie des navires silencieux, de fournir une opportunité de collaboration internationale et d'échanger des idées de recherche. Ce rapport met en lumière les recommandations et les résultats de l'atelier.

17. Mots clés Maritime – Bruits sous-marins	18. Diffusion Copie numérique

19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) —	22. Nombre de pages 71	23. Prix Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

TABLE OF CONTENTS

EXECUTIVE SUMMARY *1*

1.0 INTRODUCTION *3*
1.1 Background 3
1.2 Purpose and Objectives 4
1.3 Noise Mitigation Technology Report 4

2.0 TECHNICAL PROGRAM *5*
2.1 Impact of underwater noise on marine resources 5
2.2 Challenges in Setting Underwater Noise Targets 6
2.3 Efforts to date on reducing underwater noise 6
2.4 Industry challenges with reducing URN 8
2.5 Underwater Noise from Machinery 9
2.6 Broad Band Noise Generation of Propellers 10
2.7 CFD methodology for prediction of propeller induced URN 11
2.8 Modelling of proposed thresholds 11
2.9 Class Society Silent Notations 12
2.10 Overview of Ship Underwater Radiated Noise Technology 13

3.0 AM BREAKOUT PROGRAM *14*
3.1 URN Limits to Protect Marine Life (Group #1) 14
3.2 Propeller & Hull Design (Group #2) 15
3.3 Machinery Noise Control (Group #3) 16
3.4 URN Predictive Tools & Modeling (Group #4) 17
3.5 URN Metrics & Measurements (Group #5) 19
3.6 AM Plenary/Summary 21

4.0 PM BREAKOUT PROGRAM *23*
4.1 PM Breakout Group A 23
4.2 PM Breakout Group B 24
4.3 PM Breakout Group C 25
4.4 PM Breakout Group D 25
4.5 PM Breakout Group E 26
4.6 PM Plenary/Summary 26

5.0 RECOMMENDATIONS *29*

6.0 CONCLUSIONS *31*

APPENDIX A: Workshop Program and Speaker Curriculum Vitae

APPENDIX B: Workshop Attendee List

APPENDIX C: IMO Guideline for the Reduction of Underwater Noise from Commercial Shipping to address Adverse Impacts on Marine Life, April 7, 2014

APPENDIX D: AM Breakout Group Questionnaires

EXECUTIVE SUMMARY

In late January of 2019, Transport Canada hosted a technical workshop entitled "*Quieting Ships to Protect the Marine Environment*". The workshop was held at the International Maritime Organization Headquarters in London, UK. Around 140 subject-matter experts from around the world gathered at this event for two and half days. The purpose of the workshop was to identify the state of knowledge on quiet ship design, provide an opportunity for international collaboration, and exchange research ideas.

The London workshop followed a similar format to an event held in Halifax, Nova Scotia, Canada in November 2018. Prior to these two workshops, the topic of underwater noise from shipping and its impact on marine life has been addressed by numerous programs held by other governments and non-governmental organizations. Elevated anthropogenic underwater noise in the oceans has been a known issue since the early part of the twenty-first century, and marine biology researchers have determined that the increase in underwater-radiated noise has multiple negative impacts on various species of marine life.

For Canada, this issue is part of a broader concern with the health of the oceans and waterways that surround the country and their marine eco-systems. Canada's oceans are home to 42 distinct populations of whales. The issue of underwater noise is a predominant concern for one endangered Canadian species in particular, the Southern Resident Killer Whale, but there are also impacts on other species including the St. Lawrence Estuary Beluga and the North Atlantic Right Whale.

Ahead of this workshop, Transport Canada commissioned Vard Marine, Inc. to prepare a report on noise mitigation technologies available for commercial ships. The report was provided to all London workshop attendees ahead of the workshop. The London technical program consisted of nine topical presentations addressing topics such as the impact of underwater noise on marine life, challenges in setting underwater noise limits, marine industry activities in controlling undersea sound from shipping, engineering of noise control treatments, and methods of noise prediction from hull and propeller. All the presentations were given by experts in their field.

The key segment of the workshop was the breakout and plenary discussions held over one and half days. The workshop was divided into five groups of experts and each group was given a separate series of topics in their area of expertise. These areas included marine biology impacts, propeller & hull design, machinery noise control, predictive tools and measurements. These groups produced a large number of ideas and concepts aimed at solving the problem of excessive ship/shipping noise. There was a good amount of input, dialog, consultation and deliberation on a series of statements and recommendations.

It was widely acknowledged throughout the workshop that quieting ships to protect the marine environment is complex, but necessary. Some of the key policy and research recommendations that came out of the event include:

- Recognition that a biological limit for underwater noise levels applicable to all species, in all regions of the world, is challenging to develop at this time. Therefore, a ship-based limit was recommended.
- Ensuring that the feasibility of noise mitigation measures also aligns with efforts to improve energy efficiency and reduce Greenhouse Gas (GHG) emissions in line with the Initial IMO Strategy on Reduction of GHG Emissions from Ships (Resolution MEPC.304(72)) and the Paris Agreements.
- Continue to gather data and in situ measurements of vessels and the noise they emit in order to further the understanding of this issue and its consequences. This also relates to validating modelling measurements, establishing biological limits and the alternative of feasibility based limits;
- The potential value of explicitly identifying underwater vessel noise as a form of pollution in the relevant maritime and environmental conventions;
- Advancing research on some of the specific technological solutions identified over the course of the workshop, and develop a guide for shipbuilders on available technologies (such as Air Bubble Systems and noise mitigation for machinery);

- Development of a comprehensive framework of international standards for precision measurement in shallow water and for ships-of-opportunity, as an enabler to establish policy objectives for quieter ships; and

- Increasing education and outreach efforts with ship owners, ship designers, shipbuilders, machinery, and equipment manufacturers to better inform them of the issue of underwater noise and feasible mitigation measures. In addition, encourage companies to begin measuring the underwater noise emitted from their vessels in order to establish baselines.

The Workshop results will be brought forward to the International Maritime Organization's Marine Environmental Policy Committee in May 2019 for information.

SECTION ONE

1.0 INTRODUCTION

This report describes the proceedings of a workshop entitled "*Quieting Ships to Protect the Marine Environment*" which was organized and hosted by Transport Canada from January 30, 2019 to February 1, 2019. The workshop was held at the International Maritime Organization (IMO) headquarters in London, United Kingdom (UK). A copy of the workshop program is given in Appendix A. A list of the attendees and their affiliations is given in Appendix B.

The workshop included both a technical program and a full day of breakout and plenary discussions. Section 2 summarizes the technical sessions and Section 3 provides an outline of the activity and discussions that came from the breakout and plenary sessions. There were a couple of associated events held during the workshop. The first was a 1-hour primer (short) course on the topic of Quiet Ship Design and Noise Metrics. The workshop also included a viewing of a shortened version of *Sonic Sea* an Emmy-winning documentary film regarding the issue of increased sound in the ocean. Lastly, two evening receptions were held to promote networking and collaboration.

Section 4 provides a complete discussion on the topic of quieting ships. Section 5 provides recommendations for the future. Section 6 gives the conclusions drawn from the workshop.

This London Workshop followed the format of a similar event held in Halifax, Nova Scotia, Canada on November 28-29, 2018 (Halifax Workshop), just two months earlier. The Halifax Workshop was hosted jointly by the Canadian Network for Innovative Shipbuilding and Marine Research and Training (CISMaRT) and Transport Canada. The agenda was similar with a combination of technical presentations and breakout group and plenary discussions on the topic of quieting ships. A report on the Halifax Workshop was compiled by Mr. Roger Basu.[1]

1.1 Background

Elevated anthropogenic underwater noise in the oceans has been a known issue since the early part of the twenty-first century. Oceanographic scientists using cold-war listening stations have tracked the annual levels of underwater sound over a period of nearly sixty years. They have quantified that low-frequency background noise has approximately doubled (i.e., an increase of 3 decibels, dB) in each of the past four decades primarily as a result of increased commercial shipping.[2]

Marine biology research has also determined that the increase in underwater radiated noise (URN) has negative impacts on many species of marine life. Quoting a recent study, "*The introduction of noise can adversely affect marine life by altering the behavior; reducing communication ranges for social interactions, foraging, and predator avoidance; and temporarily or permanently reducing hearing sensitivity. Noise also can affect the physiological functions or cause generalized stress responses and may function as an additive or synergistic stressor, exacerbating other environmental and anthropogenic pressures experienced by marine life.*[3]

Several conferences, workshops and symposia have been held around the world over the last fifteen years to discuss this complex issue and have suggested possible steps forward in order to mitigate the negative effects of increased ocean noise. One important initiative led by the IMO was the development of generalized non-mandatory guidelines for reduction of URN from ships.[4] This document provided information on the prediction of underwater noise levels, a list of useful standards and references, and a discussion of design

---

[1] CISMaRT Report, Ship Noise Mitigation Technologies for a Quieter Ocean, draft report dated January 12, 2019.

[2] Wright, A.J. (ed) 2008, International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21st-24th April 2008.

[3] Southall, Brandon, Amy R. Scholik-Schlomer, Leila Hatch, Trisha Bergmann, Michael Jasny, Kathy Metcalf, LindyWeilgart, and Andrew J. Wright, Underwater Noise from Large Commercial Ships—International Collaboration for Noise Reduction, Encylopedia of marine and Offshore Engineering, online © 2017 Jon Wiley & Sons, Ltd.

[4] 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.

considerations for ships, including propellers, hull form and onboard machinery, a copy of which is given in Appendix C.

The European Union (EU) has shown leadership in this effort by funding various research programs to identify the knowledge and technology gaps in regards to URN. Two major resulting reports have been published summarizing the results of these projects, one on the *AQUO* Project[5] and another on the *SONIC* Project.[6]

In Canada, this issue is part of a broader concern with the health of the oceans and waterways that surround Canada and their marine eco-systems. Canada's oceans are home to 42 distinct populations of whales. The issue of underwater noise is a predominant concern for one Canadian species in particular, the Southern Resident Killer Whale (SRKW), but there are also impacts on other species, including the St. Lawrence Estuary Beluga and North Atlantic Right Whale. The SRKW is an acute example of this global issue, as there are only 74 Southern Residents remaining.

1.2 Purpose and Objectives

The purpose of the London Workshop was to provide an opportunity for international collaboration and allow participants to share the newest research and technical solutions for quiet ship design and retrofits. By hosting this workshop at the IMO Headquarters in London, it brought further international attention to the issue and allowed for greater participation and interest. The specific objectives were to:

- Validate current technologies and identify important gaps and challenges to further progress;
- Assess areas by ship class for innovation, and potential to determine where further research is needed;
- Understand whether improvements made to ship design for fuel efficiency overlap with improvements made to reduce noise; and
- Document the conclusions of the workshop to guide future discussions on reduction of underwater ship noise or as groundwork for a review of the existing IMO Guidelines[4].

The workshop intentionally did not focus on vessel operational and maintenance measures, such as vessel slowdowns and lateral displacements within shipping lanes. While these measures have proven effective in reducing underwater vessel noise, and should certainly be considered in regional efforts to reduce underwater noise, the workshop deliberately focused on longer-term, larger-impact engineered solutions related to quiet ship design and retro-fits.

1.3 Noise Mitigation Technology Report

Transport Canada commissioned Vard Marine, Inc (a Fincantieri Company) to prepare a report on the noise mitigation technologies available for quieting commercial ships. The draft report was circulated prior to the Halifax Workshop where participants had the opportunity to provide feedback. The report was then updated by the author, and issued ahead of the London Workshop for further review[7] along with a comment form for further feedback. See section 2.10 for discussion from the London Workshop.

---

[5] AQUO (Achieve Quieter Oceans by shipping noise footprint reduction), FP7 - Collaborative Project No. 314227, WP 5: Practical Guidelines, Task 5.1, Comprehensive Listing of Possible Improvement Solutions and Mitigation Measures.

[6] Suppression of Underwater Noise Induced by Cavitation, FP7-Collaborative Project No. 314394 - SONIC Final Report.

[7] Vard Marine Report, Ship Underwater Radiated Noise, report 368-000-01, rev 3, dated January 9, 2019.

SECTION TWO

2.0 TECHNICAL PROGRAM

The technical program consisted of nine topic presentations related to underwater vessel noise. A summary of each presentation is given in Sections 2.1 through 2.10 below[8]. Section 2.10 relates to Vard Marine's Noise Mitigation Technology Report, which was discussed during two sessions. The first session provided an overview of the report[7] as supplied to all London Workshop participants. The second session addressed comments provided by participants.

2.1 Impact of underwater noise on marine resources

The opening presentation was by Dr. Nathan Merchant, a Principal Scientist with Center for Environment Fisheries and Aquaculture Science (CEFAS) in the UK. He presented data from other researchers showing that the increase in ambient noise of approximately 3 dB per decade (10 years) matches trends in world gross domestic product (GDP) and world fleet tonnage, Figure 1. These are rapid changes to the marine soundscapes considering evolutionary timescales.

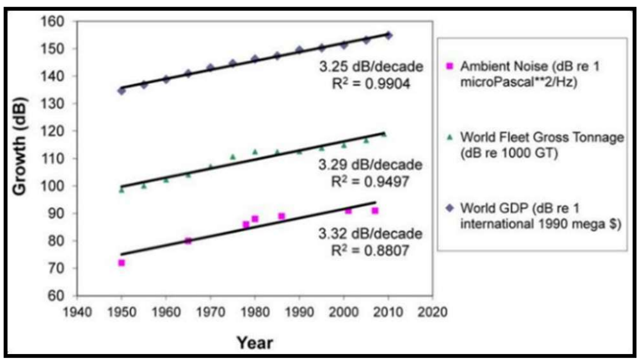


FIGURE 1: Ocean noise vs World Fleet Gross Tonnage and GDP (Frisk 2012)

Dr. Merchant highlighted four effects of increased noise on marine life: (1) masking, (2) behavioral responses, (3) physiological stress, and (4) developmental effects. The presentation documented research by Parks in 2007[9] and 2011[10], which showed the calls from North and South American Right Whales have increased in frequency over many years due to masking of sound at lower frequencies by ships. Other research showed particular changes in behavioral responses including: modifications in vocal behavior, avoidance of vessels, interruption/disruption of foraging/feeding, antipredator responses, and movement away from heavily trafficked areas. The presentation provided information showing evidence of physiological stress and other effects by right whales, turtles, jellyfish, squid, various other fish, and invertebrate species. Dr. Merchant noted that these changes in behavior along with "the physiological stress can affect life functions, and ultimately fitness and survival, potentially leading to effects on the population scale."

Workshop participants asked if there was any evidence of marine life thriving from increased noise, and whether any of the negative impacts could be from visual effects. Dr. Merchant was not aware of benefits from increased noise, although noise can affect predator/prey interactions and so some species may benefit at the cost of others, affecting ecosystem dynamics. He also acknowledged that behavioral responses could be triggered by a number of stimuli other than noise, but that the examples highlighted were almost certainly due to the effects of noise.

[8] Presentations are available at: https://drive.google.com/open?id=1JW1CcmvYO3ziHbq_Qp3WGozENIY8a4Ys
[9] Parks, S. E., Clark, C. W., & Tyack, P. L. (2007). Short-and long-term changes in right whale calling behavior: The potential effects of noise on acoustic communication. The Journal of the Acoustical Society of America, 122(6), 3725-3731.
[10] Parks, S. E., Johnson, M., Nowacek, D., & Tyack, P. L. (2011). Individual right whales call louder in increased environmental noise. Biology letters, 7(1), 33-35.

2.2 Challenges in Setting Underwater Noise Targets

Dr. Christ de Jong from the Netherlands Organization for applied scientific research (TNO) gave a presentation on the challenges in setting underwater noise limits. He posed five questions: (1) Are there any incentives for setting noise limits? (2) How effective will such limits be? (3) What is the proper metric/quantity to limit? (4) How will this limit be enforced? (5) What are the economic implications, feasibility, and acceptability of the noise limit?

While there is evidence showing the impacts of high noise on marine life there does not appear to be strong evidence of “dose-effect” responses (i.e. impact from high sound over certain duration of time). Dr. de Jong discussed whether a noise limit should be set for a radiated noise level (RNL) from individual vessels, or for a noise exposure in a given environment, possibly combining sound pressure level and exposure duration. Comparisons to highway/traffic noise regulations were presented using the EU example where limits for both road traffic noise and for vehicles themselves exist. He suggested investigating a dual approach, combining a “Type Approval” ship noise limit for individual vessels, determined by vessel class, with environmental noise regulations created for vessel noise at the receiver. This may include vessel speed limits in place of noise limits and only for particular protected areas.

Ship noise limits are currently provided by five ship classification societies: ABS, Bureau Veritas, DNV, Lloyds Register and RINA as shown in Figure 2. Three of the classification societies’ limits are in the form of RNL which is obtained from simple spherical spreading adjustment to measured sound pressure levels (e.g. 20xlog{d/d_{ref}} and does not include actual underwater transmission loss (TL). It is reported at an effective distance of 1-meter (d_{ref} = 1 meter). The RNL metric is not a pure “source level metric” and would be difficult to use in prediction of far-field noise (> 1 km). Two of the classification societies use source level type metrics for their limit. Lastly, each of the class societies have different measurement procedures which need to be harmonized.

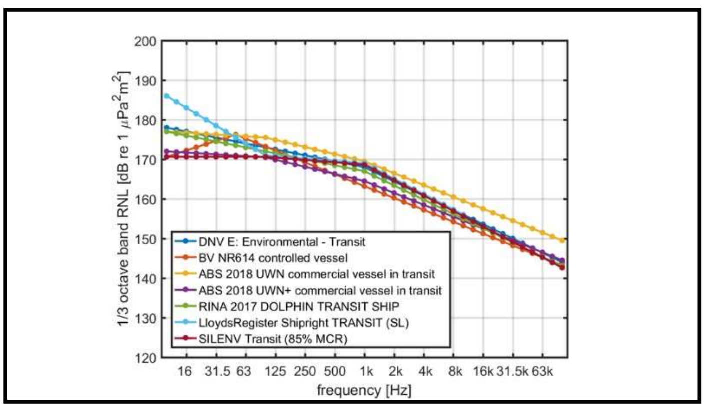


FIGURE 2: Class Society RNL Limits (Used with permission of TNO)

2.3 Efforts to date on reducing underwater noise

Two presenters addressed this topic: Mr. Eric Baudin of Bureau Veritas and Ms. Michelle Sanders, Director of the Clean Water Policy Division at Transport Canada.

Mr. Baudin gave an overview of the AQUO Project within the EU. The EU Marine Strategy Framework Directive 2008/EC/56 states that good environmental status of the marine environment is achieved when "the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment (2010 GES Dec.)”. This led to two programs between 2012 and 2015: Achieve Quieter Oceans (AQUO) and Suppression of UW Noise Induced by Cavitation (SONIC). The presentation distinguished between the single vessel scale and the ship traffic scale. Mr. Baudin addressed both technical solutions for a single vessel and operational solutions for a single vessel and how both can impact ship traffic scale as shown in Figure 3.

AQUO methodology and tools illustrate how to quantify the shipping footprint in terms of noise and impact on fauna. The reduction solution benefits are assessable the same way. An example is given with regards to the virtual enforcement of Bureau Veritas URN notation on the actual traffic data collected offshore Brittany (France) and its impact on noise and on masking effect of the Atlantic Cod fish.

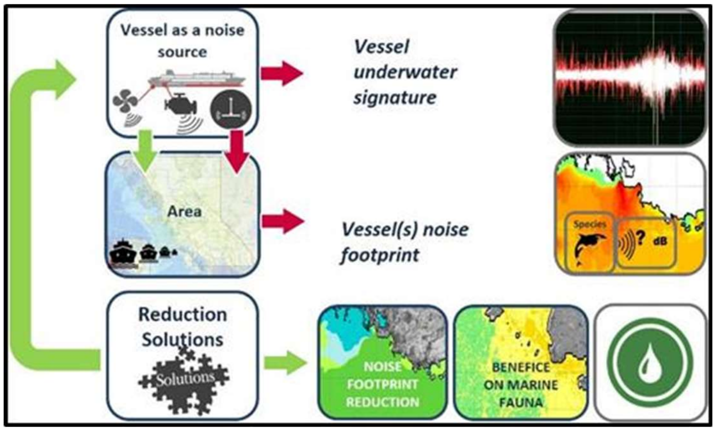


FIGURE 3: Illustration of the AQUO methodology (Used with permission of Bureau Veritas & AQUO Project)

Mrs. Sanders provided some context of why Canada has such a strong interest in finding solutions to reducing underwater noise. Specifically, Canada's coasts are home to some of the busiest ports in North America, where international marine traffic and activity overlaps with the habitat of some of the most iconic and endangered whale populations. The issue of underwater noise is a predominant concern for one Canadian species in particular, the SRKW, but there are also impacts on the St. Lawrence Estuary Beluga, Harbor Porpoise, Bottlenose Dolphin, and Pacific Herring. Canada's Southern Resident Killer Whale is an acute example of this global issue as there are only 74 individuals remaining. She pointed out that scientific evidence continues to grow and demonstrate that underwater noise can be a stressor for many marine species. This is particularly true for those species that rely on sound as a means of carrying out basic survival activities.

Ms. Sanders discussed Canada's domestic and international initiatives. Domestically, Underwater Listening Stations have been in place in the Strait of Georgia since 2016 providing a database of vessel noise profiles. A vessel slowdown trial was conducted in 2017, and a subsequent slowdown in Haro Strait in 2018, allowed experts to measure the resulting change in underwater noise based on vessel speed. The results showed that reducing speeds can result in significant underwater noise reductions.

Transport Canada has been working in partnership with the Vancouver Fraser Port Authority's (VFPA) Enhancing Cetacean Habitat and Observation (ECHO) Program to both advance understanding of underwater noise and implement various mitigation measures to reduce underwater noise. Under Canada's Whales Initiative, the Government of Canada is also pursuing Underwater Noise Management Plans (UNMPs) as a way for Canadian fleet operators to reduce their fleets' underwater noise. Further, she noted that Canada will prepare an economic analysis on supply chain and community impacts of operational measures, advance our understanding through computer modelling of mitigation measures, increase their underwater listening capacity and continue to develop and implement additional measures to address smaller vessels.

Internationally, the profile of underwater vessel noise was boosted with a United States-led conference on the subject in 2004. As a result, MEPC 58 agreed to add underwater vessel noise as a work item, led by the United States (2008). *The 2014 "Guidelines For The Reduction Of Underwater Noise From Commercial Shipping To Address Adverse Impacts On Marine Life"* were published in response. The international community recognized that underwater-radiated noise from commercial ships may have both short and long-term consequences on marine life, especially marine mammals.

Transport Canada has been working with partners on raising awareness of concerns with underwater vessel noise. Transport Canada co-hosted a domestic workshop in Halifax, Canada and this international workshop to enhance understanding of technical solutions to reduce underwater noise and inform future work at the IMO. Transport Canada is also part of a Steering Committee, with World Wildlife Fund Canada, World Maritime University and the Chamber of Shipping of America, conducting an international survey to gain insight into current efforts to reduce underwater vessel noise and identify barriers that exist to implementation.

She closed by noting that this is truly a global issue as marine mammals are not bound by borders and international shipping sees foreign vessels calling at ports around the world. This global approach to addressing underwater noise is being pursued at the IMO's Marine Environment Protection Committee (MEPC).

2.4 Industry challenges with reducing URN

Two presenters addressed the topic of industry challenges: Ms. Veronique Nolet of Green Marine and Mr. Greg Peterson of BC Ferries. Green Marine is a voluntary certification program for ship owners, ports, terminals, and shipyards to reduce their environmental footprint of marine operations. BC Ferries is one of the largest ferry operators in the world, providing year-round vehicle and passenger service to British Columbia, Canada. A summary of each talk is given below.

To achieve the Green Marine certification for its port or vessel fleet, participants must benchmark their annual environmental performance by the program's performance indicators criteria, have their results verified by an accredited external verifier, and agree to publication of their individual results. Green Marine's environmental indicators include greenhouse gas (GHG) and pollutant air emissions, oily water, and more recently underwater noise.

Green Marine started developing the underwater noise performance indicators (PI) in 2014. In 2017, two performance indicators on underwater noise were published; one for ship owners/operators and a separate one for ports. As per Green Marine model, each performance indicator has five levels of achievement. The higher the level, the more difficult the requirements, the greater the environmental benefit. Ms. Nolet reported that for 2017, the noise PI was optional. Yet, half of the ship owners voluntarily reported URN performance[11]. In 2018, the URN metric was mandatory and these results will be announced in June 2019.

In the first, voluntary reporting year, Green Marine gained valuable lessons and feedback from their members. Challenges facing the industry to implement the metric and reduce URN are limited possibilities of measurement and limited understanding of these measurements, lack of education and awareness, and most important, finding value and return on investments. These issues have resulted in skepticism from senior management at the shipyards and the ship operators. Their members have asked good questions about the goals in reducing URN, such as whether URN reductions should be all the time and everywhere or at dedicated periods in specific zones. Also, questions have arose about whether an overall cap to radiated noise is being considered and whether reducing URN would be appropriate for all vessels. Operators have also requested measurement stations, which limit cost or result in free URN measurements. One of the important unanswered question is the link between energy efficiency and noise reduction.

Mr. Peterson gave an overview of the BC Ferries (BCF) operations consisting of 36 vessels operating from 47 terminals on 24 routes. Their largest area of operations is in the Strait of Georgia (Salish Sea) in the Pacific Northwest. BC Ferries' new construction program has three distinct classes of ferries: from minor (81 m length) to major (160 m length), but all classes are double-ended configuration. BC Ferries has undertaken a careful URN measurement program using autonomous acoustic recorders deployed for two weeks. The program allowed for the measurement and compilation of speed versus RNL for many of their vessels (Figure

[11] Currently unpublished by Green Marine

4). They found that most of their larger vessels get louder as they slow down. This situation is typical of vessels with controllable pitch (CP) propeller systems.

Mr. Peterson reported that BC Ferries' challenges in reducing URN are significant. He noted that slowing down is not a good option due to need to meet mandated route schedules. BCF vessels are a unique vessel type, optimized for short crossing ferry service, and as such they would require solutions proven for a double-ended hull form. He questioned whether there is enough market demand yet for vendors to invest in the development of quiet technologies for commercial vessels. Furthermore, it would require a change in practice to establish how to contract and assign the performance risks for the design/build of a quiet commercial vessel.

Mr. Peterson expressed that ship owners are concerned with the current high cost and impractical aspect of the high-quality URN measurement. Lastly, he noted the problem with timescales given that BCF vessels are constructed and operated for a 40 to 50-year service life. The replacement of ferries under design/construction now with quieter vessels could take 50+ years.

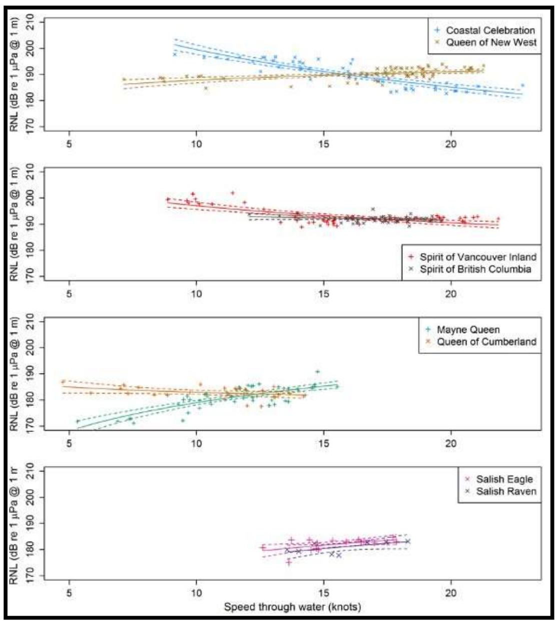


FIGURE 4: RNL vs. Speed for Various BC Ferries (Used with permission of BC Ferries)

2.5 Underwater Noise from Machinery

Mr. Jesse Spence of Noise Control Engineering, LLC in Massachusetts, USA gave a technical presentation on URN from shipboard machinery, including equipment inside the hull, specifically propulsion diesel engines, diesel generators and other auxiliary systems. Mr. Spence noted that noise is dependent on speed. More specifically, propeller noise changes with degree of cavitation, which is typically speed dependent and machinery noise changes with loading also typically speed dependent. He noted that we cannot use measured URN data alone to identify treatments without supporting vessel design information. Mr. Spence briefly spoke about the fundamentals of machinery noise predictions, methods to reduce noise and the design of quiet vessels.

Mr. Spence highlighted conventional noise control techniques, and discussed non-standard systems such as bubble emission. He also discussed the challenges that are present with reducing noise for low speed, direct drive diesel propulsion engines. Figure 5 shows a diagram of the bubble emission system as it could be deployed on a cargo ship. Such systems are used in military vessels. The bubbles provide an acoustic barrier and therefore reduce transmission of sound from inside the hull to the water. Mr. Spence estimates that such a system could reduce hull machinery noise by 10 dB. However, there are other concerns. For example, the bubbles must cover applicable areas of the hull, and fouling of air nozzles can be an issue. There will also be additional noise (and power consumed), which must be accounted for in the overall evaluation.

Mr. Spence pointed out that currently there are no examples of vibration isolation for low-speed diesel engines. The issues are that these engines are tall and extremely heavy and the engine frame provides local stiffness to the hull, which could be lost if the unit were vibration isolated. Vibration mounting would require an alternate design for thrust transfer, as the hard mounted engine provides. The presentation showed some concepts for vibration isolation that deal with these issues. Alternately, other noise control concepts for low-speed engines included tuned absorbers, secondary masses, damping and/or active vibration control.

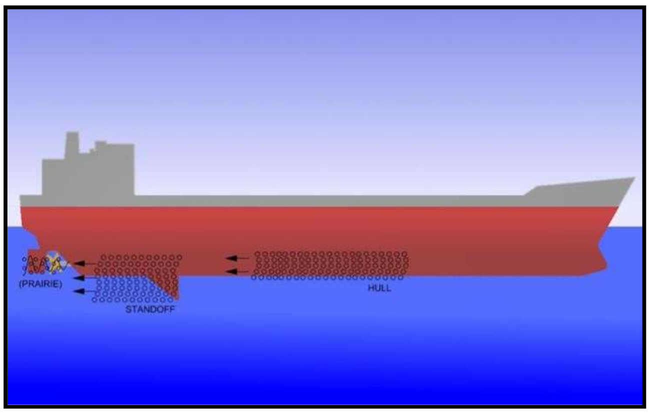


FIGURE 5: Illustration of bubble decoupling concept (Used with permission of Noise Control Engineering, LLC)

2.6 Broad Band Noise Generation of Propellers

Dr. Dietrich Wittekind of DW-ShipConsult in Schwentinental, Germany, spoke about broadband propeller noise generation. The presentation spoke about the various contributions of propeller noise to overall ship URN. Figure 6 shows these components. The ships blade passing rate (shaft speed x number of propeller blades) produces very low frequency tonal contributions to the ship spectrum. Cavitation produces both low frequency and high frequency contributions. There is a broadband 50-hertz "hump" (shown in Figure 6) in nearly all ship spectra, which is believed to be due to sheet and tip vortex cavitation. However, the exact mechanism which leads to the hump at this frequency is unknown.

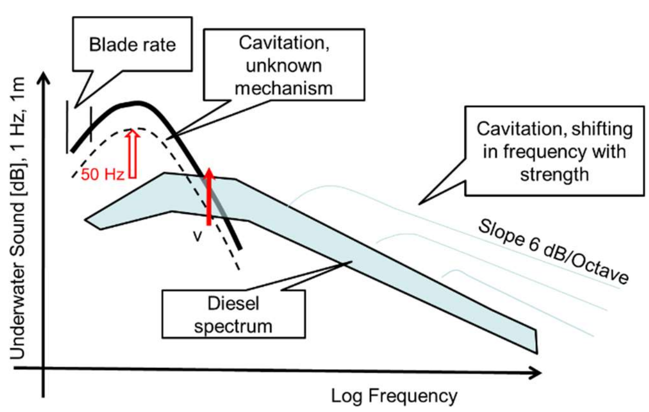


FIGURE 6: Illustration of propeller noise contributions (Used with permission of DW-ShipConsult, LLC)

Dr. Wittekind provided data, which shows increases in sound pressure level (by spectra) with increased speed. He also noted that vibration over the hull can be a good proxy for far-field URN with appropriate computations. The presentation compared computed URN using Boundary Element Methods (BEM) with measured data had good agreement. He showed four different wake equalization devices (Vortex Generator Fins, Mewis-Duct, Schneekluth-Nozzel, and Pre-Swirl Stator which are designed to improve efficiency and provide some level of sound reduction. He believes more work is required to fully understand the relationship between propeller efficiency and sound.

2.7 CFD methodology for prediction of propeller induced URN

Dr. Shameem Islam of Canada's National Research Council discussed Computation Fluid Dynamics (CFD) methodology for propeller URN prediction. There are challenges modeling propeller cavitation including: proper estimation of the cavity volume, cavitation induced pressure fluctuations, cavitation thrust breakdown, cavitation inception speed and cavitation erosion. Dr. Islam presented many details on the various CFD methods and codes that can be used for URN prediction including: empirical methods, potential-flow methods (i.e. BEM), finite volume methods (FVM, includes RANS, LES, & hybrids) and smoothed-partial hydrodynamics (SPH). These are summarized in Figure 7.

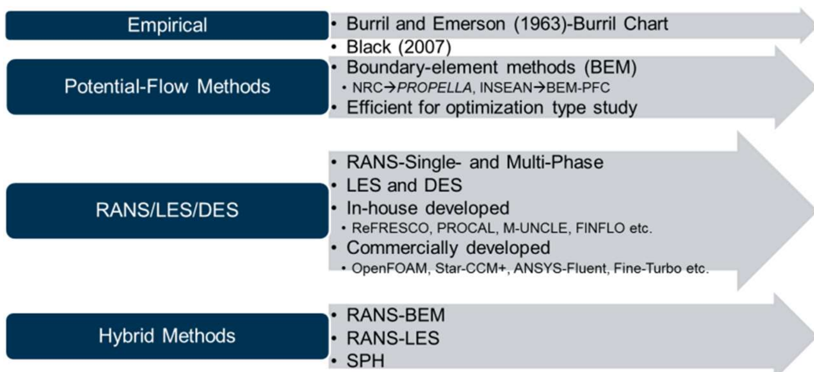


FIGURE 7: Summary of Propeller Cavitation Prediction Methods. (Used with permission of NRC)

2.8 Modelling of proposed thresholds

On the morning of Day #2, Mr. David Hannay of Jasco Applied Sciences presented information regarding a set of noise emission thresholds and the expected reduction in noise exposure to marine life. This study modeled sound emission in the Salish Sea based on measurements taken as part of the Port of Vancouver Enhancing Cetacean Habitat and Observation (ECHO) program. Ship noise measurements taken as part of that program are very numerous with over 7,000 ship-measurements of various classes including ferries, container ships, tankers, bulkers, vehicle carriers, tugs and cruise ships. The underwater listening station was located in the Strait of Georgia and was functioning between September 2015 and April 2018.

For each measurement, the Jasco deployed hardware for ECHO tracks sound and ship location and can produce a one-third octave band calibration Radiation Noise level (RNL) per ANSI S12.64 or a monopole source level (MSL). Mr. Hannay notes that there is substantial variation in sound even for vessels of the same ship class. These differences are due to differences in vessel size and measurement conditions (e.g. vessel speed, wind speed, etc.). A multi-variate analysis found significant correlations of noise emissions with several parameters such as speed, length, DWT, and wind speed).

The study developed a noise emission threshold equal to the median RNL or MSL by one-third octave band for each vessel class. Using this approach, half of the vessels in the ECHO database would already be compliant. Jasco believed that a near-100% conformance of meeting the thresholds might be possible, but it would be more realistic to assume only 90% of future compliance. To model this, they sampled 90% of the database in each class, and capped their MSL's at the median thresholds noted above. Finally, the remaining 10% of ships were left with the original noise emissions. Jasco determined that this process would require an average of 2 to 5 dB reduction in sound of the 90th percentile ships over the median threshold. Using these new source (MSL) sound spectra they computed the noise exposure for the Haro Strait area because it is a prime area for Southern Resident Killer Whale (SRKW) feeding. The Jasco modeling allowed comparison of the noise emission over a broad area in Haro Strait. The data was then compiled to examine the sound reduction across the shipping lanes as shown in Figure 8. In the center of the Strait at the shipping lane the reduction in received noise level is 4 dB on an unweighted basis and about 3 dB using a SRKW audio-gram weighting.

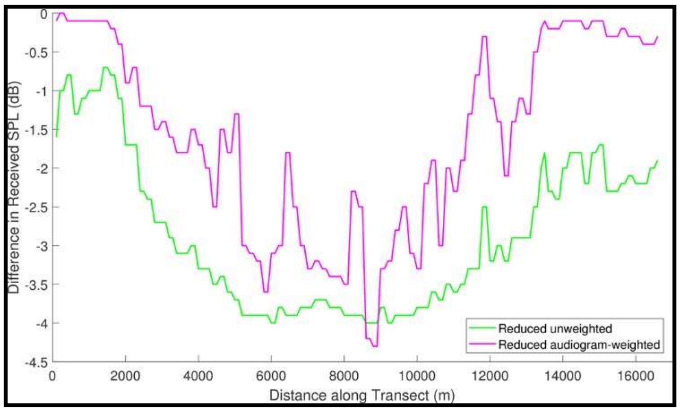


FIGURE 8: Reduction in Haro Strait Received SPL (Used with permission of Jasco Applied Sciences)

2.9 Class Society Silent Notations

On the morning of Day #3, Mr. David Hannay gave another presentation on the comparison of class society quiet notation noise limits to the ECHO program ship noise measurements. The first part of the presentation included a comparison of the different class society measurement and analysis methods and associated limits. The five class societies included: (1) DNV-GL, (2) Bureau Veritas (BV), (3) RINA, (4) Lloyds Register (LR) and (5) American Bureau of Shipping (ABS). A comparison of the class society noise limits are given in Figure 2, which were presented by Dr. de Jong earlier in the workshop.

Mr. Hannay noted that differences in the measurement procedures leads to numeric differences in measured levels between class notations. If measurement configurations are documented properly, then it is possible to adjust measurements from one class notation to compare with those of another. His approach for comparing the ECHO program measurements (using approximate methods from ANSI S12.64) with the class notation criteria was to adjust the measurements to approximately account for differences in the RNL and MSL calculation procedures.

The database of ship measurements is the same as discussed in Section 2.8. Jasco adjusted the measurements to be consistent with each of the class society limits. The resulting one-third octave band data were compared for each vessel to the appropriate class society limits. Figure 9 shows the percent of vessels meeting class society limit in all but 5 one-third octave bands. The higher the percent the least restrictive the notation and Figure 9 shows that is the ABS Transit notation, which is within 96% to 98% for all vessel classes. The most restrictive appears to be BV notation, which ranges from 0% to 15%.

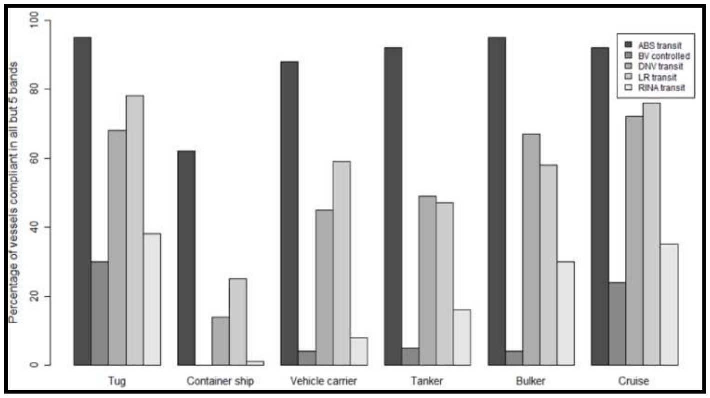


FIGURE 9: Percent vessels meeting notation thresholds in all but 5 bands
(Used with permission of Jasco Applied Sciences)

2.10 Overview of Ship Underwater Radiated Noise Technology

Mr. Andrew Kendrick is the author of the Vard report on "Ship Underwater Radiated Noise".[12] On Day #1, Mr. Kendrick presented the report and provided background and rationale for the report. This report presents the results of a review of the means of mitigating and predicting the URN from ships. The report provides an overview of URN issues, but is not intended as a complete treatise to this complex subject. The main outcome of the work undertaken is a matrix of URN mitigation measures. These are presented as an appendix to the Vard report, and can therefore be used as a stand-alone summary of options that can be used now and in the future. Measures are categorized in four main areas:

1. Propeller noise reduction;
2. Machinery noise reduction;
3. Flow noise reduction; and
4. Other, where the first three categories are not easily applied.

Each measure is described, and then defined in a standardized approach that aims to define:

- Advantages and benefits to the ship's design and operations;
- Disadvantages and challenges;
- Technology readiness;
- Cost impacts for implementation and operation;
- Applicability to different ship types;
- Effectiveness; in terms of frequency ranges and reduction in sound levels.

A final section of the matrix provides a summary of prediction methods for URN. Entries in the matrix are supported by citations, and a full list of references is provided. A wide range of mitigation measures are available to address different types of noise at varying levels of effectiveness. All will require some level of financial investment, but in some cases there are co-benefits, such as efficiency enhancements, that may offset some or all of the costs.

As previously noted, all participants were given the report ahead of the workshop and asked to read and provide written comments during the Day #1 presentation. On Day #3, Mr. Kendrick presented the various comments, and how he would incorporate them into the final edition of the report and the technology matrix. Mr. Kendrick addressed approximately forty written and verbal comments on the technology matrix. Nearly all would be incorporated into the next (and final) revision. Comments impacting the overarching document or changes in scope of the matrix or report would not be addressed at this time.

[12] Vard Marine Report, Ship Underwater Radiated Noise, report 368-000-01, rev 3, dated January 9, 2019.

SECTION THREE

3.0 AM BREAKOUT PROGRAM

Day #2 of the workshop was a full day of breakout and plenary sessions during both the morning and afternoon. During the morning the workshop attendees were organized into five “AM Break-Out Groups”. Each of the five groups had expertise based on the workshop registration in one of five technical areas as follows:

a. URN Limits to Protect Marine Life (Group #1)
b. Propeller & Hull Design (Group #2)
c. Machinery Noise Control (Group #3)
d. URN Predictive Tools & Modeling (Group #4)
e. URN Metrics & Measurements (Group #5)

Each group was given a different set of issues and topics to discuss. The questionnaires for each group are provided in Appendix D. Group leaders were appointed by the workshop chair ahead of the workshop and were asked to direct the discussion and report back to plenary at least three key ideas or concepts for quiet ship/noise reduction.

A summary of the discussion in each breakout group is given below based on the report back to plenary and notes provided by the breakout group leader. A plenary at the end of the morning session, reviewed all the concepts/ideas provided by the five AM breakout groups. This is summarized in Section 3.6.

3.1 URN Limits to Protect Marine Life (Group #1)

Led by Dr. Lindy Weilgart, Consultant and Adjunct Professor, OceanCare & Dalhousie University

DISCUSSION POINT #1: *What else would need to be done to provide a universal upper threshold of a vessel URN that would be generally tolerable for marine life? Would any/all of the class notation limits for URN (DVGL, BV, or ABS) offer reasonable protection for marine life?*

The group discussed the state of knowledge regarding the impacts of URN on marine species, and while the group agreed that there were many specific areas and species for which there exists a considerable amount of information on adverse impacts, and that URN represents a significant threat to the marine environment, it is not currently possible to establish a biologically-based threshold universal to marine life.

The group debated alternative methods of determining what a technologically feasible threshold of vessel URN would look like, and while the class notation limits for URN marked a good starting point, most studies had used median levels of operating noise to model sound reductions, and some members felt more precautionary thresholds might be needed, particularly given the long operating life of many vessels in the commercial fleet.

The consensus of the group was that while determining a universal, biologically-based limit was not achievable in the short term, a technologically feasible, precautionary standard for individual ships, based on existing ship measurement data, is currently achievable and should be pursued. The group also noted that, in addition, biologically-based limits could be undertaken in particular areas or regions where there are well-studied species of concern.

DISCUSSION POINT #2: *Back in 2008, the Okeanos Foundation recommended a 3 dB reduction per decade. Is this reduction reasonable? If not, suggest decibel reductions that you believe are doable and meaningful. Are there any particularly sensitive areas or species that require special protections?*

On the whole, the group agreed that the global 3dB reduction of noise (also endorsed by the International Whaling Commission) was still a good place to start as a policy goal, with many in the group noting this target was set to reflect and reverse the rate vessel URN had increased in recent decades, rather than a technological or biological standard.

The group acknowledged that if implementing of a global target for reducing global underwater noise, it would be important to find ways of reducing vessel URN without harming vessel efficiency or significantly increasing costs and to not only design quieter ships, but ensure that they remained quieter under different operating conditions. It was agreed that a compulsory (regulatory) approach might be required, but that any regulations would need to be implementable and enforceable to ensure a level playing field. Also, operators would benefit from some flexibility in how they would implement any noise reduction requirements as well as assistance in the form of guidance information, including case studies.

It was also suggested that implementing noise regulations in Particularly Sensitive Sea Areas (PSSA's) or specific areas should be pursued and that care should be taken for specific sources of underwater noise, like icebreaking activities, that are region specific and may require more study.

The group also agreed that while it was not possible to set a biologically universal upper threshold of URN, articulating the impact of vessel URN on marine life, and the benefits to its reduction (i.e., increased communication space), was possible in many cases.

3.2 Propeller & Hull Design (Group #2)

Led by Dr. Johan Bosschers, Senior Researcher, MARIN

DISCUSSION POINT #1: *Is Cavitation Inception Speed (CIS)[13] a parameter that large commercial vessel operators are willing and interested to be aware of for their vessel(s)? If so, what is the degree of certainty (or uncertainty) in determining this parameter for a large commercial vessel during the design stage when the vessel is operational?*

It was noted by group members that CIS is usually defined as a sudden increase of noise, typically occurring first at high frequencies. However, in relation to the influence of noise on marine life, a different definition may perhaps be required that includes for instance the increase at low frequencies as well. All agreed that most vessel operators are not aware of their vessel CIS on an operational basis. However, it was noted that a small number of owners may include CIS as part of evaluation for new ship designs.

The degree of uncertainty in determination of CIS during design stage for commercial vessels is unknown due to lack of data. For well-designed naval vessels, the CIS can be determined within 1 knot, using model tests, but the situation for commercial vessels is more complicated due to their variations in draft and due to more complex wake fields that show larger scale effects. Furthermore, CIS depends on geometrical finishing of ship and propeller to a degree that are usually not achieved for commercial vessels.

In operation, CIS can be measured in the far-field via hydrophone in water, pressure transducer, or on-board with an accelerometer mounted on the hull above the propeller. There is limited data for commercial vessels, but CIS will be measured in PIAQUO project (2020) using accelerometer methods.

DISCUSSION POINT #2: *How significant of a change to typical ship design is required for a good hull form that supports a more quiet ship and propeller designs?*

A good hull form has a low resistance for a given displacement (cargo) in combination with a wake field for the propeller such that propeller-cavitation hindrance can still be acceptable. These hull forms show a trade-off between wake field quality and resistance/displacement. Nowadays, the hull forms are often designed for multiple loading conditions and multiple ship speeds. Since the introduction of the Energy Efficiency Design Index (EEDI), significant reductions of ship resistance of large vessels have been obtained, and the group therefore expected that it may be difficult to significantly improve these hull forms to support a more quiet ship and propeller without sacrificing resistance or displacement. For smaller commercial vessels, that were not

[13] The vessel speed at which the ship's propeller first begins to cavitate.

fully optimized in the design stage, the group expected that the hull form can still be improved to support a more quiet ship and propeller design without sacrificing resistance or displacement.

DISCUSSION POINT #3: *Can propellers of existing commercial ships be improved with respect to efficiency as well as noise?*

A "well-designed (optimal)" propeller of a commercial ship is intended to have the maximum propulsion efficiency while satisfying the constraints with respect to cavitation erosion and cavitation-induced onboard noise and vibration. These propellers show a trade-off between efficiency and cavitation hindrance.

However, it is also expected that some vessels have a propeller that is not optimal because of the fast design cycle. The group could however not provide an accurate estimate of the percentage of such ships in relation to the total number of ships. Such propellers can most likely be improved with respect to efficiency as well as noise. It is therefore recommended to quantify the differences in hull/propeller design with respect to URN for a given ship type and speed to evaluate how much hull/propeller designs are below optimal and whether there is room for improvement.

It also needs to be noted that it is assumed that the design criteria for cavitation hindrance, such as cavitation-induced onboard noise and vibration, and to a lesser account cavitation erosion, also hold for URN. This assumption does require further investigation. It is therefore recommended to improve the knowledge and prediction methods for the relation between cavitation (and different types of cavitation) and URN.

DISCUSSION POINT #4: *Do quiet commercial propellers exist and can commercial shipping afford them?*

One definition of a quiet propeller for commercial shipping that was discussed by the group, is a propeller that is free from cavitation. However, a cavitation-free propeller is generally not possible for a typical current commercial vessel. Therefore, it was believed that such propellers are not affordable.

Alternative definitions of quiet propellers for commercial shipping as discussed by the group may be based on propellers that comply with class rules for URN or onboard-noise, such as cruise vessels, quiet ferries and seismic vessels. Such propellers usually show a very small extent of cavitation in the tip region (small sheet in combination with tip-vortex cavity). Considering the statements in Discussion Point #2 and #3, such propellers for commercial shipping in general can only be obtained at the costs of a reduced efficiency.

3.3 Machinery Noise Control (Group #3)

Led by Mr. Kai Abrahamsen, Senior Principal Engineer, DNV-GL

DISCUSSION POINTS #1 and 2: *What are the latest noise mitigation technologies for machinery inside the hull? For an existing vessel, what is the limit of treatment inside the hull?*

The primary issue facing reduction of noise on a global basis is the noise created by slow speed direct drive diesel engines. Slow speed engines create significant levels of underwater noise levels which can be similar to and is some cases greater than propeller contributions. Engine vibration, rather than airborne noise, is likely to be the transmission path for this URN; pointing to reduction in vibration transmission as a needed mitigation. However, to the group's knowledge, no one has looked into reducing noise from slow speed engines, and therefore potential solutions are not readily available. Further, vibration isolation of large slow speed engines is problematic. The engine needs to take the thrust and this cannot happen if it is resiliently mounted.

There are potential solutions to the challenges, but further research and investigation is necessary, which in turn requires the market force to do so. Areas for investigation include means to reduce the vibrations of the engines themselves, the design of thrust bearings, and stiffening of engine foundations. Further investigation is also required into the potential for alternatives to slow speed engines, such as medium speed engines and diesel electric systems. This would raise questions such as impacts on efficiency and emissions, specifically.

They also spoke about the use of air bubbler systems (see Figure 5), which may present an opportunity for noise mitigation that could be implemented on new or existing vessels with slow speed diesels.

Group #3 also discussed a hybrid propulsion plant design for cargo ships in place of the current direct drive slow speed diesel configuration. The main propulsion for 90% of the transit period would be by traditional slow speed diesel. There would be a secondary electric motor drive in line with the existing shafting to be used when operating in sensitive areas, and there is a need to reduce vessel speed and URN. The concept is shown in Figure 10.

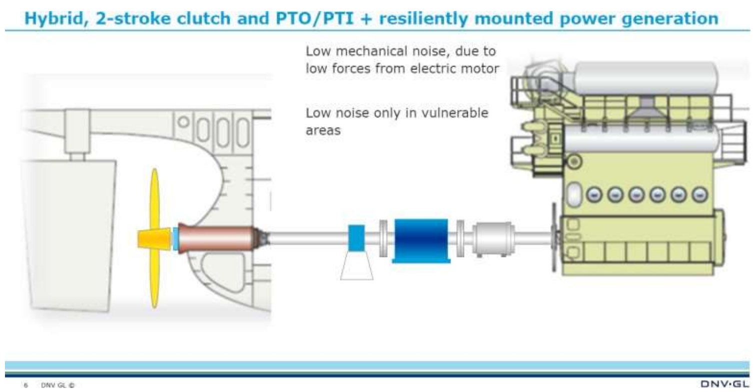


FIGURE 10: Hybrid propulsion plant configuration in place of slow speed diesel plant.
(Used with permission of DNV-GL)

The group highlighted that there needs to be a legal or economic incentive to investigate solutions to this problem. Without the right incentives, studies will not likely be performed. Also, reducing noise may have adverse impacts on greenhouse gas emissions. Given that there is currently a strong push to reduce these emissions, this must be taken into account when making any effort to reduce URN.

Finally, the group offered several specific comments on the Noise Mitigation Technology Report by Vard Marine that were taken by the author for incorporation into the update of the report, following the workshop

DISCUSSION POINT #3: *What is needed for accurate URN modeling of machinery noise sources?*

The group noted that better models of engine excitations, using details of combustion processes, are needed. A challenge with this is that combustion curves are proprietary and are generally not shared. Additionally, specialized expertise is required to perform the modelling and interpret the results. There needs to be a legal or economic incentive to investigate solutions to this problem. Without the right incentives few studies will likely be performed.

3.4 URN Predictive Tools & Modeling (Group #4)

Led by Mr. Trevor Walton, Noise & Vibration Specialist, the Thales Group

DISCUSSION POINT #1: *Do we have enough resources, software tools, and data to perform ship and propeller noise predictions accurately?*

The group indicated that the short answer to the question is ‘yes’ in the military and ‘no’ in the commercial sector.

The group noted that there is a variability in URN data, which does not match the experiences within the group for validation of source level models and mitigation methods. The group believes that certainty in cavitation prediction modeling remains illusive and lacks full-scale data. Thus, there is a need for a database of validation data and case studies that would help with the validation of predictive tools; full scale data from URN measurements need to be more widely available. The group suggested more work is needed to correlate source level reduction with cost benefits. There is a need to establish simple and robust models to calculate cost/benefit. Also, guidance is needed on setting up models correctly to ensure a common basis for evaluation. Additionally, the group reported that there is very little information available about small craft URN and the sector needs more testing facilities for development of quiet propellers.

DISCUSSION POINT #2: *What are the best commercial software packages for propeller noise and ship noise predictions?*

Propeller software packages and their limitations were well presented by Dr Islam (see section 2.7). Computation of cavitating flow is still difficult especially for the case of instantaneous cavitating vortices and cavitation collapse. Software *OpenFoam* provides good capabilities for propeller noise prediction. They suggested that *VAONE* (SEA code) is good for inboard machinery and hull radiated noise. It is only limited by knowledge of input impedance and machinery noise/vibration input levels. Lastly, a good number of satisfactory open-source underwater sound propagation prediction tools are available, again only limited by input data. The group suggested that the workshop not just consider commercially available software, as there are many in house codes available.

DISCUSSION POINT #3: *Do owners and shipbuilders have budget and resources to use predictive tools and/or hire experts to perform the computations?*

The group generally answered “no”, except for the larger shipyards. There is a need to educate these businesses, raise awareness and incentivize them to use of such tools. Experience suggests that they will only invest in tools and expertise if there is a financial incentive. It was suggested to combine URN with other environmental factors, such as air emissions early in the design phase so as to reduce the added cost.

The effort will be undertaken if the requirements can be properly articulated. There also needs to be a demonstration of the cost effectiveness of URN modeling approaches. For example, shipbuilders might only be required to perform URN predictions once per vessel class rather than for each ship. Budgets will only be set aside if there are regulations, but ones that have a level playing field. URN evaluations could be a mandatory part of commissioning and ongoing demonstration, but lack of certainty of outcome seen as high risk to costs and schedule. There is also a perceived lack of skills and expertise within the industry.

DISCUSSION PONT #4: *What would be required to move the vessel URN predictions (such that it could be compared with a design criteria such as a class notation, for example) from the realm of the specialist to a broader use in the industry during the ship design process? What are the pros and cons?*

On this point, the group identified the following needs:

- increased confidence and validation of the approach and standardization of methods to enable comparisons with other results;
- development / provision of standards for validation / correlation of models;
- distillation of specialist knowledge and to simplify requirements for integration within the procurement and design process;
- increased understanding within community regarding machinery lineups;
- introduction of uncertainty metrics for measured and modeling outputs to feed into certification requirements;

- regulations for noise that go beyond the existing IMO regulations;
- a clearer breakdown of vessel types;
- methodologies for each design phase;
- increase in "Suitably Qualified and Experienced People" (SQEP) within ship building community;
- tools that are easier to use and interpret; and
- incentives for URN prediction within the design process; the commercial ship building industry needs to be convinced to commit to a noise reduction strategy.

In addition to the above points, the group identified several additional needs:

- make advances in scaling the results from propeller modeling to full scale;
- improve numerical modeling for predictions of propeller noise, specifically with respect to cavitation speed and mechanisms of cavitation dynamics and collapse given that numerical modeling is a cost effective means to study effects of ship modifications;
- account for regional requirements within the global regulatory framework;
- push for route optimization and improved docking procedures, i.e. to link logistics with URN;
- establish relevance and synergies with other ship & environmental attributes & regulations;
- develop tools for fleet level management;
- identify the global scale of the challenge at the governmental level to raise awareness alongside global warming;
- look at the impact of small high speed craft, not just large cargo ships;
- improve processing of URN measurement to remove background and reverberation effects
- provide standards for modeling and measurement of drive point impedance at foundations of machinery to improve URN predictions;
- conduct routine monitoring of noise and vibration vs URN to assess the performance of modelling work and ship design/palliatives; and
- combine strategy for measurements and modeling to better realize the benefits of both.

3.5 URN Metrics & Measurements (Group #5)

Led by Dr. Michael Ainslie, Senior Scientist, JASCO Applied Sciences

DISCUSSION POINT #1: *What are the proper metric(s) for reporting underwater ship noise?*

The "source metrics" include radiated noise level (RNL), monopole source level (MSL, also known simply as "source level") and dipole source level (DSL, also known as "surface-affected source level"). MSL is most suitable for performing far-field noise predictions. However, to compute MSL there is an important assumption of the source depth, which must be specified by the measurement procedure or otherwise selected by the user. The group was not sure if the prediction methods could handle use of DSL. All group members supported the use of MSL, provided that source depth is also reported. Two sound field metrics were considered, the sound pressure level (SPL) and sound exposure level (SEL), with appropriate statistics, and averaging or integration time.

The group had discussed several issues and raised a couple of questions. Should the metrics focus on properties of the source or of the received sound field? The group decided to focus on the source. How can a source metric be made relevant to impact on marine life, in particular on different animals, with different hearing characteristics? The group proposes that one should retain the entire vessel spectrum (whether of RNL or MSL) to facilitate the option of frequency weighting at a later stage. These spectra will depend on ship speed.

DISCUSSION POINT #2: *Have proper URN measurement methods been developed (i.e. ANSI, ISO, class societies) and what are limitations to those methods.*

The RNL metric is standardized in both ANSI/ASA S12.64-2009[14] and ISO-17208-1:2016[15]. There is a standard under development by ISO (ISO 17208-2) for measurement of MSL. The class notations are a combination of RNL and MSL metrics. For example, MSL metrics are used by Lloyds Register and Bureau Veritas, whereas RNL is used by DNV-GL, ABS, Bureau Veritas and RINA. The shipyard Fincantieri organized an initiative to harmonize these methods.

The group addressed the limitations of these metrics and methods. The RNL metric is suitable for assessing differences in vessel noise under like circumstances, e.g., for examining changes over time for a ship in different stages of its life cycle. The MSL metric is suitable for prediction of the sound field; if MSL is used to assess differences, a valid comparison can be made by keeping the choice of source depth unchanged. The vessel class notations are not harmonized. They also do not specify any particular class of ship; for example, container ships are given same threshold as tugboats or tankers, but this is not a limitation of the measurement method. Currently the ANSI and ISO methods are limited to deep water.

Lastly, we should have a standard for the URN measurement of “ships-of-opportunity”. The ships-of-opportunity is a term being used to refer to the type of the URN measurement where the subject vessel just happens to pass by a previously established monitoring station and its URN is measured with a single pass. This is in comparison to the ANSI and ISO methods which requires a very specific test configuration and multiple passes in order to get statistically better set of URN data.

DISCUSSION POINT #3: *What is best way to simplify measurement and reporting, but still get accurate information? Do we need something special from standards organizations such as ISO?*

The group noted the need for a standard procedure that’s more practical and feasible for industry, particularly a method that can be performed in shallow water. The group suggested use of different measurement grades, as is done in ANSI/ASA S12.64. It is important to have a credible evaluation of uncertainty. All reporting needs to follow ISO standard terminology: ISO 18405[16]. Again, there is a call for a shallow water standard and a simplified standard (e.g. one with single hydrophone, accepting higher – but always quantified uncertainty). The group emphasized the need for a standard for measurement of vessels of opportunity, taking account of the cost of the measurement. Lastly, group members involved with standards work noted that the ISO underwater noise committee needs more resources.

DISCUSSION POINT #4: *Are there beneficial sound propagation properties that can be taken advantage of such that reductions to receivers can take place without reduction in the sources?*

The group considered an alternative interpretation of this discussion point as: what changes in shipping practice can be considered without requiring a reduction in vessel source level? In other words, is there a way to increase propagation loss? For example, by adjusting practice according to local conditions such as wind speed, sound speed profile, or sea surface temperature. Are there more favorable or less favorable conditions? In addition, there is a dependence of MSL or RNL on sea state/Beaufort force. Can the number of ships be reduced, with more cargo on larger ships? It was noted that is happening already, larger cargo ships (containers, tankers), but not higher RNL. This would provide for lower total sound exposure. It was pointed out that there are practical reasons why ships’ size cannot be increased indefinitely.

---

[14] American National Standard, ANSI S12.64-2009, “American National Standard Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements”

[15] International Standard, ISO-17208-1:2016, “Underwater acoustics -- Quantities and procedures for description and measurement of underwater sound from ships -- Part 1: Requirements for precision measurements in deep water used for comparison purposes”

[16] International Standard, ISO-18405:2017, Underwater Acoustics – Terminology

3.6 AM Plenary/Summary

At the completion of the AM breakout group session all groups reconvened in the plenary session and group leaders presented an overview of their group discussions, as reported above. The group leaders were also asked to present a list of three knowledge gaps and/or implementation challenges and associated research topics for further discussion by all workshop attendees. Table 1 lists the results.

TABLE 1: AM Breakout group knowledge gaps, challenges & research topics.

Group #	Idea/Concept
1	• Although a universal, biologically-based limit was not achievable in the short term, a technologically feasible, precautionary standard for individual ships, based on existing ship measurement data, is currently achievable and should be pursued. The group also noted that, in addition, biologically-based limits could be undertaken in particular areas or regions focused where there are well-studied species of concern. • Noise regulations should be implemented in PSSAs or specific areas with species where better data is available. Care should also be taken for specific sources of underwater noise, like icebreaking activity, that are region specific and may require more study and discussion within bodies like the Arctic Council. Any regulation must be implementable and enforceable to ensure a level playing field without harming vessel efficiency or significantly increasing costs. • A compulsory approach will be necessary to motivate the building of new vessels with reduced levels of vessel URN, as well as for the maintenance of these levels in operation. To help with implementation of URN reductions, a design guide, with case studies, would be beneficial.
2	• For propeller/hull designs that are optimized for maximum propulsion efficiency while satisfying constraints with respect to cavitation, there is a trade-off between efficiency and cavitation hindrance. • Quantify the differences in URN for given ship types and speed to evaluate how much hull/propeller designs are below optimal and assess the room for improvement. Improve the knowledge of the variability of CIS with commercial ship operation and the relation between propeller cavitation and URN.
3	• There needs to be legal or economic incentives to investigate solutions for commercial vessels • Studies of mitigation strategies for 2-stroke, slow speed diesels need to be performed • How would an air bubble system be implemented and how effective would it be?
4	• Need to close the loop on ship source level vs impact, to provide some certainty and simplification to support ship builders and regulators. As with global warming there will be significant reluctance to move without a good foundation of evidence. This will help ship builders focus their efforts and ensure that any measures adopted actually benefit the whale and other endangered populations. • Provide incentives to improve the balance of cost / benefit. This could include providing practical guidance material to shipbuilders demonstrating benefits

	available through, for example, reduced maintenance / loss of platform availability. • Set up global body for collaboration & sharing of data & testing /modelling methodologies. This has a proven track record within the defense world providing a cost efficient way to establish metrics, standards, modeling methods and increase confidence that you are doing the right thing.
5	• Develop standards for shallow water and ships of opportunity for SL and RNL (with uncertainty and clear terminology). This would require support for ISO working groups (especially for convener). • Harmonize class notations (with method of evaluating uncertainty and clear terminology) • Standardize data formats (sound pressure time series; ship traffic data; then make data available (for measurements of received sound field)

SECTION FOUR

4.0 PM BREAKOUT PROGRAM

During the afternoon of Day #2 another set of breakout sessions were held. Attendees were organized into five groups (A through E) of mixed professional backgrounds. The workshop chair selected five different participants to lead the afternoon breakout groups.

The groups were all given a consolidated summary list of concepts based on the morning discussion (see Table 2 below). The afternoon breakout groups were then instructed to further discuss the importance of the concepts/ideas, and if possible, rank them in order of importance. The afternoon breakout groups were also asked to provide feedback on co-benefits, energy efficiency and implementation.

TABLE 2: PM Breakout group ideas/concepts organization

ID#	Idea/Concept
[1]	A biology based universal limit is not possible at this time. A ship-based limit is recommended.
[2]	Higher CIS gives less efficient propeller function.
[3]	Close the loop on source level versus damage.
[4]	Global 3 dB reduction of average ambient ocean noise from shipping needed in order to reverse the trend as a starting point.
[5]	Quantify the measured differences in URN for hull/propeller design for given ship types vs. speed (for example repeat ECHO in other ports)
[6]	There needs to be legal or economic incentives to investigate solutions for commercial vessels
[7]	Provide incentives for operators to have quieter ships (e.g. maintain good underwater noise level)
[8]	Commercial shipbuilding needs to have more collaboration and sharing of data with respect to URN design of ships.
[9]	Develop standards for shallow water and ships-of-opportunity, for SL and RNL
[10]	Harmonize class notations (with method of evaluating uncertainty and clear terminology)
[11]	Standardize data formats; then make data available (for measurements of received sound field)
[12]	Studies of mitigation strategies for 2-stroke, slow speed diesels need to be performed
[13]	Evaluate how Air (bubble) System(s) could be implemented into commercial ships.
[14]	Create a ship design guide for URN in order to meet certain noise standards. There should be a required compulsory measurement for quiet ships.
[15]	Improve the URN prediction methods for propeller cavitation.

A summary of the discussion in each PM breakout group is given below based on the reports back to plenary and notes provided by the breakout group leaders. A plenary at the end of the afternoon session, reviewed all the concepts/ideas provided by the five PM breakout groups. This is summarized in Section 4.6.

4.1 PM Breakout Group A

Led by Per Andersen, Technical Lead, Lloyds Register

Group A believed that ideas [5] & [8], and [6] & [7] could be grouped together. There was general agreement with item [1] and it was noted that the fact that a biological noise limit could not be provided at this time was the workshop's most important statement. However, they also noted that it may be counterproductive, as it may give the impression that there is not sufficient scientific background for setting limits, which was agreed is not the case.

Item [2] regarding CIS was noted as an obvious statement. Some noted that CIS is not a well-defined parameter and that the correlation with environmental URN is not clear. There was general support on the 3 dB reduction, item [4]. Some expressed that this needs a baseline to be meaningful. The definition of this is also not clear; whether the 3 dB is for each ship or for received sound levels.

Item [6] regarding legal or economic incentives and item [7] regarding incentives were highly supported. It was suggested that incentive programs, like the one at the Port of Vancouver, should be replicated and expanded. It is important that the incentives are robust and clearly defined. Some participants suggested there should be link(s) between URN and EEDI. It was also mentioned that for many ships, there would be a trade-off between energy efficiency and URN mitigation. Regarding incentives it was recommended to link this to the Ship Energy Efficiency Management Program (SEEMP) with requirements to be stated by the ports. Some concerns about this were raised as ports are also businesses, and it was unclear who would compensate ports offering incentives.

For items [8] and [9], it was noted that sharing of data can be difficult due to potential intellectual property (IP) rights, but maybe government involvement could help. Development of measurement standards was highlighted as an important action. Some concern was raised about the uncertainty and repeatability of the measurements. An idea of using calculated values instead of measured values was voiced, as this could increase the repeatability. This would require validated calculation methods to implement.

4.2 PM Breakout Group B

Led by Fraser Winsor, Senior Engineer, National Research Council.

This group noted that item [2] could use a better general statement given that ship noise is an important environmental issue. They suggested trying not to make categorical statements that dwell on the relationship between noise and efficiency. There is a trade-off between efficiency and noise reduction for optimal propellers.

Regarding the suggested 3-dB reduction, item [4], it was asked if this is an action or a goal. The group believed it was difficult to define, measure, and enforce. Even if a universal biological standard is not possible, a regional or species standard may be possible. Group B thought it would be reasonable to have a baseline ship noise measurement. While there is evidence of the trend of increasing noise, they suggested removing the 3-dB target. There is still confusion on the definition of this value and what it is applied to. They suggested the action of supporting by collaboration and funding the establishment of noise baselines. This will support the policy (goal) to reverse the increasing noise trends.

Regarding quantifying URN, the group thought this was a good idea and suggested that other parameters that influences URN may need to be considered. Considering legal consequences, they stated that regulation of URN can be linked to emissions reductions and EEDI. There should be educational opportunities for ship owners (and supply chain vendors), as to why URN is important.

There needs to be an organization to collect and share URN data. The practicalities of sharing large data sets needs to be explored. Data "owners" are often reluctant to share data. The value of sharing data needs to be explained. There may be a role for Class Societies to encourage data collection and sharing. The data could be used to improve (benchmark or validate) computational methods for prediction and modeling. Shipyards need to be educated about the benefits of this type of activity. There is also the impression that ship owners are not requesting quieter ships (links back to legislation and incentives).

Regarding standards, item [9], there needs to be more work on calculations for shallow water methods. There may be a role for IMO to support standards work at ISO, or other organizations to support and participate in this effort. It is critical to establish thresholds (other quantiles) for ship types. Certain class societies are working on this and there is a willingness to harmonize. There are actions underway related to standardizing data formats.

Data sharing may need to be legislated in order to see progress. It was suggested it would be helpful if data could be anonymized and be made publicly available. From a design perspective, the current focus is on vibration and noise reductions with respect to crew comfort. There needs to be a structured process on how to achieve a quiet ship. Class notations are awarded after the ship is completed, you either achieve it, or you don't.

Group B agreed that studying methods for mitigation of URN from 2-stroke, slow speed diesels need to be performed as a priority. The also suggested to evaluate how Air Bubble system be implemented into cargo ships both for the propeller and the hull. In either case, the effectiveness of such systems needs to be determined.

Group B was also in favor of developing high level ship design guidelines (similar to IMO[4]), but agreed it needs to be implemented at the engineering level. The knowledge and expertise of engineering companies needs to be improved. The education process will be important to implement this policy/regulation to shipyards. They also pointed out that ship design requires compromise.

Regarding ship measurements, Group B noted there should be a required compulsory measurement for quiet ships, but we need to harmonize how data should be collected. Standards for measurement, storage formats, and analysis are also needed. These standards currently exist for deep water URN measurements. Also, there are standards for fuel consumption data, which could be the model for noise related data (standard data products and shared analysis scripts, etc.).

Regarding URN prediction methods for propeller cavitation, Group B were in agreement on the need for better and accurate methodology, especially for the relationship between efficiency and noise. It is important for URN baselines to be established during the design phase of a vessel.

4.3 PM Breakout Group C

Led by Charles Massicotte, President, Multi-Electronique

This group developed a ranking of the top five concepts. The first was a research recommendation for studies of noise mitigation technologies with estimation of added cost. This approach should include study of mitigation for two-stroke engines [12] and air bubble systems [13]. The second concept is to provide incentives (legal and economic) for owners to have quieter ships, such as is done at the Port of Vancouver.

The third ranked concept is to develop measurement standards for shallow water and ships-of-opportunity. They agreed that commercial shipbuilding needs to have more collaboration and sharing of data with respect to URN design. There should be data sets of statistically-based, vessel-anonymous URN available to shipbuilders. This should include links between noise emissions and design parameters (dimensions, block coefficient, thrust loading coefficient of the propeller, etc.). Finally, data formats should be standardized, with measurement methods following ISO or ANSI methods.

The forth ranked concept was to harmonize the various "Silent Class" notations (with measurement methodology, method of evaluating uncertainty, clear terminology, uniform limits, adding AIS class category definitions, grandfather clauses). There should be a required compulsory measurement for all ships. The fifth ranked concept was to improve the URN prediction methods for propeller cavitation.

4.4 PM Breakout Group D

Led by Cécile Rafat, Legal Affairs Expert, French Ship-Owners Association (Armateurs de France)

Group D has issues with the wording of a "universal" URN limit for marine life". Getting a universal number in the light of/according to the biology-based approach does not seem achievable today. At a first stage, they recommend a more realistic approach that would rely on an economically and feasible approach to limit URN for ships. They further recommended separate consideration of URN from existing and new ships, and for existing ships, first focus should be on the noisiest. This would rely on precise measurements at the beginning of any effort. Group D noted that it would be difficult to have limits for the various classes of vessels. They further suggested a link between efficiency and URN, up to a point where efficiency is compromised by further noise reduction measures.

Broadly noted, the suggestion was that each new ship should be quieter than the last, and to link noise with efficiency, and a commonality with reducing SOx and URN. The group also discussed the “3 dB reduction” global target per decade and considered it as an aspirational target. This "3 dB" standard needs further understanding. Finally, the group strongly considered that economic incentive seems to be an efficient tool. Class notations needs to be linked to incentive measures in order to invite ship-owners to get notations.

4.5 PM Breakout Group E

Led by Sadaharu Koga, Manager of the Regulation Unit, Japan Ship Technology Research Association

Group E believed that one of the first priorities was concept [9]; to develop standards for sound measurement in shallow water and for ships for opportunity. There should be compiled URN data for hull/propeller designs for given ship types, sizes, speeds, and load conditions. They agreed with the importance of standardization of data formats, and then make data available [11], as well as encouraging its use. The Group considers those concepts essential in order to have a common and objective norm for quantifying URN.

Understanding that a biology based universal limit is not possible [1], Group E agreed that, in considering a ship-based limit, recognizing the overall environmental footprint including greenhouse gas and SOx is necessary and that the balance must be kept among all those important environmental issues.

They agreed that the global 3 dB reduction [4], but pointed that it should be an overarching “goal” instead of a specific action. On the other hand, they agreed that there needs to be legal and/or economic incentives scheme for operators to have quieter ships, as shown in concepts [6] & [7].

Lastly, they added a new item which was not mentioned prior. Group E recommended the awareness of the subject of underwater noise be encouraged and promoted. The Group also agreed that development of a method to determine the input energy from the machinery to the structure is useful for improving URN prediction.

4.6 PM Plenary/Summary

As with the morning sessions, at the completion of the PM breakout group session all groups met back in a plenary session at which point the group leaders presented an overview of their group discussions, as reported above. The afternoon breakout groups were mixed expertise and the assignment was to review the ideas/concepts that were summarized in Table 2. Each group was given this table as the point of discussion.

There was general agreement between workshop attendees that three statements could be made regarding the current state of knowledge. Briefly, these three statements concern:

(1) The inability to provide a marine-life based impact noise limit;

(2) A vessel-imposed noise limit should be developed based on feasibility; and

(3) Quiet propellers will not automatically be more efficient.

These statements will be addressed in greater detail in Section 6. There was broad agreement by the workshop participants regarding recommendations for future action and research that is addressed in Section 5.

After the breakout reports, the workshop chairman and Transport Canada organizers encouraged all attendees to freely discuss ideas that had not already been addressed in the two breakout sessions. To start, there was an open discussion on noise mitigation treatments and solutions not already mentioned. The ideas brought forth are discussed in the paragraphs below.

One of the attendees suggested developing a "Noise Technical File". This would be similar to what is done for NOx emissions. This file could be produced while the ship is under construction, and set a baseline for a vessel with low sound characteristics. The ship owners would then receive the file and it would provide information on how the shipbuilder got to the baseline URN. The ship owner could then go back to the technical file if the baseline URN was exceeded.

There were suggestions for low noise propulsion systems. One such suggestion was a wind-based vessel (sails, kites, etc.). There would be benefits from both fuel efficiency and noise perspectives. There was mention of using solar panels, but these have very low power density and it was not clear there would be a reduction in URN. This is likely to be more feasible for smaller vessels. Nuclear powered vessels would be quieter, but that technology is not likely politically feasible. Fuel cells are a more likely form of power, but they too have low power density. There was a suggestion to design commercial cargo ships with twin propellers (vs. single shaft and propeller) and that this would provide an improvement in CIS and the loss of total efficiency.

Another novel idea was development of super quiet tugs, able to move in and out of sensitive areas. This approach would put all the noise mitigation on the quiet tugs, which would then provide propulsion and navigation control for the noisy commercial ships. In such a case, the ship would then not need to operate their propulsion plant.

"Arneson Drives" were also suggested for quiet propulsion. They are not very efficient but can be used for a short distance, such as whale watching vessels. There was also a suggestion to use a hybrid propulsion configuration using a large electric motor in line with 2-stroke engine to be used during sensitive water transit (see Figure 10).

Potential benefits of speeding up were discussed, assuming that the vessel URN remains about the same. By speeding up, sound exposure level would be decreased[17], which is relevant when considering impact to marine life. The operators would need to consider safety issues as increased speed could lead to more animal strikes or potential safety issues. This approach may be applicable in some areas but is unlikely it would be applicable everywhere.

Another way to minimize the noise exposure is spatial planning. For example, if vessel traffic lanes are moved greater distances from critical habitat areas or the traffic flow is organized in such a way that the duration of high URN is reduced. Vessel traffic lane shifts, known as lateral displacement were trialed in Vancouver, British Columbia, Canada during the summer of 2018. The data is currently being analyzed to determine the effectiveness of the lateral displacement.

The use of diesel electric plants on a commercial cargo ship was discussed. It was noted that such plants are far less efficient, the initial capital cost is greater, and reliability is lower.

There was call from participants for the need to understand optimization of vessel design for efficiency, noise and the trade-off between the two. This should be discussed further with quantitative data and new research.

There was a discussion about viability of the air (bubble) systems. It was noted that the system is currently on two cruise ships (the Princess Cruise Lines *Diamond Princess* and the Norwegian Cruise Lines *Norwegian*

[17] Sound exposure level considers both sound level and time duration

Joy). It was suggested that the ship could be ranged for URN to provide an understanding of impact by testing with and without the system operating.

There was a short discussion about the design and construction of a “Model Quiet Cargo Ship”, focusing on whether this is a feasible undertaking. For example, there was a new article in the Maritime Executive publication regarding an all-electric tanker.[18] Discussion about this ship arose concerning noise and energy capacity. It was noted that BC Ferries is using hybrid-electric vessels. It was suggested that it would be far more reasonable (and cost efficient) to do a paper study on this concept instead of construction at this point.

There was a discussion whether noise should be separated out from other design and environmental matters such as GHG, SOx, and NOx. The group recommended that it should not be separated. The issue is therefore to ensure that all these parameters get addressed while designing for best efficiency, without jeopardizing one for the other. Greenhouse gas and energy efficiency are two priorities already being addressed by the United Nations (UN), though noise has recently been garnering greater attention, specifically through the UN Oceans work.

Additional points of discussion included:

- Class societies could give a “notation” to have the ship measured – increase awareness and ports could provide incentives;
- The need to add a concept of dB per cargo tonnage transported. Bigger ships are faster, fewer big ships would be beneficial;
- Understanding underwater sound propagation is also an important matter;
- Encourage CIS monitoring for vessel crew/operational guidance;
- Treat recreational boats as a local issue;
- The need for an overarching/opening statement on URN to gain broad agreement. For example, URN from ships is a problem and should be mitigated;
- The need to replicate URN listening stations. There are already stations existing in Canada and planned in Sweden and Germany, but they need better standardization. ISO could do standardization work but it needs a convener to lead the work;
- New build URN measurement is not easy to organize. It was suggested that measurement equipment be located near the shipyards to make it easier. Also, onboard vibration may be available from existing machinery condition (health) monitoring systems;
- The need to consider how any noise mitigation feature impacts vessel and crew safety; and
- URN reduction at port is also important. Cold ironing reduces URN, emissions, invasive species, and bio fouling.

Lastly, there was a discussion on the co-benefits of URN reduction. One of the primary benefits noted was that a ship with low URN will also have reduced interior ship (compartment) noise. This can result in reduced crew fatigue, which then greatly improves safety. Additionally, quieter propellers reduce hull vibration which results in lower ship noise, health and safety benefits (reduced crew fatigue) as noted above and the added benefit of less wear on the propeller (limited cavitation erosion).

SECTION FIVE

5.0 RECOMMENDATIONS

The breakout and plenary sessions produced many ideas for future action and research. Sections 3 and 4 document these ideas.

Table 3 lists the recommended actions, which could be completed in a 1-2 year period. Table 4 lists the recommended actions, which could be completed in a 2-5 year period. Table 5 lists the recommended actions, which could be completed in a 5 year or greater time period.

All time periods are estimated based on assumed political will and/or interest in achieving reduced URN. In addition, based on comments at the workshop, and knowledge of organizational roles and responsibilities, potential "implementing bodies" have been suggested as a way to move the recommendations forward. However, it is recognized that appropriate responsibility for the recommended actions and research will require further discussions.

TABLE 3: Recommendations for Action & Future Work
(1-2 year time frame)

Recommendation	**Potential Implementing Bodies**
Publicize existing quiet ship design guides[19] to allow for immediate dissemination of such information.	Engineering NGO[20] Govt. Sponsor(s)
Create an updated (new) quiet ship design guide to educate vessel owners and operators regarding ship design and noise mitigation features required in order to meet Class Society or other noise limits.	IACS[21] Engineering NGO
Develop a standard set of URN limit curves similar to the airborne noise NC or RC curves as shown in Figure 11. These curves could later be adopted by the Class Societies.	ISO TC 43/SC 3[22]
Harmonize the "Silent" Class URN limits and measurement methodologies used by class societies.	IACS
Encourage CIS monitoring for research and operational guidance.	Shipping NGO R&D Consortium[23]
Add URN listening stations to at least one major port for each of the largest shipping nations.	Port(s) Govt. Sponsor(s)

19 Vard Technology Report & Matrix (2019), Encyclopedia of Maritime and Offshore Engineering (2017), & SNAME MVEP T&R Bulletin 6-4 (2014)

20 Non-Governmental Organizations

21 The International Association of Classification Societies' (IACS) is a technically based non-governmental organization that currently consists of twelve-member marine classification societies with offices located in London, UK

22 ISO Technical Committee 43 (acoustics); subcommittee-3 (underwater acoustics); secretariat is currently the Acoustical Society of America (ASA), located in Melville, NY-USA.

TABLE 4: Recommendations for Action & Future Work
(2-5 year time frame)

Recommendation	**Potential Implementing Bodies**
Develop standard methodologies for ship URN measurements in shallow water and for ships-of-opportunity (i.e. single pass by). There should also be standard formats for URN reporting and other associated information.	ISO TC 43/SC 3 Govt. Sponsor(s)
Develop a universal and publicly accessible database of ship URN data, which includes vessel type, noise control features, and other characteristics. It should use standard data reporting formats as noted above.	Govt. Sponsor(s)
Develop design for sound & vibration isolation of 2-stroke, slow-speed diesels engines on commercial ships.	Industry Govt. Sponsor(s)
Develop design for "Air Bubble" System for sound attenuation on commercial ships.	Industry Govt. Sponsor(s)
Develop improved codes/software for hull and propeller URN prediction.	R&D Consortium
Develop more knowledge of sound propagation and implement as algorithms in new prediction codes (as above).	R&D Consortium

TABLE 5: Recommendations for Action & Future Work
(>5 year time frame)

Recommendation	**Potential Implementing Bodies**
Establish economic incentives and/or legal consequences to encourage and/or mandate ship owners/operators to invest in noise mitigation for quieter ships.	Shipping NGO
Establish a regulatory ship noise limit based on engineering feasibility and phased in over time. This limit should not result in increases in other environmental emissions.	IMO Government
Establish a requirement for compulsory URN measurement of ships.	IMO Government
Encourage greater research toward the understanding of ship URN versus impact on marine life.	R&D Consortium Govt. Sponsor(s)

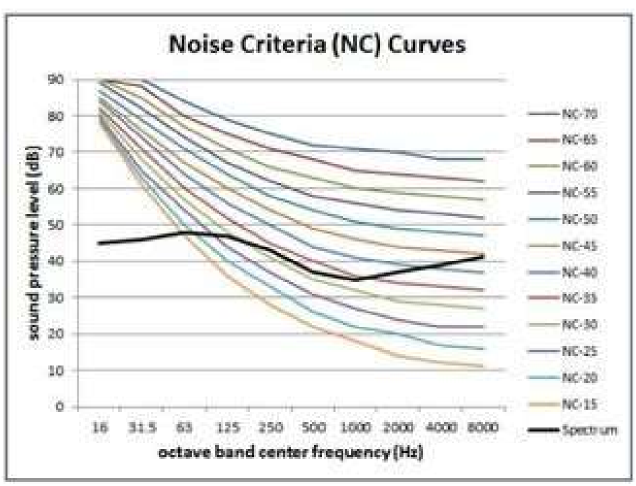


FIGURE 11: Noise Criterion (NC) Curves[24]

[24] ANSI/ASA 12.2-2008; Criteria for Evaluated Room Noise

SECTION SIX

6.0 CONCLUSIONS

The workshop was a great success with nearly 140 people attending the two- and half-day event. Participants came from all parts of the world, including Europe, North America, and Asia. The workshop was attended by numerous experts in the fields of underwater acoustics, ship design & quieting, marine biology, and policy. The IMO headquarters proved to be a good central meeting point for international experts, and holding the workshop at IMO demonstrated the support for work on this topic at the highest levels of the marine regulatory body.

The workshop presenters provided up-to-date information and data regarding impacts to marine life, ship silencing, industry activities in the field and its limitations. All are important factors to addressing the problem at hand. It was agreed upon by participants that ship underwater noise is increasing every day, and this increase has a menacing effect on marine life.

The breakout and plenary discussion produced many important suggestions which are reported in Sections 3 and 4. Section 5 outlines key recommendations that resulted from the various breakout sessions along with potential implementation timing and bodies.

Of all the suggestions, there are three that are statements of fact, which should be clearly noted and recognized.

1. **Even though underwater noise impacts to marine life have been documented by numerous researchers, there is currently not enough information to develop a biology-based universal (receiver-type) noise limit for the seas. A ship-based limit is more feasible.**

2. **As a starting point, there should be a goal of a 3 dB/decade reduction of global (or at least regional) underwater shipping noise in order to reverse the trend of the past 60 to 80 years.**

3. **The optimal hull and propeller configuration has a maximum efficiency with tradeoffs between cavitation hindrance and energy efficiency. Put another way, lower propeller noise (i.e. cavitation) does not automatically give higher efficiency.**

The first two statements are directly connected. During the workshop, marine biologists explained that there is significant proof showing that increases in ship noise are impacting marine life. However, there is not enough knowledge to set a universal ocean noise limit; a point at which, below such a noise level, there is no harm to marine life. Ship designers and engineers have been asking for this limit. However, a biology-based universal noise limit would translate to different ship-based noise requirements depending on distance sound travels through the water and the local oceanographic conditions. Therefore, it seems clear that even if the universal noise limit could be developed, it would not easily result in information which engineers could employ to design quieter ships.

Since a biology-based noise limit cannot be realized at this time, it is recommended that a noise limit be established for individual ships (by class, speed, tonnage or other). This limit should be based on current URN emissions (by class etc.) which can be gradually reduced over some period. This limit shall depend on feasible engineering noise controls for ships. Establishing a ship noise limit should follow the format of many of the class societies notations already established at ABS, BV, DNV-GL, and RINA. Harmonization of these notations would greatly improve the marine industry's ability to comply with such new requirements

.

APPENDIX A

Workshop Program and Speaker Curriculum Vitae

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT

Technical Workshop

hosted by:
Transport Canada

location:
International Maritime Organization (IMO) Headquarters, London, UK

January 30 to February 1, 2019

Transport Canada

ACENTECH
ACOUSTICS AV/IT/SECURITY VIBRATION

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT

Technical Workshop

Hosted by: Transport Canada

International Maritime Organization (IMO) Headquarters, London, UK

January 30 to February 1, 2019

Objectives:

This technical workshop provides an opportunity for international collaboration and allows participants to share the newest research and technical solutions for quiet ship design and retrofits. The specific objectives of the workshop include, but are not necessarily limited to:

- ☒ Validating current technologies and identifying important gaps and challenges to further progress;
- ☒ Assessing areas by ship class for innovation potential to determine where more focused research may be needed;
- ☒ Understanding whether improvements made to ship design for fuel efficiency overlap with improvements made to reduce noise; and
- ☒ Documenting the conclusions of the workshop to guide future discussions on reducing underwater ship noise or as groundwork for a review of the existing *Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life*.

Detailed Agenda (subject to change):

Day One – January 30, 2019		
11:00 – 14:00	*Registration*	
13:00 - 14:00	*Optional: Quiet Ship Design & Noise Metrics Primer*	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech Christ de Jong, TNO
14:00 – 14:15	**Opening Address**	*Plenary Room (CR 9)* Hiroyuki Yamada, Director of Marine Environment Division, International Maritime Organization,
14:15 – 14:30	Overview of the Objectives and Format	*Plenary Room (CR 9)* Michelle Sanders, Transport Canada Michael Bahtiarian, Acentech

14:30 – 16:00	**Setting the Stage – Context and Challenges** • Impact of underwater noise on marine resources • Challenges in Setting Underwater Noise Targets • Efforts to date on reducing underwater noise • Industry challenges with reducing URN	*Plenary Room (CR 9)* • Nathan Merchant, CEFAS, UK (15 min) • Christ de Jong, TNO (15 min) • Eric Baudin, AQUO (15 min); Michelle Sanders, Transport Canada (15 min) • Veronique Nolet, Green Marine (15 min); Greg Peterson, BC Ferries (15 min)
16:00– 16:15	Coffee Break	*Delegates Lounge*
16:15 – 17:15	**Technical Overview: Predictions and Mitigation** • Overview of *Ship Underwater Radiated Noise Technology Review* Technology Review • Underwater Noise from Machinery • Broad Band Noise Generation of Propellers • CFD methodology for prediction of propeller induced URN	*Plenary Room (CR 9)* • Andrew Kendrick, VARD Marine (15 min) • Jesse Spence, Noise Control Engineering (15 min) • Dietrich Wittekind, DW Ship-Consult (15 min) • Dr. Shameem Islam, National Research Council Canada (15 min)
17:15 – 17:40	Viewing of 'Sonic Sea'	*Plenary Room (CR 9)* • Film introduction by Producer Michael Jasny, Natural Resources Defense Council (NRDC)
17:40 – 18:30	*Reception at the IMO Headquarters*	*Delegates Lounge*

Day Two – January 31, 2019		
08:30 – 08:45	Short Recap of Day One	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech

08:45 – 9:15	**Modelling of proposed thresholds** • Definition of new thresholds based on the measured vessel distributions • Modelling of noise savings in the Salish Sea, assuming different participation rates in meeting quiet certification thresholds	*Plenary Room (CR 9)* David Hannay, JASCO
09:15 – 10:45	**Breakout sessions – Technology Review** • Participants will break out into smaller groups/tables (chosen in advance) to collaborate on the technical details related to specific ship design topics and technologies. Breakouts include: 1. URN Limits to protect marine life 2. Propeller & Hull design; 3. Machinery noise control 4. URN Predictive Tools & Modelling 5. URN Metrics & Measurements	*Plenary Room (CR 9) – Group 1* *Room CR 6-8 – Group 2* *Room CR 11 – Group 3* *Room CR 12 – Group 4* *Room CR 13 – Group 5*
10:45 – 11:00	Coffee Break	*Delegates Lounge*
11:00 – 12:00	Report back from Breakout Groups to plenary	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech
12:00 – 13:30	*Lunch Break*	*Various Local Options Available*
13:30 – 15:00	**Breakout sessions** • Structured brainstorming to prioritize ideas and identify ways to encourage the implementation (e.g. demonstrate co-benefits, energy efficiency index, design tools/ checks to plan). • Mixed Expertise	*Plenary Room (CR 9) – Group A* *Room CR 6-8 – Group B* *Room CR 11 – Group C* *Room CR 12 – Group D* *Room CR 13 – Group E*
15:00 – 15:15	*Coffee Break*	*Delegates Lounge*

15:15 – 17:15	Report back from Breakout Groups to plenary, plenary discussion & review	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech
18:00 – 20:00	*Reception*	*Canada House, Trafalgar Square*

Day Three – Morning - February 1, 2019		
08:30-9:00	Recap of Day Two	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech
09:00 – 10:15	**Class Society Silent Notations** • The Vancouver ECHO program dataset: how it was collected and its value for understanding commercial vessel ship noise variation • Multi-variate analysis of the ECHO dataset to examine noise emissions variations with ship parameters and measurement conditions • Comparison of the ECHO dataset (scaled for vessel and measurement differences) with five quiet notation certification thresholds	*Plenary Room (CR 9)* David Hannay, JASCO
10:15 – 10:30	*Coffee Break*	*Delegates Lounge*
10:30-11:45	Discussion of comments on *Ship Underwater Radiated Noise* Technology Review	*Plenary Room (CR 9)* Andrew Kendrick, VARD Marine
11:45-13:15	*Lunch Break*	*Various Local Options Available*
13:15-14:15	**Plenary discussion - Brainstorming**	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech Andrew Kendrick, VARD Marine
14:15-14:30	*Coffee Break*	*Delegates Lounge*
14:30 – 15:30	**Conclusion and Next Steps**	*Plenary Room (CR 9)* Michael Bahtiarian, Acentech Michelle Sanders, Transport Canada
	Workshop Concludes	

Kai A. Abrahamsen

Senior Principal Engineer, DNV GL

Leader for AM Breakout Group 3

Kai A. Abrahamsen is a Senior Principal Engineer at DNV GL Section for Noise and Vibration. He has been with the company since 1982 and has carried out a wide range of projects related to noise and vibration in a variety of marine applications. Recently, he has been responsible for noise control for several new ocean research vessels, naval vessels, yachts, high-speed vessels and cruise vessels. He has been responsible for developing of several DNV GL class notations, viz. SILENT, NV Class and Comfort Class. Before joining DNV GL, Mr. Abrahamsen worked at the Acoustical Laboratory of SINTEF at the University of Trondheim. He is a graduate of Aeronautical Engineering from the University of Salford and has a M.Sc. in Sound and Vibration from the University of Southampton.

Michael Ainslie

Senior Scientist, JASCO

Leader for AM Breakout Group 5

Michael Ainslie is a Senior Scientist at JASCO Applied Research and Visiting Professor at the Institute of Sound and Vibration Research, University of Southampton (UK). He holds degrees in physics (Imperial College, 1981) and mathematics (University of Cambridge, 2011), and a PhD in seabed acoustics (University of Southampton, 1991). He is author of the book Principles of Sonar Performance Modeling (Springer, 2010), and his research interests include sonar performance modeling and effects of sound on aquatic life. He is Convenor of the ISO working group responsible for the development of ISO 18405:2017 Underwater acoustics – Terminology and is now Project Leader for the ongoing review of ISO 80000-8 Quantities and Units – Acoustics. He is a founding member of the EU expert group Technical Group Noise.

Per Trøjgård Andersen

Technical Lead at Lloyds Register - Engineering Dynamics

Leader for PM Breakout Group A

Per graduated from the Technical University in Denmark with a degree in acoustics in 1995. Has has worked as consultant within noise, vibration, acoustics (including underwater noise) for more than 20 years in the company Odegaard & Danneskiold-Samsøe, and since 2005 at Lloyds Registers Engineering dynamics Team in Copenhagen, Denmark, where he currently holds the position as Technical Lead. He is the main author of the *Lloyds Register* underwater noise notation. He has further participated in ISO Technical Committee TC43 workgroup, developing the international standards for underwater noise measurements, including the ISO 17208 series.

Michael Bahtiarian

Principal Consultant, Acentech

Workshop Chair

Michael Bahtiarian has worked in the field of shipboard noise control for nearly all of his 34-year career, which started at General Dynamics Electric Boat Division. There he served as a sound and vibration engineer for the USS SEAWOLF Class submarines. He spent the last 24 years working in ship silencing at Noise Control Engineering, LLC. There he completed numerous shipboard noise control projects most notably the NOAA Fisheries Research Vessel (FRV-40), the R/V HUGH R. SHARP (University of Delaware), the R/V SIKULIAQ (Alaska Region Research Vessel), the R/V NEIL ARMSTRONG (AGOR-27) and R/V SALLY RIDE (AGOR-28). All of the vessels were designed to underwater noise requirements.

Mr. Bahtiarian was the convener of the ISO Working Group (TC 43/SC 3/WG 1) that is tasked with the development of standards for the measurement of underwater noise from ships. He was the Chairman of Working Group 47 under the Acoustical Society of America (ASA) S-12 Committee on Noise that was responsible for the development of the first commercial standard for measurement of underwater noise from ships, ANSI/ASA S12.64-2009. Further, Mr. Bahtiarian has been an advisor to the US delegation to the International Maritime Organization (IMO) Design and Equipment (DE) meetings in 2012 and 2013.

Mr. Bahtiarian currently works at Acentech, Inc. in Cambridge, Massachusetts in both the Noise/Vibration and the Architectural Acoustics groups where he helps with commercial and industrial noise control problems. He is a Board Certified member of the Institute of Noise Control Engineering (INCE) and is a member of the INCE Board of Directors.

Eric Baudin

Bureau Veritas Marine and Offshore

Technical Presenter

Eric Baudin is heading the onsite measurements activities of Bureau Veritas Marine and Offshore. He is graduated mechanical engineer from “Conservatoire National des Arts et Métiers de Paris.” He joined BV in 2000 as onsite measurement engineer where he has been involved in various technical assistances mainly in the field of noise, vibrations and strain measurements. In 2009, Eric joined the Research Department, bringing its field expertise to various projects. Internally, he set-up and conducted the sloshing model tests campaigns carried out by BV, in tight relation with calculation teams. He has also been deeply involved in several research projects and JIPs on sloshing, carbon dioxide geological storage, hydroelasticity of ultra large container vessels.

More recently, Eric has managed for BV, measurements related R&D through EU projects on underwater noise such as SILENV and AQUO. He has led the French representation to IEC 62600-40 on acoustical characterization of marine energy converters. He also joined the IMO workshop for underwater noise guidelines in 2013 and the i3 initiative “Racket in the Ocean” in 2016. He is regularly supporting the French delegation to MEPC, focusing mainly on underwater noise and on marine plastic litters. Since 2016, with its team he offers measurements and monitoring expertise the maritime industry and R&D projects from spot check to dedicated monitoring systems, aiming at helping solving problems and anticipating new issues. He carried on developing within BV the measurements related rules such as NR614 class notation on underwater noise updating these rules throughout continuous exchanges with the main stakeholders.

Johan Bosschers

Senior Researcher, MARIN

Leader for AM Breakout Group 2

Johan Bosschers started his career at the National Aerospace Laboratory (NLR) in the Netherlands where he worked on helicopter and wind turbine aerodynamics. The last 22 years he has been working at MARIN, the Maritime Research Institute Netherlands, on propulsor hydrodynamics and hydroacoustics. He is the principal developer of a boundary element method for the prediction of propeller hydrodynamics and hydroacoustics, including the prediction of hull-pressure fluctuations and underwater radiated noise (URN) by propeller cavitation, and he has been involved in related CFD projects. He has been responsible for the measurement of the URN of propeller cavitation in MARIN’s Depressurized Wave Basin and has been involved in sea trials on hull pressure fluctuations and URN for commercial as well as naval vessels. He recently combined some of his research in a PhD thesis on “Propeller Tip-Vortex Cavitation and its Broadband Noise.”

Johan was active in the EU/FP7 project SONIC on URN of commercial vessels, he was chairman of the research group on cavitation noise measurement in the EU Hydrotesting Alliance and Hydrotesting Forum. He is chairman of the Specialist Group on Hydrodynamic Noise of the 29th ITTC, the International Towing Tank Conference, and was secretary and chairman of the previous Specialist Groups on this topic. Johan currently works as a senior researcher on Propulsors and Cavitation in the Research & Development Department of MARIN. He holds a MSc in aeronautical engineering from Delft University of Technology, he finished the Diploma Course at the von Karman Institute for Fluid Dynamics, and he holds a PhD in mechanical engineering from University Twente.

Christ De Jong

Ship Acoustic Advisor, Royal Netherlands Navy

Technical Presenter

Christ De Jong obtained an MSC (1986) and PhD (1994) in Technical Physics from the University of Eindhoven in The Netherlands. In 1986 he joined the Netherlands Organization for Applied Science (TNO). Since then he has been working in the fields of underwater and ship acoustics. He is ship acoustic advisor for the Royal Netherlands Navy and responsible for research projects aimed at managing the underwater acoustic signature of naval platforms. Since 2007 he has been also involved in studies of the environmental impact of anthropogenic underwater sound, for example of the effects of the dredging for the Rotterdam Port extension and of the construction of offshore wind farms in the North Sea on harbor porpoises, harbor seals and fish (larvae). He is an active member of the ISO/TC43/SC3 working groups responsible for the development of measurement standards for underwater radiated noise of ships and of marine piling.

Sarah Fountain Smith

Deputy High Commissioner for Canada to the United Kingdom of Great Britain and Northern Ireland and Alternate Representative to the International Maritime Organization

Host - Canada House Reception

Sarah Fountain Smith has been Deputy High Commissioner of Canada to London since August, 2017. Ms. Fountain Smith joined the Department of External Affairs and International Trade in 1989 and has since served abroad at Canada's Permanent Mission to the United Nations in New York and the Embassies of Canada in Argentina and Brazil. From 2009-2012, Ms. Fountain Smith was Ambassador of Canada to the Republic of Chile and Honorary President of the Chile-Canada Chamber of Commerce.

In Ottawa, she has held several management positions, including as Director for South America and Inter-American Affairs from 2005-2007, and as Director responsible for Canada's relations with the United States of America from 2007-2009. From 2012 to 2016, Ms. Fountain Smith was Director General for International Organizations, with responsibility for Canada's engagement in the United Nations, the Commonwealth, the Francophonie and the UN Development Agencies. From 2013 to 2015, she was also a Governor on the Board of the International Development Research Centre (IDRC). From March 2016 until July 2017, Ms. Fountain Smith was Assistant Deputy Minister of Global Issues and Development, responsible for humanitarian assistance, gender equality and women's empowerment, multilateral development programming, global health, education, environment, climate change and food security, as well as Canada's relations with international organizations.

David Hannay

Chief Science Officer, JASCO Applied Sciences

Technical Presenter

David Hannay is the Chief Science Officer at JASCO Applied Sciences, where he has worked as a marine acoustics scientist for almost 30 years. He has a master's degree in Physics from University of Victoria, Canada, specializing in underwater acoustics. David has been a research scientist at JASCO for almost 30 years.

He has worked on a wide variety of topics related to underwater acoustics at JASCO. His research specialties include field measurements and computer modelling of marine noise, primarily for assessing its effects to marine fauna. He has led several major projects in North America and the arctic aimed at characterizing noise from a variety of human sources, including shipping, marine construction, and oil and gas exploration. From 2007-2014, David was the chief scientist for the acoustics program of the multi-discipline Chukchi Sea Environmental Science Program. This project deployed several hundred acoustic monitoring devices in the ocean to monitor year-round soundscapes. For the last 6 years David's work has focused on characterizing oil and gas ship noise and commercial ship noise. This has included developing and evaluating strategies to reduce ship noise in sensitive ocean environments. For the last 4 years he has led the Port of Vancouver's ECHO program acoustic studies, that have included making several thousand systematic measurements of commercial vessel underwater noise emissions. This work has involved installing and operating a real-time cabled underwater listening station, that performs fully-automated vessel noise emission measurements.

Shameem Islam, PhD

Researcher, National Research Council

Technical Presenter

Shameem Islam has worked in the fields of marine, offshore and arctic engineering with technical expertise in both physical and numerical modeling, particularly for harsh environmental conditions. Throughout his career Dr. Islam has carried out various ocean and naval architectural engineering related research and development projects, with particular focus on hydrodynamics and marine propulsors. Dr. Islam has extensive experience managing design and performance evaluation related projects on various naval and commercial ships and offshore systems, both using physical model experiments and numerical modeling using both commercial and in-house developed CFD tools. Dr. Islam's current research interest includes marine propulsion, hydrodynamic modelling, noise measurements and modeling, offshore structures, ice-structure interactions, VIV and VIM.

Dr. Islam's research work has been disseminated through more than sixty publications and presentations at various international journals and conferences, including several editions of the SNAME Transactions, RINA Transactions, ISP, OE, JNAME, JSR, JSDP, and OMAE Journals. He is a member of the Society of Naval Architects and Marine Engineers (SNAME), the International Society of Offshore and Polar Engineers (ISOPE) and the Professional Engineers and Geoscientists of Newfoundland. Dr. Islam has completed his Doctoral research from Memorial University of Newfoundland in 2008 and is currently a member of the Professional Engineers and Geoscientists of Newfoundland.

Michael Jasny

Senior Policy Analyst, National Resources Defence Council

Technical Presenter

Michael Jasny is a Senior Policy Analyst at NRDC (Natural Resources Defense Council) and Director of its Marine Mammal Protection Project. He is an expert in the law and policy of ocean noise pollution, and has worked domestically and internationally for two decades through litigation, lobbying, science-based policy development, and public advocacy to improve regulation of this emergent problem. Michael is also engaged in securing protection for endangered marine mammal populations and their critical habitat, opposing development projects that threaten marine mammals off North America, and improving management of fisheries and other sectors under the Marine Mammal Protection Act, the leading U.S. instrument for the conservation of these species. Michael is an author or co-author of numerous publications in legal, policy, and scientific journals. He holds a bachelor's degree from Yale College and J.D. from Harvard Law School.

Andrew Kendrick

Vice President, Ottawa, Vard Marine Inc.

Technical Presenter

Andrew Kendrick is Vice President, Ottawa, for Vard Marine Inc. He is a naval architect with extensive experience in ship design, marine research and development, and public policy formulation, including supporting Transport Canada in the development of several IMO Codes. He has a long-standing involvement in noise and vibration issues, having started his career in the UK Ministry of Defence in the surface ship noise reduction group, and more recently with participation in the design team for a number of research vessels for clients worldwide.

Kitack Lim

Secretary-General, International Maritime Organization (IMO)

Invited Speaker

Mr. Lim was born in Masan, Gyeongsangnam-do, in the Republic of Korea. He majored in nautical science at the Korea Maritime and Ocean University (KMOU), Busan, graduating in 1977. He worked on ships as a Korean naval officer and for an international shipping company. He joined the Korea Maritime and Port Administration in 1985, while continuing with further studies at the Graduate School of Administration, Yonsei University, obtaining a Master's Degree in 1990. He then studied maritime administration at the World Maritime University (WMU), graduating with a master's degree. From 1995 he attended a doctoral programme for international law at KMOU, completing course work in 1998.

Mr. Lim began attending IMO meetings as part of the Republic of Korea's delegation in 1986 and he engaged in activities to promote maritime safety through effective implementation of IMO conventions in his country and other IMO Member States in the Asian region. He was elected Chair of IMO's Sub-Committee on Flag State Implementation (FSI - now III) in 2001 and of the Tokyo Memorandum on Port State Control in 2004.

In 2006, Mr. Lim was appointed Director General of the Maritime Safety Bureau of the Ministry of Land, Transport and Maritime Affairs (MLTM) and then as a Senior Maritime Attaché at the Embassy of the Republic of Korea in London and led all IMO work for the Republic of Korea, serving as an Alternate Permanent Representative to IMO up to August 2009. Following that, he was re-appointed Director General for Maritime Safety Bureau (MLTM). In March 2011, Mr. Lim was appointed Commissioner of the Korean Maritime Safety Tribunal (KMST). In July 2012, he assumed the position of President of Busan Port Authority, until January 2016 when he took up his appointment as Secretary-General of IMO.

Charles Massicotte

President, OpDAW Systems/Multi-Electronique

Leader for PM Breakout Group C

Charles Massicotte is president of OpDAQ Systems and Multi-Electronique, two companies specialized in ship performance monitoring, underwater noise measurement equipment and oceanographic buoys.
Holding a bachelor degree in Electrical Engineering, Charles has 15 years of experience in ship performance monitoring. Since 2018, he has been involved in developing ship URN measurement solutions with the combined expertise of the two companies.

Nathan Merchant, PhD

Noise and Bioacoustics, Centre for Environment, Fisheries and Aquaculture Science (CEFAS)

Technical Presenter

Nathan Merchant leads the Noise and Bioacoustics team at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS). He is a principal scientific advisor on underwater noise to the UK Department for Environment, Food & Rural Affairs (DEFRA) and oversees scientific advice on underwater noise to regulatory bodies in England and Wales. He co-chairs the OSPAR Intersessional Correspondence Group on Noise, which provides scientific coordination on underwater noise policy for the North-East Atlantic, and is a member of the European Technical Group on Underwater Noise, which advises on the implementation of Descriptor 11 of the EU Marine Strategy Framework Directive (MSFD). Nathan has delivered a wide range of projects on measurement, modelling, and impact assessment of underwater noise and implications for policy, published in leading journals in the fields of acoustics, ecology, environmental policy and conservation. He holds a PhD in underwater acoustics from the University of Bath, an MSc in Acoustics from the University of Edinburgh, and a BSc (Hons) in Physics and Astronomy from Durham University. Nathan is also the 2018 recipient of the A.B. Wood Medal from the Institute of Acoustics for distinguished contributions to the application of underwater acoustics.

Véronique Nolet

Marine Biologist, Green Marine

Technical Presenter

Véronique Nolet is a marine biologist who graduated from the Université du Québec à Rimouski in Canada. She has worked for a major part of her career for the protection and conservation of marine mammals in the St. Lawrence River. She had a leadership role in producing A Mariner's Guide to Whales in the Northwest Atlantic, as well as having collaborated in creating other similar educational and awareness tools for the shipping industry. Ms. Nolet joined Green Marine in 2014 to work specifically on projects related to assessing and mitigating underwater noise generated by shipping activities and their impacts on marine mammals. She has given several training sessions aboard commercial ships to raise the awareness of mariners regarding the presence of whales. From 2014 to 2017, she led a binational workgroup on underwater noise, gathering various expert representatives (scientists, naval architects, port authorities, ship owners, acousticians and governmental agencies) to develop Green Marine's new performance indicators on underwater noise. Sought out nationally and internationally, she conducted a study on behalf of Transport Canada to provide the Canadian government with a summary report on this issue, was invited to the United Nations as a Canadian advisor on the topic of underwater noise and is seated on a European steering committee lead by the Ocean University Initiative at the European Institute for Marine Studies in Brest and by the Centre in Management Research at the Ecole Polytechnique in Paris. Now working as a program manager for Green Marine, the North American environmental certification program for the shipping industry, she is in charge of everything related to the interactions between ships and whales, underwater noise generated by shipping activities, and waste management.

Greg Peterson

Director of Engineering Services, British Columbia Ferry Service, Inc.

Technical Presenter

Greg Peterson is Director, Engineering Services with BC Ferries where he has served in a variety of capacities for almost 30 years. Greg is an alumni of the Canadian Coast Guard Marine Engineering program and served in the west coast fleet before joining BC Ferries as a 1st Class Chief Engineer in the 1990's. BC Ferries has provided Gra rich experience in maintenance and engineering operations and projects, environmental aspects, technical investigations and research, and regulatory regimes in general. A post-secondary education in public administration his curiosity remains with the interactions between technology, people and society.

Cecile Rafat

Armateurs de France

Leader for PM Group D

Cécile Rafat is an environmental lawyer who worked at the French Ministry of Ecological and Solidarity Transition within the Department of Maritime Affairs (DAM) for 3 years. Involved in environmental issues as a policy officer, she has been in charge of implementing IMO instruments within the domestic legislation. Member of the French delegation to the IMO at MEPC committees and PPR sub-committees, she has a specific expertise on ballast water and air emission issues.

Since January 2019 she has joined the French ship owners association (« Armateurs de France ») to deal with legal, technical and communication aspects in the field of the environment in the shipping sector.

She also works as a consultant for the IMO under the Integrated Technical Cooperation Program (ITCP) to provide assistance for State in implementing IMO conventions within their national legislation.

Michelle Sanders

Director, Clean Water Policy, Transport Canada

Host

Michelle is the Director of Clean Water Policy with Transport Canada, where she is responsible for the development and implementation of policy relating to the interaction of vessels and marine mammals, as well as other marine transportation and environmental issues. She has held various positions within the Canadian government focusing on matters of environmental law and policy, including species at risk, oil spill response, environmental enforcement, and environmental assessments. Prior to joining the public service, she worked with a non-government organization in the US on environmental and energy policy, and in the field of law. Michelle is the founding editor-in-chief and an Advisory Board member of the McGill International Journal of Sustainable Development Law and Policy and holds a Master's in Law in Global Sustainability and Environmental from the University of Ottawa.

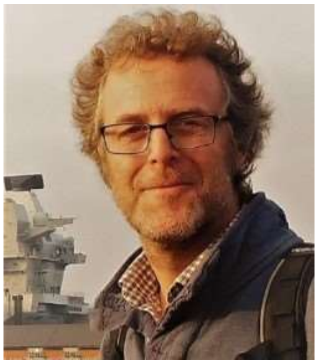
Jesse Spence

President, Noise Control Engineering, LLC (NCE)

Technical Presenter

Mr. Spence is the President Noise Control Engineering, LLC (NCE), a consulting company based in Massachusetts (USA) that specializes in the design of quiet vessels. Mr. Spence holds a bachelor's degree in mechanical engineering from the University of Rochester and a master's degree in Acoustics from Boston University. Since joining NCE in 2001 he has led efforts to develop and implement technologies and techniques that facilitate solutions to complex marine acoustic and vibration problems. He has developed solutions for airborne noise, vibration, and underwater noise on cargo ships, platform supply vessels, offshore patrol vessels, ferries, large and small navy vessels, research vessels, dredgers, drillships, drilling and production platforms, high speed catamarans, tugboats, cruise vessels, and other vessel types.

Mr. Spence has led efforts to develop and enhance NCE's Designer-NOISE® shipboard acoustic prediction software and NCE's finite element analysis capabilities. He also led efforts to develop NCE's Buoy Acoustic Measurement System (BAMS) for accurate measurements of underwater noise from vessels.



Trevor Walton

Aircraft Carrier Alliance, Noise & Vibration Manager

Leader of AM Breakout Group 4

After studying Noise and Vibration at both Salford and Heriot-Watt Universities, Trevor started his career in N&V at the Admiralty Research Agency on Portland, developing Finite Element and Statistical Energy Analysis modeling technologies to predict structural response and URN. Following the first Gulf War, Trevor was recruited as the Senior UK Representative within the NATO Alliance on issues of Land Systems Acoustic Stealth & Survivability. Within this role Trevor lead a campaign of field measurement to capture acoustic source data and far field measurements to facilitate validation of long range acoustic propagation prediction methods.

Trevor joined Westland Helicopters in 1998, where he held the N&V Specialist Airworthiness Flight Approval Signature, responsible for ensuring safety of flight on all WHL platforms. During his many flight test activities on Vancouver Island and around Halifax, Trevor also became known as the The Hammer Guy through his dynamic testing exploits using hammer excitation. He managed an ISO accredited environmental test house and held responsibility for implementation of vibro-acoustic simulation capabilities to support the development of noise control solutions for VVIP helicopters.

In 2016 Trevor returned to his roots, taking a specialist acoustic signatures role within Thales UK. He is currently the acting noise and vibration manager within the Aircraft Carrier Alliance, delivering N&V advice and trials support to the numerous organisations responsible for the design and implementation of noise control solutions to meet complex certification requirements for the QE Class Aircraft Carrier programme. He now provides advice to the Royal Navy on all aspects of URN and continues to enjoy combining simulation and test to provide practical solutions for sea platform designers and operators around the world.

Speaker Bio

Lindy Weilgart

Adjunct Professor, Department of Biology, Dalhousie University

Leader for AM Breakout Group 1

Lindy Weilgart has been specializing in underwater noise pollution and its effects on cetaceans since 1994. She has studied whales since 1982, primarily sperm whales, and her M.Sc. (Memorial Univ. of Newfoundland), Ph.D. (Dalhousie), and post-doctoral studies (Cornell) were all in the field of whale acoustic communication in the wild. Lindy has served as invited expert on several panels, workshops, and committees concerned with underwater noise impacts (e.g. Department of Fisheries and Oceans Canada, U.S. Marine Mammal Commission, International Whaling Commission, etc.). She has met with members of NATO, the European Parliament, the European Commission DG Fisheries, the Convention on Biodiversity, and the United Nations to discuss ocean noise issues, given many lectures on this topic and others, and published numerous peer-reviewed papers. She is currently an Adjunct in the Department of Biology, Dalhousie University, Canada, and was previously employed as Scientific Advisor by the private Okeanos Foundation. She co-organized five Okeanos-sponsored scientific workshops on noise: 1) Alternative Technologies to Seismic Airgun Surveys for Oil and Gas Exploration and their Potential for Reducing Impacts on Marine Mammals; 2) Assessing the Cumulative Impacts of Underwater Noise with Other Anthropogenic Stressors on Marine Mammals; 3) Noise from Shipping Operations and Marine Life: Technical, Operational and Economic Aspects of Noise Reduction; 4) Noise-Related Stress in Marine Mammals; and 5) Spatio-Temporal Management of Noise. She also serves as Scientific Advisor for the International Ocean Noise Coalition, Ocean Policy Consultant for OceanCare, a Swiss NGO, and was a Scientific Expert on the German government's Antarctic Commission. She is currently a member of the Technical Group on Noise for the European Union's Marine Strategy Framework Directive.

Fraser Winsor

Naval Architect, National Research Council Canada (NRC)

Leader for PM Breakout Group B

Fraser Winsor is an Engineer & Naval Architect with over 34 years experience in the physical model testing of ships, offshore structures, and renewable energy concepts. Fraser has extensive training in project and program management. He has worked in private industry and public sector, with 29 years at NRC's Ocean, Coastal & River Engineering (OCRE) Research Centre, located in St. John's, Newfoundland. Most recently he was Program Leader NRC's Marine Vehicles program which focused on efficiency improvements and emissions reductions for ships, and risk reductions for ship operators Fraser is a graduate of Memorial University of Newfoundland, with Bachelor and Master of Engineering Degrees. He is a Professional Engineer and a member of the Society of Naval Architects and Marine Engineers. Fraser is currently serving as an interim board member for the Canadian Network for Innovative Shipbuilding, Marine Research and Training (CISMaRT).

Dietrich Wittekind, Dr-Ing.

Managing Director, DW-ShipConsult GmbH

Technical Presenter

Dietrich Wittekind is a naval architect since 1981. He worked in submarine design on two German shipyards, 10 years as a design manager. Among others, he was responsible for acoustics of the German U 212A submarine and successors. Before he founded DW-ShipConsult in 2004 he was managing director of The Hamburg Ship Model Basin (HSVA). DW-ShipConsult is a leading consultant and service provider in ship acoustics and underwater acoustics. Besides naval ships the core business of the company are mega yachts, research vessels such as the Deep Sea Research Vessel Sonne and cruiseliners with regard to noise onboard, in the sea and in harbor. A major occupation is measurement and prediction of the noise level in the sea and of individual ships. Mr. Wittekind is lecturer for ship acoustics at the Hamburg University of Technology, is member of the German Society of Maritime Technology (STG) and chairs the German MoD Advisory Committee for Noise Reduction of Ships of the Armed Forces.

Hiroyuki Yamada

Director of Marine Environment, IMO

Invited Speaker

Mr. Hiroyuki Yamada majored in Naval Architecture at Tokyo University, and worked for the Ministry of Transport of Japan, including a post at the Japanese Embassy in London, before joining IMO. After joining IMO in 2005, he engaged in various technical issues, as well as operational and human element issues, at Maritime Safety Division (MSD), including environment-related matters. In October 2018, Mr. Yamada was appointed Director of the Marine Environment Division (MED) of IMO. As MED Director, Mr. Yamada has to deal with a lot of environmental challenges, e.g. reduction of GHG emission, 2020 sulphur limit, underwater noise problem, to name but a few.

APPENDIX B

Workshop Attendee List

Quieting Ships to Protect the Marine Environment
London, January 30 to February 1, 2019

FIRST NAME	LAST NAME	ORGANIZATION/COMPANY
Kai	Abrahamsen	DNV GL
Benoit	Adam	DG Shipping - Federal public service mobility and transport
Maryanne	Adams	Republic of the Marshall Islands
Michael	Ainslie	JASCO
Lars	Åkesson	Swedish Agency for Marine and Water Management
Jørgen	Andersen	Femern A/S
Per	Andersen	Lloyds Register
Mathias	Andersson	FOI - Swedish Defence Research Agency
Christian	Audoly	Naval Group
Jonas	Backstrom	Rolls-Royce AB Sweden
Michael	Bahtiarian	Acentech
Keith	Bainbridge	CS LNG Ltd
Eric	Baudin	BUREAU VERITAS
Andrew	Birchenough	International Maritime Organization
Sarah	Bobbe	Clean Shipping Coalition
Simon	Bonnett	Republic of the Marshall Islands
Johan	Bosschers	MARIN
Elizabeth	Bouchard	Republic of the Marshall Islands
Francois-Regis	BOULVERT	NAVAL GROUP
David	Bruce	Republic of the Marshall Islands
Nicolaos	Charalambous	EMSA
Jim	Covill	Lloyd's Register
Christ	de Jong	TNO
René	Dekeling	Ministry of Defence NL
Damien	Demoor	Naval Group
Sander	den Heijer	Netherlands Maritime Technology
Anne-France	Didier	Ministere Francais de la transition ecologique et solidaire-Direction des affaires maritimes-délégation à la mer et au littoral
Andreas	Dinkelmeyer	IFAW - International Fund for Animal Welfare
Tarquin	Dorrington	UK Department for Environment Food and Rural Affairs
Ian	Eames	University College London
Yousef	El Bagoury	The CSL Group Inc
Mario	Felli	CNR-INM
Sarah	Ferriss	International Whaling Commission
Margaret	Fitzgerald	International Marine Contractors Association
Patrick	Fortier-Denis	Innovation Maritime
Abigail	Fyfe	Transport Canada
Tomaso	Gaggero	University of Genova, Italy
Sara	German	Transport Canada
Mohammad	Ghasemi	DNV GL
Jens	Gørtz	MAN Energy Solutions
Bodo	Gospodnetic	Dominis Engineering Ltd.
Ulf	Göttsche	Hamburg University of Technology (TUHH) - Fluid Dynamics and Ship Theory (M-8)
Danielle	Grabiel	Environmental Investigation Agency
Gillian	Grant	High Commission of Canada
Göran	Grunditz	Rolls-Royce AB
Paul	Gunton	ShipInsight
Fredrik	Haag	International Maritime Organization
Ethan	Hall	UK Department for Transport
Jan	Hallander	SSPA Sweden AB
David	Hannay	JASCO Applied Sciences
Todd	Hass	Puget Sound Partnership
Nobuhiro	HASUIKE	Nakashima Propeller Co., Ltd
Dick	Hazelwood	R&V Hazelwood Associates LLP
David	Hedgeland	BP
Wolfgang	Hintzsche	German Shipowners' Association
Masaya	Hirano	Daihatsu Diesel
Anton	Homm	WTD 71
Ryota	Horiuchi	Daihatsu Diesel (Europe) Limited
Daniel	Hubbell	Environmental Investigation Agency
Mohammed (Shameem)	Islam	National Research Council

Bjarne Holm	Jakobsen	Femern A/S
Jukka-Pekka	Jalkanen	Finnish Meteorological Institute
Philippe	JANVIER	Représentation permanente française à l'OMI
Michael	Jasny	NRDC
Capt Paul	Jeffrey	Oldendorff Carriers
Pierre	Jenniss	First Nation Maleseet of Viger
Jeppe Skovbakke	Juhl	BIMCO
andrew	kendrick	vard marine inc
Gerrard	Kenny	Liberian Registry
Niels	Kinneging	Rijkswaterstaat
Lutz	Kleinsorge	Mecklenburger Metallguss GmbH
Bongchan	KO	Korean Register
Sadaharu	Koga	Japan Ship Technology Research Association
Kourosh	Koushan	SINTEF Ocean
Wojciech	Kozyro	Polski Rejestr Statków
Natalia	Kutaeva	Marine Rescue Service
Ian	Lancaster	Maritime New Zealand
Sophie	LAPEZE	Armateurs de France
Amélie	Laprade	Transport Canada - Innovation Centre
Trevor	Larking	Mitsubishi Corporation (Gas4Sea)
Jean-François	LE BERT	Naval Group
Nick	Lurkin	Royal Association of Netherlands' Shipowners (KVNR)
Benedicte	Madon	UBO
Anita	Mäkinen	Finnish Transport and Communications Agency
Charles	Massicotte	Multi-Electronique
Tafsir	Matin	World Maritime University
Nathan	Merchant	Cefas
Farrah	Mohd Fadil	Singapore High Commission
Lorenzo	Moro	Memorial University of Newfoundland
Andreas	Müller	Müller-BBM GmbH
Veronique	Nolet	Green Marine
Anne	Norderud	Maersk Line
Federica	Pace	JASCO Applied Sciences (Deutschland) GmbH
Carlo	Pestelli	Wartsila
GREGORY	PETERSON	BC FERRY SERIVES INC
Wei	Qiu	Memorial University
Cécile	Rafat	Armateurs de France
Andres Galvan	Ramirez	Embassy of Spain in London
Nils	Reichstein	Fr. Lürssen Werft GmbH&Co.KG
Bjørn	Reppe	Norwegian Maritime Authority
Enrico	Rizzuto	University of Genoa
Stephen	Robinson	National Physical Laboratory
Duncan	Ross	Heidmar UK Limited
Panos	Roussos	Herbert Engineering Corp.
Michelle	Sanders	Transport Canada
Nicholas	Schneider	Teekay
Clive	Schofield	World Maritime University
Kana	Selverajah	Malaysia
Sonia	Simard	Shipping Federation of Canada
Tuomas	Sipilä	VTT Technical Research Centre of Finland
Sarah	Smith	International Whaling Commission
Samuel	Soo	High Commission of the Republic of Singapore
Jesse	Spence	Noise Control Engineering, LLC
Shiara	Stevens	Panama
Gwilym	Stone	UK Maritime and Coastguard Agency
Mariano	Suchy	Técnicas y Servicios de Ingeniería S.L.
Sten	Sundberg	Finnish Transport and Communications Agency
Peter	Swift	Royal Institution of Naval Architects
Joonas	Syrjälä	Finnish Transport and Communications Agency Traficom
Cato C.	Tjabbes	CaTO Marine Ecosystems
Koji	Tomioka	Japan Marine United Europe Limited
Grit	Tuengler	Federal Ministry of Transport and digital Infrastructure, Germany
Seyedvahid	Vakili	WMU
Hester	van der Sprong	Dutch Ministry of Infrastructure and Water Management
Tomi	Veikonheimo	ABB Maine & Ports
Trevor	Walton	THALES UK
Lian	Wang	National Physical Laboratory

Lindy	Weilgart	OceanCare & Dalhousie University
Mateusz	Weryk	Ship Design and Research Centre
Lindsey	Wilbur	Thyssen Bornemisza Arts Contemporary
David	Williams	Fednav Ltd
Matthew	Williams	International Chamber of Shipping
Fraser	Winsor	National Research Council
Dietrich	Wittekind	DW-ShipConsult
AListair	Worsley	Christie & Grey
Hiroyuki	Yamada	International Maritime Organization
Qing	Yu	ABS
Anna	Ziou	UK Chamber of Shipping
Pepijn	zoet	PZdynamics Ltd

APPENDIX C

IMO Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts toMarine Life

ACENTECH

INTERNATIONAL MARITIME ORGANIZATION

E

4 ALBERT EMBANKMENT
LONDON SE1 7SR
Telephone: +44 (0)20 7735 7611 Fax: +44 (0)20 7587 3210

MEPC.1/Circ.833
7 April 2014

GUIDELINES FOR THE REDUCTION OF UNDERWATER NOISE FROM COMMERCIAL SHIPPING TO ADDRESS ADVERSE IMPACTS ON MARINE LIFE

1 The Marine Environment Protection Committee, at its sixty-sixth session (31 March to 4 April 2014), with a view to providing guidance on the reduction of underwater noise from commercial shipping, and following a recommendation made by the Sub-Committee on Ship Design and Equipment, at its fifty-seventh session, approved the annexed *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life.*

2 Member Governments are invited to use the annexed Guidelines from 7 April 2014 and to bring them to the attention of all parties concerned.

***

ANNEX

GUIDELINES FOR THE REDUCTION OF UNDERWATER NOISE FROM COMMERCIAL SHIPPING TO ADDRESS ADVERSE IMPACTS ON MARINE LIFE

1 Preamble

1.1 Concern has been raised that a significant portion of the underwater noise generated by human activity may be related to commercial shipping. The international community recognizes that underwater-radiated noise from commercial ships may have both short and long-term negative consequences on marine life, especially marine mammals.

1.2 It is important to recognize that both the technical and cost-effectiveness of measures considered, either individually or in combination, will be strongly dependent on the design, operational parameters, and mandatory requirements relevant for a particular ship. A successful strategy to reduce radiated noise should consider interactions and contributions from measures provided to achieve other objectives such as reduction of onboard noise and improvements in energy efficiency.

1.3 When efforts have been made to mitigate underwater noise, as far as reasonable and practical, evaluation should be undertaken to determine the success or otherwise of ship noise reduction efforts and to guide and enhance future activities at noise reduction. Such evaluation can include forms of radiated-noise measurements, simulations or other ways of data gathering.

2 Application

2.1 These Guidelines can be applied to any commercial ship.

2.2 These Guidelines do not address the introduction of noise from naval and war ships and the deliberate introduction of noise for other purposes such as sonar or seismic activities.

3 Purpose

3.1 These non-mandatory Guidelines are intended to provide general advice about reduction of underwater noise to designers, shipbuilders and ship operators. They are not intended to form the basis of a mandatory document.

3.2 Given the complexities associated with ship design and construction, the Guidelines focus on primary sources of underwater noise. These are associated with propellers, hull form, onboard machinery, and operational aspects. Much, if not most, of the underwater noise is caused by propeller cavitation, but onboard machinery and operational modification issues are also relevant. The optimal underwater noise mitigation strategy for any ship should at least consider all relevant noise sources.

3.3 These Guidelines consider common technologies and measures that may be relevant for most sectors of the commercial shipping industry. Designers, shipbuilders, and ship operators are encouraged to also consider technologies and operational measures not included in these Guidelines, which may be more appropriate for specific applications.

4 Definitions

4.1 *Cavitation inception speed* is the lowest ship speed at which cavitation occurs.

4.2 *Propeller cavitation* is the formation and implosion of water vapour cavities caused by the decrease and increase in pressure as water moves across a propeller blade. Cavitation causes broadband noise and discrete peaks at harmonics of the blade passage frequency in the underwater noise spectrum. The broadband noise is caused by growth and collapse of a vast amount of individual cavitation bubbles in water. The discrete noise peaks are caused by the volume fluctuations of the sheet and tip vortex cavities.

4.3 *Underwater noise,* or the *underwater-radiated noise level,* for the purposes of these Guidelines refers to noise from commercial ships*.

5 Predicting underwater noise levels

5.1 Underwater noise computational models may be useful for both new and existing ships in understanding what reductions might be achievable for certain changes in design or operational behaviour. Such models may be used to analyse the noise sources on the ship, the noise transmission paths through the ship and estimate the total predicted noise levels. This analysis can help shipowners, shipbuilders and designers, to identify noise control measures that could be considered for the specific application, taking into account expected operational conditions. Such measures may include amongst others: vibration isolation mounts (i.e. resilient mounts) for machinery and other equipment, dynamic balancing, structural damping, acoustical absorption and insulation, hull appendages and propeller design for noise reduction.

5.2 Types of computational models that may assist in reducing underwater noise include:

.1 Computational Fluid Dynamics (CFD) can be used to predict and visualize flow characteristics around the hull and appendages, generating the wake field in which the propeller operates;

.2 Propeller analysis methods such as lifting surface methods or CFD can be used for predicting cavitation;

.3 Statistical Energy Analysis (SEA) can be used to estimate high-frequency transmitted noise and vibration levels from machinery; and

.4 Finite Element Analysis (FEA) and Boundary Element Method (BEM) may contribute to estimate low-frequency noise and vibration levels from the structure of the ship excited by the fluctuating pressure of propeller and machinery excitation.

5.3 The value of a modelling exercise is enhanced if its predictive capabilities are assessed in case studies under various operational conditions.

* Underwater-radiated noise level is reported in sound pressure levels in decibels and expressed as 10 times the logarithm of the square of the ratio of the rms sound pressure to a reference pressure of 1 micro Pascal. When it is a ship source level, the sound pressure level is adjusted to a level at 1 m from the source.

6 Standards and references

6.1 Underwater noise should be measured to an objective standard for any meaningful improvements.

.1 The International Organization for Standardization (ISO) has developed the (ISO/PAS) 17208-1 – Acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: General requirements for measurements in deep water. This measurement standard is for deep water which implies that the water depth should be larger than 150 m or 1.5 times overall ship length (engineering method), whichever is greater. This is a temporary publicly available standard. This standard is based on the American National Standards Institute and the Acoustical Society of America (ANSI/ASA) S12.64-2009 "Quantities and Procedures for Description and Measurement of Underwater Sound from Ships, Part 1: General Requirements".

.2 ISO is also developing ISO/DIS 16554 – Ship and marine technology – Measurement and reporting of underwater sound radiated from merchant ships – deep-water measurement, which is expected to be published in 2013. The standard would provide shipyards, shipowners and ship surveyors with a well-established measurement method for underwater sound radiated from merchant ships for use at the final delivery stage of ships.

6.2 Several research ships have been designed using the noise specification proposed by the International Council for the Exploration of the Sea (ICES) Cooperative Research Report No.209 (CRR 209). It should be noted that the ICES CRR 209 noise specification was designed for fishery research ships so that marine life would not be startled during biomass surveys; it was not intended to be used as a commercial ship design standard to prevent potential harm of marine life. However, certain design arrangements used to meet ICES CRR 209 may still be useful for new commercial ships to reduce underwater noise.

6.3 Other underwater noise rating criteria are available and may prove useful as guidance.

7 Design considerations

7.1 The largest opportunities for reduction of underwater noise will be during the initial design of the ship. For existing ships, it is unlikely to be practical to meet the underwater noise performance achievable by new designs. The following design issues are therefore primarily intended for consideration for new ships. However, consideration can also be given to existing ships if reasonable and practicable. While flow noise around the hull has a negligible influence on radiated noise, the hull form has influence on the inflow of water to the propeller. For effective reduction of underwater noise, hull and propeller design should be adapted to each other. These design issues should be considered holistically as part of the overall consideration of ship safety and energy efficiency.

7.2 *Propellers*

7.2.1 Propellers should be designed and selected in order to reduce cavitation. Cavitation will be the dominant radiated noise source and may increase underwater noise significantly. Cavitation can be reduced under normal operating conditions through good design, such as optimizing propeller load, ensuring as uniform water flow as possible into propellers (which can be influenced by hull design), and careful selection of the propeller characteristics such as: diameter, blade number, pitch, skew and sections.

7.2.2

7.2.3 Ships with a controllable pitch propeller could have some variability on shaft speed to reduce operation at pitch settings too far away from the optimum design pitch which may lead to unfavourable cavitation behaviour (some designs may be able to operate down to a shaft speed of two thirds of full).

7.2.4 The ship and its propeller could be model tested in a cavitation test facility such as a cavitation tunnel for optimizing the propeller design with respect to cavitation induced pressure pulses and radiated noise.

7.2.5 If predicted peak fluctuating pressure at the hull above the propeller in design draft is below 3 kPa (1st harmonic of blade rate) and 2 kPa (2nd harmonic) for ships with a block coefficient below 0.65 and 5 kPa (1st harmonic) and 3 kPa (2nd harmonic) for ships with a block coefficient above 0.65, this could indicate a potentially lower noise propeller. Comparable values are likely to be 1 kPa higher in ballast condition.

7.2.6 Noise-reducing propeller design options are available for many applications and should be considered. However, it is acknowledged that the optimal propeller with regard to underwater noise reduction cannot always be employed due to technical or geometrical constraints (e.g. ice-strengthening of the propeller). It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency.

7.3 *Hull design*

7.3.1 Uneven or non-homogeneous wake fields are known to increase cavitation. Therefore, the ship hull form with its appendages should be designed such that the wake field is as homogeneous as possible. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull.

7.3.2 Consideration can be given to the investigation of structural optimization to reduce the excitation response and the transmission of structure-borne noise to the hull.

8 Onboard machinery

8.1 Consideration should be given to the selection of onboard machinery along with appropriate vibration control measures, proper location of equipment in the hull, and optimization of foundation structures that may contribute to reducing underwater radiated and onboard noise affecting passengers and crew.

8.2 Designers, shipowners and shipbuilders should request that manufacturers supply information on the airborne sound levels and vibration produced by their machinery to allow analysis by methods described in section 5.2 and recommend methods of installation that may help reduce underwater noise.

8.3 Diesel-electric propulsion has been identified as an effective propulsion-train configuration option for reducing underwater noise. In some cases, the adoption ofa diesel-electric system should be considered as it may facilitate effective vibration isolation ofthe diesel generators which is not usually possible with large direct drive configurations. The use of high-quality electric motors may also help to reduce vibration being induced into the hull.

8.4 The most common means of propulsion on board ships is the diesel engine. The large two-stroke engines used for most ships' main propulsion are not suitable for consideration of resilient mounting. However, for suitable four-stroke engines, flexible couplings and resilient mountings should be considered, and where appropriate, may significantly reduce underwater noise levels. Four-stroke engines are often used in combination with a gear box and controllable pitch propeller. For effective noise reduction, consideration should be given to mounting engines on resilient mounts, possibly with some form of elastic coupling between the engine and the gear box. Vibration isolators are more readily used for mounting of diesel generators to foundations.

8.5 Consideration should be given for the appropriate use of vibration isolation mounts as well as improved dynamic balancing for reciprocating machinery such as refrigeration plants, air compressors, and pumps. Vibration isolation of other items and equipment such as hydraulics, electrical pumps, piping, large fans, vent and AC ducting may be beneficial for some applications, particularly as a mitigating measure where more direct techniques are not appropriate for the specific application under consideration.

9 Additional technologies for existing ships

In addition to their use for new ships, the following technologies are known to contribute to noise reduction for existing ships:

.1 design and installation of new state-of-the-art propellers;

.2 installation of wake conditioning devices; and

.3 installation of air injection to propeller (e.g. in ballast condition).

10 Operational and maintenance considerations

10.1 Although the main components of underwater noise are generated from the ship design (i.e. hull form, propeller, the interaction of the hull and propeller, and machinery configuration), operational modifications and maintenance measures should be considered as ways of reducing noise for both new and existing ships. These include, among others:

10.2 ***Propeller cleaning***

Propeller polishing done properly removes marine fouling and vastly reduces surface roughness, helping to reduce propeller cavitation.

10.3 ***Underwater hull surface***

Maintaining a smooth underwater hull surface and smooth paintwork may also improve a ship's energy efficiency by reducing the ship's resistance and propeller load. Hence, it will help to reduce underwater noise emanating from the ship. Effective hull coatings that reduce drag on the hull, and reduce turbulence, can facilitate the reduction of underwater noise as well as improving fuel efficiency.

10.4 ***Selection of ship speed***

10.4.1 In general, for ships equipped with fixed pitch propellers, reducing ship speed can be a very effective operational measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed.

10.4.2 For ships equipped with controllable pitch propellers, there may be no reduction in noise with reduced speed. Therefore, consideration should be given to optimum combinations of shaft speed and propeller pitch.

10.4.3 However, there may be other, overriding reasons for a particular speed to be maintained, such as safety, operation and energy efficiency. Consideration should be given in general to any critical speeds of an individual ship with respect to cavitation and resulting increases in radiated noise.

10.5 *Rerouteing and operational decisions to reduce adverse impacts on marine life*

Speed reductions or routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life.

APPENDIX D

AM Breakout Group Questionnaires

ACENTECH

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT - International Maritime Organization (IMO) Headquarters, London, UK;
January 30 to February 1, 2019

BREAKOUT GROUP ORGANIZATION
Revision 9 (final), dated 01/24/2019

AM GROUP ID	**#1**
GROUP TOPIC:	**URN Limits to protect marine life**
GROUP LEADER:	Lindy Weilgart
GROUP MEMBERS:	See Separate List
NOTE TAKER	To be determined on site
MEETING ROOM:	CR 9 (252)

As your group discusses the points below, please consider the Vard URN Technology Report and Matrix, and reference items from that report as possible.

DISCUSSION POINT #1: What else would need to be done to provide a universal upper threshold of a vessel URN that would be generally tolerable for marine life? Would any/all of the class notation limits for URN (DVGL, BV, or ABS) offer reasonable protection for marine life?

DISCUSSION POINT #2: Back in 2008, the Okeanos Foundation recommended a 3 dB reduction per year. Is this reduction reasonable? If not, suggest decibel reductions that you believe are doable and meaningful. Are there any particularly sensitive areas or species that require special protections?

DISCUSSION POINT #3: If there are no specific limits that can be offered, what are the reasons for this?

Please list up to three relevant implementation challenges and associated future research topics that the Workshop should discuss as a group:

1. ______________________________
2. ______________________________
3. ______________________________

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT - International Maritime Organization (IMO) Headquarters, London, UK;
January 30 to February 1, 2019

BREAKOUT GROUP ORGANIZATION
Revision 9 (final), dated 01/24/2019

AM GROUP ID	**#2**
GROUP TOPIC:	**Propeller & Hull Design**
GROUP LEADER:	Johan Bosschers
GROUP MEMBERS:	See Separate List
NOTE TAKER	To be determined on site
MEETING ROOM:	CR 6-8 (32)

As your group discusses the points below, please consider the Vard URN Technology Report, and Matrix and reference items from that report as possible.

DISCUSSION POINT #1: Is Cavitation Inception Speed (CIS) a parameter that large commercial vessel operators are willing and interested to be aware of for their vessel(s)? If so, what is the degree of certainty (or uncertainty) in determining this parameter for a large commercial vessel during the design stage and then when the vessel is operational?

DISCUSSION POINT #2: How significant of a change to typical ship design is required for a good hull form that supports a more quiet ship and propeller designs?

DISCUSSION POINT #3: Can propellers of existing commercial ships be improved with respect to efficiency as well as noise?

DISCUSSION POINT #4: Do quiet commercial propellers exist and can commercial shipping afford them?

Please list up to three relevant knowledge gaps and/or implementation challenges and associated future research topics that the Workshop should discuss as a group:

1. ____________________
2. ____________________
3. ____________________

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT - International Maritime Organization (IMO) Headquarters, London, UK;
January 30 to February 1, 2019

BREAKOUT GROUP ORGANIZATION
Revision 9 (final), dated 01/24/2019

AM GROUP ID	**#3**
GROUP TOPIC:	**Machinery Noise Control**
GROUP LEADER:	Kai Abrahamsen
GROUP MEMBERS:	See Separate List
NOTE TAKER	To be determined on site
MEETING ROOM:	CR 11 (36)

As your group discusses the points below, please consider the Vard URN Technology Report, and Matrix and reference items from that report as possible.

DISCUSSION POINT #1: What are the latest noise mitigation technologies for machinery inside the hull?

DISCUSSION POINT #2: For an existing vessel, what is the limit of treatment inside the hull?

DISCUSSION POINT #3: What is needed for accurate URN modeling of machinery noise sources?

Please list up to three relevant knowledge gaps and/or implementation challenges and associated future research topics that the Workshop should discuss as a group:

1. ______________________________
2. ______________________________
3. ______________________________

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT - International Maritime Organization (IMO) Headquarters, London, UK;
January 30 to February 1, 2019

BREAKOUT GROUP ORGANIZATION
Revision 9 (final), dated 01/24/2019

AM GROUP ID	**#4**
GROUP TOPIC:	**URN Predictive Tools & Modeling**
GROUP LEADER:	Trevor Walton
GROUP MEMBERS:	See Separate List
NOTE TAKER:	To be determined on site
MEETING ROOM:	CR 12 (28)

As your group discusses the points below, please consider the Vard URN Technology Report, and Matrix and reference items from that report as possible.

DISCUSSION POINT #1: Do we have enough resources, software tools, and data to perform ship and propeller noise predictions accurately?

DISCUSSION POINT #2: What are the best commercial software packages for propeller noise and ship noise predictions?

DISCUSSION POINT #3: Do owners and shipbuilders have budget and resources to use predictive tools and/or hire experts to perform the computations.

DISCUSSION POINT #4: What would be required to move the vessel URN predictions (such that it could be compared with a design criteria such as a class notation, for example) from the realm of the specialist to a broader use in the industry during the ship design process? What are the pros and cons?

Please list up to three relevant knowledge gaps and/or implementation challenges and associated future research topics that the Workshop should discuss as a group:

1. ______________________________

2. ______________________________

3. ______________________________

QUIETING SHIPS TO PROTECT THE MARINE ENVIRONMENT - International Maritime Organization (IMO) Headquarters, London, UK;
January 30 to February 1, 2019

BREAKOUT GROUP ORGANIZATION
Revision 9 (final), dated 01/24/2019

AM GROUP ID	**#5**
GROUP TOPIC:	**URN Metrics & Measurements**
GROUP LEADER:	Michael Ainslie
GROUP MEMBERS:	See Separate List
NOTE TAKER:	To be determined on site
MEETING ROOM:	CR 13 (36)

As your group discusses the points below, please consider the Vard URN Technology Report and Matrix, and reference items from that report as possible.

DISCUSSION POINT #1: What are the proper metric(s) for reporting underwater ship noise?

DISCUSSION POINT #2: Have proper URN measurement methods been developed (i.e. ANSI, ISO, class societies) and what are limitations to those methods.

DISCUSSION POINT #3: What is best way to simplify measurement and reporting, but still get accurate information? Do we need something special from standards organizations such as ISO?

DISCUSSION POINT #4: Are there beneficial sound propagation properties that can be taken advantage of such that reductions to receivers can take place without reduction in the sources?

Please list up to three relevant knowledge gaps and/or implementation challenges and associated future research topics that the Workshop should discuss as a group:

1. ____________________
2. ____________________
3. ____________________