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NOISE FROM COMMERCIAL SHIPPING AND ITS ADVERSE IMPACTS ON MARINE LIFE

Report of the Correspondence Group

Submitted by the United States

SUMMARY	
Executive summary:	This document is the report of the Correspondence Group on the issue of "Noise from commercial shipping and its adverse impact on marine life". The Correspondence Group was established to identify and address ways to minimize the incidental introduction of noise from commercial shipping operations into the marine environment to reduce potential adverse impacts on marine life. This is the second report from the Correspondence Group.
Strategic direction:	1, 7 and 13
High-level action:	1.1.2
Planned output:	1.1.2.3
Action to be taken:	Paragraph 10
Related documents:	Resolutions A.989(25), A.982(24), A.900(21), A.720(17) and A.468(XII); MSC/Circ.1014; MSC 84/INF.4; MSC 83/28; MEPC 59/19; MEPC 59/19/1; MEPC 58/19; MEPC 57/INF.4 and MEPC 57/INF.22

Introduction

1 MEPC 58 approved the inclusion of a new high priority item in the work programme of the Committee on "Noise from commercial shipping and its adverse impact on marine life". The Correspondence Group continued its work on this issue between MEPC 59 and MEPC 60. Two rounds of comments were exchanged. While the work is ongoing, this document summarizes the interactions and progress on this issue thus far.

2 The following Member States, observer organizations and entities were on the e-mail list for this Correspondence Group, although not all actively participated in the discussions:

Argentina	Italy	Republic of Korea
Australia	Japan	Singapore
Bahamas	Liberia	Sweden
Canada	Marshall Islands	United Kingdom
China	Netherlands	United States
Germany	Panama	
CLIA	IFAW	IWC
UNEP/CMS	IMAREST	WWF
FOEI	INTERTANKO	
ICOMIA	ISO	
ICS	IUCN	

Substantive issues

3 The Correspondence Group discussed a number of technological issues which are set out in annexes 1 and 2. There are questions and proposals posed in both annexes and input on these issues is welcome in order to progress this work.

4 Several participants suggested that simplicity may be the best approach and that the Correspondence Group should concentrate its efforts on the major element of cavitation. It was suggested that the other aspects of incidental underwater noise generated from shipping should be noted but at this stage simply retained for future reference.

5 A few participants raised the issue of the regulatory framework. In doing so, it was noted that there are other entities that are working on regional legislation for various types of noise. With regard to this issue, it must be emphasized that the Correspondence Group's terms of reference are confined to the work on *non-mandatory* technical guidelines for ship-quieting technologies as well as potential navigation and operational practices. Therefore, the Correspondence Group was not instructed to develop a regulatory framework for this issue.

6 The Correspondence Group noted that two groups have been working on the development of standards for underwater noise. Information on these efforts is appended as annex 3.

7 In an effort to support and guide research efforts on this issue, Correspondence Group Members were asked to identify the research needed in this area as well as identify the facilities where research on the issue of underwater noise from commercial shipping is being done or could be done. It was suggested that such research should be done simultaneously with the work of the Correspondence Group. The responses are provided in annex 4.

Outreach efforts

8 In an attempt to obtain additional input from those entities that may have useful information on this issue, the Correspondence Group approached additional stakeholders. The Group first approached national shipowners. Feedback included the important points that while some larger shipping companies have an impact on how a ship is designed and built, most buy ships that have already been built or on which construction has already begun. Therefore, shipowners would in many instances not have an impact on noise reduction measures since the vessel design stage has already been completed. It was suggested that perhaps shipyards may have more input on ship design.

9 The Group also approached model basins for their input. Model basins generally carry out hydrodynamic tests in tanks to test ship models for the purpose of designing a new, full-sized ship or refining the design of a ship to improve the ship's performance at sea. Annex 5 is a listing of the model basins that were approached, the letter that was sent, and a summary of the responses received.

Action requested of the Committee

10 The Committee is invited to take note of the report of the Correspondence Group, provide input to the questions and proposals set out in the annexes, and take any other action it deems appropriate.

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ANNEX 1

TECHNOLOGICAL ISSUES[1]

One participant stated that before we try to identify possible countermeasures, we need to assess the potential contribution for each of the ship components to the radiated sound power. Otherwise the discussion would become too complex and unspecific.

What are your thoughts on this? Is this possible to do? Should it be done before we try to identify possible ways forward on individual ship components?

The information set forth below in this annex pose the same series of questions for the following three areas: (1) the propeller, (2) the machinery, and (3) the hull. For each of these areas, the following overarching questions have been posed: A) identified issues, B) type of noise produced, C) how do we fix the identified issues, and D) other information pertaining to the designs listed in C(1).

I Propeller

A. <u>Identified Issues</u>

1. Cavitation. The initial and primary focus of the Correspondence Group's efforts is expected to be on issues related to propeller cavitation since it is known to be a significant (and often dominant) source of low frequency underwater noise from large vessels:

   a. Initial design of the propeller
   b. Damage causing a change of its hydrodynamic shape
   c. Marine growth
   d. When speed of a ship is not adjusted by the rate of propeller rotation, but by adjusting propeller pitch and keeping shaft speed constant – this may lead to cavitation at speeds other than those for which the ship was specifically designed
   e. Shallow propulsion immersion--ships in ballast produce more cavitation noise than when fully loaded

2. Blade rate tonal sounds: non-uniform distribution of low frequency, as whether noise reduction needs to focus on specific bandwidths/spectral components, and how to ensure that in doing so acoustic energy is not re-distributed to other low or high frequency output.

B. <u>Type of noise produced</u>

1. Cavitation is broadband but generally and predominantly low frequency; frequencies <100 Hz at high propeller loads, continuous spectrum; this spectrum has a broad "hump" at low frequencies (about 50 Hz) followed by a continuum that decreases by 6 db per octave; at high speeds the continuum can contribute a significant fraction of radiated noise power.

2. Blade rate tonal sounds are narrow-band and also generally low frequency.

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[1] As noted previously, the Correspondence Group is focusing first on technologies and then will take up the issues pertaining to the animal/receptor part of the equation.

3. Depending on the pitch settings and loading of a propeller, a controllable reversible propeller (CRP) propeller may generate higher frequency noise.

4. Propeller depth is important in terms of long-range noise propagation.

C. <u>How do we fix the identified issues—are there any things that have been done to other types of ships that can be used on commercial ships?</u>
(One participant stated that propeller design is critical to efficiency as well as minimizing the sound generated)

1. Design:
   a. main dimensions of the hull and the hull/propeller interaction are optimized to improve the wake field around the propeller and reduce hull resistance;
   b. twin screw propulsion have smaller propeller loadings and a more homogenous wake field therefore better working condition for the propellers compared to single-screw propellers;
   c. wing thrusters;
   d. surface piercing, non-cavitating, and advanced blade section propellers; (one participant stated that non-cavitating propellers probably do not exist. It is more realistic to speak of minimizing cavitation.);
   e. electric and Voith-Schneider propellers;
   f. contra-rotating propellers (one participant stated that these provide overall improvement in performance but do not necessarily reduce noise), propellers with tip (winglet), and ducted propellers;
   g. designs with tips without added weight, large diameters; low RPMs, long blade lengths; bulbs on the tips, and/or refined trailing edges;
   h. propeller pods to place the blades deeper in the water column; single screw systems with open (high) screw propulsion to allow for a smoother (less turbulent) wake field; (One participant stated that draft increases may be an issue. Pods are good for maneuverability and they are quieter on board, but their development has not necessarily been driven by reducing radiated noise.);
   i. forward-skewed nozzle-propeller blades to allow for increased cavitation inception speeds and reduced cavitation on the leading edge of the blade; (One participant agreed with this statement in general.);
   j. podded propulsion systems (e.g., azipods or azimuth electric propulsion drive) systems to allow for an improved wake field, greater hydrodynamic efficiency, and ultimately less cavitation and noise, although motor (mechanical) noise generated from azipods is an important consideration in their overall effectiveness, as is their potential application on very large vessels;
   k. water-jet propulsion;
   l. pod propulsion systems which allows long propeller shafts to be avoided and can provide minimum disturbed flow to the propeller;
   m. Praire-System which involves blowing air into the flow around the propeller through tiny holes in the blades. *See also* the attached tables from *Southall and Scholik-Schlomer 2008;* and (One participant stated that these are likely to be too complicated for commercial ships. They have been developed and applied to warships which have particular design constraints.);

n. propellers constructed of composite material – reduce vibrations, pitch adaptive (i.e., as the propeller turns it shapes itself to the optimum angle of attack with regard to the velocity of wake field inflow).

2. Damage to the propeller is usually repaired during drydocking.

3. Marine growth does not usually occur given the high usage of ships, but barnacles can cause premature and more severe cavitation if it goes unnoticed.

D. Other information pertaining to the designs listed in paragraph C(1)

1. How much sound reduction can be obtained by using the above designs?

One participant made the following observations: Optimization hull/propeller design is the primary means of improving the wake field around the propeller and improving the propulsive efficiency (C1(i)). The propelling options and propeller designs listed in C1(ii) through C1(xii) are all viable options of increasing the propulsive efficiency and reducing cavitation of the propeller. It is difficult to predict the amount of reduction in cavitation achievable by using a particular option or a combination of options without further studies. Propellers and propulsion systems vary according to the type of vessels, however, optimization of hull/propeller interaction may be done on all types of ships, which will reduce propeller cavitation and the radiated noise, except it may be for deeper submerged propulsion systems, such as the podded propellers, and water jet propulsion.

2. Are the designs listed in C(1) being used on commercial ships?

a. If so, on what types of ships?
One participant noted that different types of commercial vessels have different types of propulsion systems: the fixed pitch, cavitating, single screw, low RPM propellers are mainly used for bulk and OBO carriers and tankers. Water jet propulsion (which is especially popular for high speed ferries and it is growing in popularity) is used mainly in specialized smaller size vessels, and podded propellers are mainly used in ferry/passenger/large slower ships – there are specific benefits and limitations for each type of propulsion systems.

b. If not, why not?
No responses were received to this question.

c. Is their frequency of use likely to increase in the near future as a result of other realized commercial ship design pressures (e.g., fuel efficiency, carbon emissions)?
One participant stated that it is anticipated that with the new vessel design index and air emission requirements being finalized by IMO, vessel owners, designers and builders will place greater emphasis on hull/propeller interactions. It is anticipated that advanced propeller designs and propulsion systems will also be used.

3. Is there anything in each of the designs that we should consider relating to their field of application, their operational envelop, their technical status, and potential future or present relevance?

One participant stated the following:

One of the main noise sources is definitely the cavitating propeller. Therefore we need more insight into the complex physical behavior of cavitation and its related consequences like noise and pressure fluctuations, also those reflected by the ship's hull.

For years the fixed pitch propeller will be the main propulsion unit for commercial ships, the second in line will be the controllable pitch propeller. Therefore our efforts must be put on these units.

The important task is to find which type of cavitation (sheet, bubbles, clouds, vortices) contributes to the measured noise level. Knowing this we can start talking about possible countermeasures.

If we look into the available information (mostly from navy ship investigations), one can assume that for good propeller designs an improvement of about 10 dB on the noise output can be expected. This can also be achieved when improving the setting conditions for controllable pitch propellers. But keep in mind that this normally goes hand in hand with a reduction of efficiency. This needs special attention when talking to owners. On the other hand we should remember that many of the available noise data for different ships are years old and therefore are related to much worse propeller design compared to what we have today. In other words, the improvements we can expect may be much higher.

Another participant suggested that we limit our focus in this area to minimize propeller cavitation to fixed pitch propellers and controllable pitch propellers and to twin vs. single screw arrangements.

Another participant stated the following:

It is to be expected that most of the ships in the foreseeable future (> 90%) will be propelled by conventional screw-propellers of more or less sophisticated design driven by an engine inside the ship connected to the propeller via a shaft. The reason for this arrangement is its high efficiency and mechanical simplicity. I recommend not to look into too much detail in other systems like pods, Voith-Schneider-Propellers and other systems which will always have a limited range of application and none for high powered ships.

The potential in the screw-propeller when designing it for low underwater radiated noise is not known because it has not been a criterion in the past. However, from experience with noise levels from merchant ships and from naval ship propellers, it may be in the order of 10 dB for a good design and much more than that for an originally bad design. This may be true for a fixed pitch propeller.

For a controllable pitch propeller things are more complex. Ships with this propulsion system can be categorized in ships with constant shaft speed adjusting speed only with pitch setting and ships which adjust speed by a combination of shaft speed and pitch setting. This combination is usually fixed for maximum fuel efficiency. Changing the combination for minimum noise output results in possibly 10 dB less noise but unacceptable working conditions for the engine.

Note that the question for the propeller is not only cavitation but more importantly which type of cavitation as they may have very different noise characteristics.

Any application of principles to reduce radiated noise will require research, which can easily be identified and described. It is to be expected that the effect on fuel efficiency will not be positive.

Another participant, in responding to the above point that reduced cavitation and noise would likely produce an adverse effect on fuel efficiency, stated that this view is markedly different from what they have heard.

Yet another participant stated the following:

Towing tank tests to determine skin friction and hull/propeller interactions with different types of propellers and hull forms, and validating the results with full scale designs should be done. Making the results available to the design community will help future design efforts.

Since the vessel design parameters and the operating conditions are rarely the same, the optimization of hull/propeller interaction and selection of the propulsion system should also be performed based on the vessel operating conditions.

II Machinery

A. Identified issues

1. Operating machinery because of vibrations that radiate via the hull; becomes significant for ships operating at low speeds (i.e., with low prop loadings as in harbor approach).

2. Reduction gears of medium speed engines.

3. Medium speed diesel generators.

B. Type of noise produced

1. Operating machinery is at frequencies <100 Hz at lower ship speeds.

2. Reduction gears of medium speed engines may generate noise at higher frequencies >1kHz.

3. Medium speed diesel generators sometimes contribute considerably to radiated noise >50Hz when not masked by cavitation noise.

4. Machinery-induced noise may remain constant at lower ship speeds (e.g., diesel generator noise is not dependent on ship operating speeds).

C. How do we fix the identified issues—are there things that have been done to other types of ships that can be used on commercial ships?

1. Equipment and propulsion systems may be fine-tuned to achieve more appropriate harmonics.

One participant stated that a) varying degrees of benefit may be obtained with the application of technologies as listed. Slow and medium speed diesel engines are balanced for even load generation between the cylinders and the resultant harmonics; b) they are generally used; and c) their use is expected to increase.

2. Resilient mountings for medium speed engines and auxiliary machinery; double stage mounting system may reduce noise transfer from diesel generators to ship structures to a substantial degree; resilient mounting for piping (i.e., ducts of exhaust gas system in all ship types); active mounting systems.

One participant stated that:
a) Resilient mountings are rarely used in the commercial large ocean going vessels; however, large diameter exhaust/stem pipes are generally resiliently mounted; and
b) cost/benefit.

Another participant noted that 2-stage mounts (rubber mounting, then hard platform, then another rubber mounting) are even better – 20 dB or more reduction could be achieved if well designed. Single stage at a minimum recommended. Resilient mountings shouldn't cost significantly more, mounting of some kind is needed so it might as well be rubber.

3. Variable speed pumps, optimum electric load control (reducing the number of auxiliary engines operating for power generation at a given time).

One participant stated that:
a) Not widely used;
b) cost/benefit; and
c) use expected to increase.

4. Acoustic filters, desurgers, and flow control valves may minimize sound from fluids to and from equipment.

One participant stated that:
a) Not generally used; and
b) cost/benefit.

5. Propulsion: electric drive propulsion; hybrid power generation using fuel cells and/or a combination of solar, wind, and shore power; pod propulsion so that there are smaller power plants which can be mounted in a more shock absorbing manner and be placed in a part of the ship less likely to conduct sound; diesel-electric.

One participant stated that:
a) electric drive propulsion systems are mainly used in commercial vessels where reduced vibration is needed, such as passenger vessels and hybrid power generation is not used except for a few demonstration projects; and
b) electric drive propulsion has a lower propulsion efficiency and hybrid power is still considered experimental.

6. Airborne noise insulation—cladding of a quiet ship's interior.

One participant agreed that this could be of use.

Another participant stated that other than the cruise vessels, machinery rooms of a commercial vessel are not cladded to reduce air borne noise.

7. Damping treatment to structures; adding buffering layers under or within the hull.

One participant stated that these are not used in commercial vessels. Another participant stated that these would be secondary to mounting.

8. Active mounting systems.

One participant stated that these are not used in commercial vessels.

Another participant stated that this is still at concept and military prototype stage. It is still a long way to go before commercial application.

9. Engine synchronization.

One participant stated that only the auxiliary engines/shaft alternators are synchronized for parallel power generation. Multiple main engines for master/slave operation are sometimes synchronized.

10. Identify/consider benefits in terms of reduced maintenance of propulsion systems from quieting technology treatments.

One participant stated that well-balanced and optimal used of machinery is expected to generate less vibration that will reduce wear, tear and fatigue of the machinery/systems and reduce maintenance - Performance based maintenance is designed to do just that. Also, reduced propeller cavitation will require less propeller maintenance.

11. Selection of low-noise equipment in the first place.

12. Isolate large slow speed diesels and gear-boxes.

D. Other information pertaining to the designs listed in paragraph C(1)

1. How much sound reduction can be obtained by using the above?

One participant stated that overall there maybe 15-20 dB reduction in noise from machinery fixes.

Another participant stated that the amount of radiated noise reduction that can be achieved needs to be researched. (a) Resilient mountings for main engines of large commercial vessels may not be feasible due to the weight of the engines. These mountings for auxiliary diesel engines and machinery are feasible and will reduce hull transmitted noise, but the cost of such application may have to be justified. (b) Variable speed pumps and optimum electric load control are expected to reduce vibration, optimize operation of auxiliary engines and can be applied on all types of vessels, given the cost/benefit analysis. (c) Unless the propulsion efficiency of electric drives is improved, these systems may only be used on board cruise/passenger vessels. Hybrid power generation may come of age for application on board the nearshore vessels.

2. Are they being used on commercial ships?
   a. If so, on what types of ships?
      No responses were received to this question.
   b. If not, why not?
      No responses were received to this question.
   c. Is their frequency of use likely to increase in the near future as a result of other realized commercial ship design pressures (e.g., fuel efficiency, carbon emissions)?
      No responses were received to this question.

3. Is there anything that we should consider relating to their field of application, their operational envelop, their technical status, and potential future or present relevance?

One participant noted:
Medium speed engines as one of the dominating noise generators are resiliently mounted in modern ships reflecting the need for crew comfort. Observing the efficiency of these mountings there is a large range of improvement in the order of 10-15 dB reduction with little effort. A comparison is possible of cargo ship diesel generator installations and those on mega-yachts and cruise liners. There is no other pressure to improve noise form machinery except crew comfort.

Another participant noted that there is no real impediment to resilient mountings, there will be cost only.

III. **<u>Hull:</u>**

A. <u>Identified issues</u>

1. Flow noise around the hull is generally minimal but increases significantly at low frequencies as the vessel speed increases.

   a. Flow around underwater appendages (what these are needs more discussion; however,

One participant stated that they are stabilizers, extra keel structures, sea chests, orifices in the hull. Each of these will generate noise at a range of frequencies related to vessel speed.

Another participant stated that they vary by vessel type, some of the important ones are: i) Skeg shape/trailing edge; ii) Bow thruster scallops/grids, minimizing resistance of hull openings; iii) Rudder profile and propeller; iv) “A” frame).

2. Hull configuration and wake field.

B. Type of noise produced

1. Appendage noise are of low intensity at frequencies below <20 Hz.

C. How do we fix the identified issue

1. Hull design.

One participant stated that new hull designs of commercial ships are usually optimized and towing tank tested which may include break bulk carriers, tankers, OBOs, container vessels, Ro-Ros, etc; cost is usually the primary reason and there may not be enough incentive for the designer/builder to optimize the design; usage is likely to increase in the near future due to IMO regulations on the vessel design index to reduce GHG emissions.

2. Underwater appendages could be streamlined and rudder (rudder bulb) and skeg designs optimized to improve flow of water and to reduce drag and noise.

One participant stated that the hull, appendages and the bulbous bow are designed according to vessel type and other factors; cost is usually the primary reason and there may not be enough incentive for the designer/builder to optimize the design; usage likely to increase.

3. Reduce turbulence-elliptical bow shape; no abrupt change of shape in the waterline; minimization and alignment of appendages and fittings; flush welds, undistorted plates, and smooth paint works; optimize hull dimensions.

One participant stated that there are many factors that are considered for the design of the bow and bulbous bow. Undistorted plates are more a concern of vessel construction and faired and smooth hull plates will certainly reduce the skin friction. Smooth hull coating will mainly depend on the condition of the hull plates; usage is likely to increase.

Another participant stated that the information they had suggested that such coatings on both the hull and propellers are becoming more common as a way of optimizing performance by maintaining a good finish.

4. Hull cleaning/silicon based coating to reduce hull resistance and propeller loading

One participant stated that for all ships, hull cleaning of non-silicon based coating is performed periodically. Hulls with silicon based coating are still not very common; In-water hull cleaning of hulls with non-silicon based coating is performed periodically, depending on the time, cost, regulations and the amount of fouling. During scheduled drydocking, the same functions are routinely carried out. The jury is still out on the silicon based coating; usage is likely to increase.

D. Other information pertaining to the designs listed in paragraph C(1)

1. How much sound reduction can be obtained by hull design?

No responses were received to this question.

2. Is this being done on commercial ships?

   a. If so, on what types of ships?
   No responses were received to this question.

   b. If not, why not?
   No responses were received to this question.

   c. Is their frequency of use likely to increase in the near future as a result of other realized commercial ship design pressures (e.g., fuel efficiency, carbon emissions).

   No responses were received to this question.

3. Is there anything that we should consider relating to their field of application, their operational envelop, their technical status, and potential future or present relevance?

One participant stated that there is a good relationship between hull drag and hydrodynamic noise. Probably at this stage there is no much to be gained (compared to propeller and machinery approaches) as hulls are already fairly well optimized. Intersects with commercial imperative are necessary for efficiency.

Another participant noted that the only effect of hull design influencing noise is the effect on resistance (limited) and on the wake field to the propeller (potentially high). This is always in the focus of designers because it is very much linked to fuel efficiency.

Another participant noted that the range of noise impact of all the above can only be fully understood and thus sensibly mitigated when taking into account the context of the environmental conditions in which the vessel is operating such as:

- existing ambient noise levels at the frequency of interest; and
- sound propagation conditions such as:
    1. layer depth;
    2. CZ potential;
    3. sea state; and
    4. water depth, bathymetry, and sea bed type (One participant noted that this could lead to the development of a world map of noise propagation something that many navies already have).

COMMENTS ON TABLES BELOW

One participant stated that all the measures in tables for the three contributing components—the propeller, the machinery, and the hull—are smartly consolidated. They suggested that the Correspondence Group limit its focus to the following items:

- minimize propeller cavitation for fixed pitch propellers and controllable pitch propellers;
- twin vs. single screw arrangement;
- hull shape configuration, wake field;
- maintenance: propeller geometry and fouling, hull fouling; and
- speed reductions.

They also stated with regard to MEPC 59/19/1 (FOEI, IFAW) paper: Almost none of the measures to minimise cavitation have been implemented to decrease the radiated noise, but to avoid erosion or to improve propulsion efficiency.

Another participant basically agreed with the above views about the main topics to focus on with an emphasis on operations.

On the design side:

- minimize propeller cavitation;
- twin v. single screw arrangement; and
- hull shape configuration, wake field.

On the operation side

- speed reductions; and
- routeing.

NEW DESIGN OPTIONS FOR VESSEL-QUIETING

One participant asked whether this table is based on single platform gains and what happened in areas of high shipping activity? Additionally, it was suggested that another column be added to note the reduction in impact in relation to the species, that is the environmental benefit.	**Advantages/Benefits**	**Disadvantages/ Challenges**	**ROUGH Cost Estimates (Low, Med, High)**	**Anticipated GENERAL Magnitude of Quieting (Low, Med, High)**
Minimize Propeller Cavitation (propeller shape, configuration, size, etc.)	Reduction of tip vortex; reduction of pressure pulses; forward-skewed ducted props expected to increase cavitation inception speeds, hence lower cavitation noise levels (duct can serve for site of injecting air and also a *de facto* prop guard); "ring" propeller can eliminate tip vortex	Variable results in terms of quieting, operational efficiency	**Variable (potentially low)**	**High**
Minimize Propeller Cavitation (variable pitch propellers)	Good in terms of radiated noise at nominal pitch; can identify minimum noise output	Poor in terms of operational efficiency; Potentially misused for speed control	**High**	**Variable (potentially high)**
Twin vs. Single Screw Propulsion Systems	Enables the use of large diameter propellers that turn more slowly; System redundancy is safety benefit	Only have half the thrust per system; major difference in design of entire ship	**High**	**Variable (potentially high)**
Podded Propulsion (Azipods)	Potentially great improvement of wake field; reduced cavitation; reduced vibration	Not sufficiently powerful yet; high electrical noise; efficiency can be poor	**High**	**Moderate (especially for low-frequencies, but some high frequency tonal spikes)**

Hull Shape/Configuration	Improvement of wake field (may also improve efficiency)	Some difference in design of entire ship; Requires model testing	**Medium (highly uncertain)**	**High (especially for low frequency)**
Air Injection Systems (ducted air emission)	Air injection around the prop (bubble shield in front of and around the propeller) could be advantageous in terms of noise (requires slightly more power); inject air around propeller tips may work but has to be investigated	Navy-type approach is too expensive and difficult to maintain; May be some increase in radiated noise	**Medium**	**Uncertain**
Passive Equipment Mounts (Vibration Isolators)	Reduces Structure-borne path noise	Increasingly less effective for frequencies below 200 Hz for large diesel engines due to large mass; requires dynamically stiff foundations (impossible for very large engines)	**Mounts cheap but overall application can be very high**	**Medium to High (depending on frequency)**
Dynamic (Active) Equipment Mounts	Show significant promise; work well in other applications	Not widely available yet (still somewhat experimental)	**High**	**Potentially High**
Pump Isolations, Acoustic Filters, Pipe Hangers	Pretty simple generally	Takes some engineering effort; may not be relevant for consideration because of masking from propulsion noise on most large ships (very small point – way down the list)	**Medium**	**Low to Moderate**

Acoustic Insulation	Reduces AB & SB Transmission; for engine room only	More directed to minimizing airborne versus underwater noise; This likely further down the list than propulsion systems	**Low [$1-$4/sq. ft]**	**Low to Moderate**
External and Internal Coatings (Dampening Products)	Relatively simple	Effectiveness depends on material 'compliance' and thickness; some limitations for internal coatings; maintenance can be very difficult on external coatings; Both only work at higher frequencies (200 Hz +); secondary consideration	**Low [$8-$12/sq. ft]**	**Low to Moderate**
Maintenance	Reduce machinery source level; can increase overall efficiency of propulsion and other systems	Cost can be significant if much greater than nominal schedule	**Variable**	**Variable (potentially moderate to high)**

RETROFITTING OPTIONS FOR VESSEL-QUIETING

Treatment	**Advantages/Benefits**	**Disadvantages/ Challenges**	**ROUGH Cost Estimates (Low, Med, High)**	**Anticipated GENERAL Magnitude of Quieting (Low, Med, High)**
Minimize Propeller Cavitation (propeller shape/configuration)	Reduction of tip vortex and pressure pulses; forward-skewed props should increase cavitation inception speeds	Variable results in terms of quieting, operational efficiency	**Variable (potentially high)**	**High**
Minimize Propeller Cavitation (variable pitch propellers)	Good in terms of radiated noise	Poor in terms of operational efficiency	**High to very high**	**Variable (potentially high)**
Passive Equipment Mounts (Vibration Isolators)	Reduces surface-borne path noise	Difficult as a retro-fit; Not effective for frequencies below 200 Hz for very large diesel engines due to large mass; requires dynamically stiff foundations	**High to very high**	**Low to Moderate**
Dynamic (Active) Equipment Mounts	Show significant promise; work well in other applications	Not widely available yet (still somewhat experimental)	**High to very high**	**Variable (potentially high)**
Pump Isolations, Acoustic Filters, Pipe Hangers	Pretty simple generally	Can be difficult as a retro-fit option	**Variable (potentially low)**	**Low to moderate**
Acoustic Insulation	Reduces AB & SB Transmission	More directed to minimizing aerial versus underwater noise	**Generally low [$1-$4/sq. ft]**	**Low to moderate**
External and Internal Coatings (Dampening Products)	Relatively simple	Effectiveness depends on material 'compliance' and thickness	**Generally low [$8-$12/sq. ft]**	**Low to moderate**

OPERATIONAL OPTIONS FOR VESSEL-QUIETING

Treatment	Advantages	Disadvantages	ROUGH Cost Estimates (Low, Med, High)	Anticipated GENERAL Magnitude of Quieting (Low, Med, High)
Speed Reductions	Appears to generally be one of the most promising ways to reduce vessel noise emission; should be some distinction between open-ocean and near-shore; Suggestion for some better routeing/scheduling around busy ports	Economically, politically, logistically very difficult; limited benefit on local scale more application on regional scale	**Variable (Potentially very high)**	**Variable (potentially high)**
Routeing (Area Restrictions)	Avoiding where animals are or operating in environments that do not favor long-range transmission	Economically, politically, logistically very difficult; Spatiotemporal aspects and environmental variability will prove challenging	**Variable (could be locally high)**	**Variable (could be locally high)**

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ANNEX 2

MISCELLANEOUS BUT IMPORTANT ISSUES

50 Hz Predominance

1 In the last Correspondence Group Report, there was a discussion of the 50 Hz predominance. One participant stated that the cause of the 50 Hz noise contribution must be revealed and a solution for the reduction of this level should be found. Another participant stated that it seemed to have been agreed in the Group that it not pursue just the 50 Hz predominance. When I put this issue out for discussion in May 2009, I received the following comments:

.1 This issue is a very important point for the whole of this work…we are 'standing into danger' of 'putting the cart before the horse' … what environmental impacts are we trying to resolve by addressing shipping noise … it is no good putting forward engineering solutions when they may not be addressing an identified impact … or worse that we provide a solution at a single ship level only to find that when groups of ships are present the solution provided does not work … understanding in the nature of the impact to be addressed then sensible solutions that are effective can be offered up.

.2 The 50 Hz hump is only related to cavitation issues. Concerning all the different measures concerning noise reduction, this must be checked case by case and depending on some of the basic answers we are looking for.

Noise signature of propellers tends to consist of:

- very discrete tones attributed to blade rate;
- hulls; and
- true broad band (the latter two are often lumped into "cavitation").

Machinery Medium speed diesel 25 Hz up. Discrete tones.

3. There are two things involved in the 50Hz discussion: The broadband hump around 50Hz should remain in focus as this is one key issue for our goal. The 50Hz/60Hz components caused by the electrical mains should be excluded from the discussion, as a narrowband mechanical structural vibration of this frequency and a magnitude able to generate sufficient underwater noise has not been reported according to our knowledge.

4. It is strongly recommended to include the 50 Hz hump as a primary issue in the Correspondence Groups's work. It is the predominant feature of distant shipping noise, see e.g., Ross, D.G. (1976). Mechanics of Underwater Noise. Pergamon, New York, New York, 370 pp., Hatch et al 2008 or Andrew, R.K., Howe, B.M. & Mercer, J.A. (2002). Ocean ambient sound: comparing the 1960s with the 1990s for a receiver off the California coast. Acoustics Research Letters Online, 3, 65-70. The latter is the initiator of the discussion leading to foundation of this correspondence group.

5. The discussion about the 50 Hz includes a misunderstanding in connection with the 50 Hz mains on board some ships. The 50 Hz hump discussed here is caused by cavitation. One participant disagreed with this statement. If one only treats one source then what is achieved may only be a 3Db reduction, although the hump will the eliminated, what will be left is the platform of noise on which the hump will be super-imposed.

6. While it may be interesting to investigate the cause of the 50 Hz predominance, our focus should be on noise reduction for the 10 to 1000 Hz band.

2 So what is the way forward on this issue? It seems from the comments received lately that this issue only pertains to cavitation. Is a way forward that what we need to do in these guidelines is to give a number of noise control solutions that clients could ask of naval architects and shipbuilders? Please give me your opinion on this issue so that we can be clear about the way forward.

Issues and IMO Committee and Subcommittees

3 Are there issues being worked on by an IMO Committee or sub-committee or regulations or guidelines recently adopted where opportunities may exist for the introduction of the consideration of underwater noise? If so, how could we integrate such consideration? How would we manage a detailed understanding and integration with these other issues and still maintain a consistent and reasonable focus with regard to the overall issue of shipping noise? One participant stated that they felt that at this stage of our work we should not be considering these issues. Please provide your opinion on the questions posed.

4 Here are a few areas that might merit our further consideration. Please provide any thoughts you may have on how we may integrate our work into these issues.

.1 Design & Equipment Subcommittee is working on revising the Guidelines for ships operating in Arctic ice-covered waters.

.2 Is there a way to integrate a consideration of underwater noise? Annex VI was just revised and amendments adopted. Is there a way to integrate a consideration of underwater noise? One participant stated that they do not see a direct influence of the revised Annex VI to any kind of underwater noise.

.3 Greenhouse Gas Emissions – It was said repeatedly during the discussions of this issue at MEPC that there may be an impact on the noise issue. What is that impact?

.4 How can we integrate our work into the discussions?

One participant stated that the impact of the actual outcome of the GHG working group to underwater noise from ships can be seen in the requirement for more economical speed (meaning slow steaming) which might have a major influence on the underwater noise level of ships. This participant felt that this issue is already covered under the technological issues/speed reductions.

Another participant stated that one view that has been expressed in the Correspondence Group is that measures to improve fuel efficiency will be the same measures that offer the greatest promise for noise reduction. We should determine if this view is widely held. If yes, there is a connection of course to the GHG discussion. As a practical matter, it probably takes us back to the recommendations that may be best developed by the naval architecture community.

.5 Amendment of Annex V – Is there anything that might be applicable here? A few participants answered "No".

One participant agreed that Annex VI as it stands today is unlikely to be relevant, but that question is better answered when we see a set of peer-reviewed design recommendations and whether the GHG debate results in any amendments to Annex VI.

.6 DE's work on noise on board ships. One participant stated that if ships become more silent onboard, their underwater noise level might be lower as well; however, it should be considered that the propeller is not the dominant exciter for airborne noise in any case; on large container ships the airborne noise level is nearly independent from propeller effects. Another participant questioned why large container ships were singled out and queried whether it was related to noise associated with loading and unloading operations.

Other Proposals Raised by Participants

5 Please consider these proposals which are by two individual participants and no decisions have been taken on them by the Correspondence Group. What are your opinions on them? How, and should, the Correspondence Group integrate them into our future work? Are these points necessary to consider in the development of the guidelines?

First Proposal:

.1 Under the assumption that propeller noise is taken as the dominant noise source, this participant proposes to develop a simple tool based on an empirical or semi-empirical approach to estimate the sound power emitted by the propeller-wake interaction. This tool shall be used for both, ships in service and new builds, to predict/ reproduce the noise that can be or has been measured on one of the sound ranges.

.2 This participant stated that they would distinguish between following fixed and variable parameters to be considered in the approach:

Fixed:

.1 Design

- ship type
- hull form characteristics → wake characteristic
- definition of dominating load conditions
  - Tanker / Bulker: fully loaded or pure ballast
  - Container Ship: variable draught around a mean draught

.2 Propulsion system:
- Propeller diameter
- Propeller depth, propeller-hull clearance
- single screw/ twin screw
- fixed pitch propellers FPP / controllable pitch propellers CPP
- number of blades, shaft speed rpm
- pitch, skew
- propulsion power

Variable:
.3 Operating condition
- speed through water, reference speed V_{ref} vs refence power P_{ref} loading: draught (at aft perpendicular → propeller immersion), trim, heel, etc(?).

.3 This participant plans to combine available design data from ships under Germanisher Lloyd class with available test data for these ships at HSVA, as in the German mirror Correspondence Group there are competence and experts for ship design and operation, model basin tests, underwater noise and ship acoustics onboard ships.

.4 The participant stated that what we need is reliable UW noise data and any corresponding information from measurements of cargo ships to link those to our set of design parameters, model test results and full scale onboard-measurements, and finally to calibrate our rough empirical model approach. Preferably, these measurements are taken from the same one or two measurements ranges and allow the calculation of the standardised source level at 1m.

.5 To be successful in our simple approach, we have to be sure that one specific ship shows the same underwater-noise measurements values under similar operating conditions.

.6 We consider the studies to link UW-Noise to AIS data as the key to identify:
•the same ship ←→always same noise level?
•are there noisy types?
•are there noisy seasons ?
•or any other correlation ?

.7 The main purpose is to have a simple tool to be able to predict the impact of any technical measure we will discuss to decrease ships noise. Secondly, we gain a better understanding and can proceed in a more targeted way to apply all the big tools like numerical simulations and model basin tests.

Second Proposal:

.8 Since the propeller is assumed as the dominant noise source, this participant proposes the development of radiated sound prediction tools on advanced methodologies for the estimate of propeller noise (including the effects of propeller-wake and propeller-hull interactions). Such tools are able to account for the effect of main parameters of blade design and operation. An example for this is given by the development effort within the upcoming EDA project NAPNOP.

Of course, the high accuracy of results has a counterpart in the large computational burden. However, such tools may also be intended as a reference for the development of simplified procedures (for instance, to be implemented within numerical optimisation procedures), and a support for empirical procedures.

.9 Propeller/hull and propeller/rudder interactions are already addressed as a part of work programme of the EU FP7 project SILENV. Hull shape optimisation is a main subject of study at INSEAN since many years, and interaction with propeller is a challenging topic for those methodologies.

.10 An accurate modelling should guide the development of powerful prediction methods on both sides, sources and receptors. So, attention is to be paid to most work to the opportunity provided by joint work by marine biologists and mathematicians involved in the development of models for marine mammals hearing apparatus.

.11 This participant considers the possibility to link Underwater Noise characteristics to AIS data as a means to build models for the prediction of "noise footprints", similar to the tools for the study of environmental impact of airport areas.

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ANNEX 3

WORK ON STANDARDS

There have been two groups that have been working on the development of standards pertinent to the issue of incidental underwater noise generated by commercial ships. Information on the work of these two groups is set out below.

1 International Standards Organization

ISO/TC8/SC2 Marine Environment Protection
Report of Exploratory Meeting on Underwater Noise Measurement Standard Development
Koichi Yoshida, Chairman of ISO/TC8/SC2

ISO/TC8/SC2 is now developing an ISO standard for measurement of underwater noise generated by merchant ships. The goal of the ISO standard would be to provide the method of determination of power level of the source of underwater sound emitted from ships and specification of measurement method and measuring instrument. ISO/TC8/SC2 met in July 2009 right after MEPC 59 and hold an exploratory meeting on this issue. Following is the report of the group.

The exploratory group met on 22 July 2009, and made discussion as follows:

- There was a general agreement to develop an International standard for measurement of underwater noise emitted from merchant ships;
- Measurement target is to obtain underwater noise source power of ships;
- Measuring equipment may be deployed by buoy or land-base, should be commercially feasible for merchant ship measurement, should be specified in the standard;
- Measurement conditions, e.g., background noise level and sea depth as well as measuring frequency band, should be taken into account;
- The condition of the target ship, e.g., draught, speed, engine operation, should be also taken into account;
- The concept of the standard is illustrated in the figure below;
- The group was informed that an ANSI activity will result in near future publication of **ANSI S 12.64** on almost the same subject. The SC2 chairman will contact with the ANSI group and its chair person;
- After the consultation with ANSI, SC2 chairman will develop the next draft by the end of October and circulate it to the members of the exploratory group, aiming to developing an ISO standard;
- The exploratory group should meet in conjunction with the next SC2 plenary meeting toward starting the new work item; and
- SC2 is invited to inform the progress to IMO MEPC and its correspondence group on underwater noise.

2 The American National Standards Institute (ANSI)

ANSI S12.64

AMERICAN NATIONAL STANDARD
Quantities and Procedures for Description and Measurement of Underwater Sound from Ships -

Part 1: General Requirements

The American National Standards Institute is developing a standard for the measurement of underwater sound associated with vessels. This standard describes the measurement systems, procedures, and methodologies used for the beam aspect measurement of underwater sound pressure levels from ships for a given operating condition. The resulting quantities are reported as nominal source level values. It does not require the use of a specific ocean location, but the requirements for an ocean test site are provided. The underwater sound pressure level measurements are performed in the far-field and then corrected to a reference distance of 1 m. This standard is applicable to any and all surface vessels either manned or unmanned. This standard is not applicable to submerged vessels or to aircraft. Measurement systems are described for measurement of underwater sound pressure levels and also the distance or range between the underwater transducers and subject vessel. Processing and reporting of the data are described and informational guidance is provided. This standard does not specify or provide guidance on underwater noise criteria.

The standard was approved in May 12, 2009 and should be issued by the end of 2009.

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ANNEX 4

RESEARCH NEEDS

There is a need for more research in this area and that any such work should be done simultaneously with the work of our IMO Noise Reduction Team. The below list represents suggestions from Correspondence Group members. Additionally, Correspondence Group participants were asked to identify any facilities where research on the issue of underwater noise from commercial shipping is being done or could be done. Participants were also asked to note whether such facilities would have any associated issues related to national security or access to information.

1 One participant suggested that the relationship of the magnitude of radiated noise due to propeller cavitation and vessel speed should be measured, using appropriate metrics and reporting standards measured. It was felt that this will need to be undertaken on instrumented ranges to ensure comparisons can be made by ships measured in differing parts of the world. The noise ranges must work with the same methodologies. Another participant, in responding to the latest round of comments, noted that there is currently a lot of work being done in this area. They suggested that it would be more useful to direct additional work towards predicting propeller noise at the design stage.

2 Another participant suggested that the relationships between propeller pitch settings, propeller loading, and other propeller design parameters also need to be measured with respect to underwater radiated noise for different vessel categories. One participant felt that the noise range must encompass all possible engineering options such as speed and pitch.

3 Another participant raised the issue of active mounting systems: Today, these can be considered proven and commercially available but not universally used to quiet ships, even for military applications. These might be helpful in certain special applications in commercial ships but some additional research is required, and careful consideration given to the cost/benefit of implementing and maintaining the efficiency of such approaches relative to other possible treatments (esp. those in the propulsion systems). One participant stated that the requirement to use this technology is only limited because of supposed cost and that there is no legal requirement to use it although if this were to change then it was thought that there would be greater use of such technology. Another participant, in response to the last round of questions from the Correspondence Group, stated that they thought active mounting systems were still at the concept/prototype stage in military applications. They suggested that the focus should be on exhaust quieting options for passive mounts first.

4 Another participant raised the measurement and classification of ship noise levels. The second piece of work that is worth considering is to increase the database of ship noise records that contain information about the vessel (speed, size etc.). This would tell us how the noise levels vary with ship size, speed etc. This can be done if two simultaneous data sets are available – the noise recordings and the characteristics of the vessel making that noise. Most historical noise data sets do not include the latter, but the introduction of Automatic Identification System (AIS) could change this. If the AIS data can be recorded at the same time as the noise data, then with some noise propagation modeling to allow for noise attenuation over distance, the noise recordings can be linked to the noise at the vessel for its given speed and size.

- In response to this comment, one participant passed on the reference to *Hatch et al 2008 (and correction to table)* for such a study. A similar study (linking passive acoustic array data to AIS records) is being completed off the coast of Southern California. It was noted that this is a level of resolution on the per-ship basis that was not the focus of the Hatch et al. study but is certainly possible and may provide an option for evaluating some detailed aspects of shipping noise outside of model basin or Naval test facilities. Also it could provide methods for monitoring post guidelines introduction/implementation.
- Another participant stated that understanding and record of the environmental parameters is required to ensure that comparisons of noise classification can be made. Yet another participant suggested that information as to the impact of the environmental noise, such as wave action, water current and other noise than that generated from the vessel, and how these noise sources can be isolated to obtain the noise generated by the vessel. Moreover, we should look at the impact of water temperature, density, etc., on the noise measurement and how the measured data can be normalized.
- Another participant recommended limiting the discussion on measuring standards and field measurements to concentrate on measures for individual ships.
- Another participant also noted that if the ship operator is willing to provide additional data it might be possible to also link it to prop blade loading etc. There are two types of noise recorder deployment configurations that could be used to generate this information: In locations of light shipping, with only one vessel in range at a time, then just a single noise recorder will provide a one-on-one connection between the noise and the vessel.
- One participant noted that the distance between the noise source (ship) and the hydrophone and the acoustic profile of the water column must also be recorded; otherwise, the data may not be meaningful. In response to this comment, one participant stated that this is also possible in areas of moderate-heavy shipping, with a dense enough array of hydrophones or a close enough recording proximity to the vessel of interest (involves filtering background noise to determine single vessel noise profile).
- One participant stated that for locations where there are several ships in range at once, the location of the noise source has to be known in order to link it to the specific ship. This requires an array of noise recorders to be deployed in order to get a fix on the source. It was noted that several such arrays exist in the Indian, South Pacific and South Atlantic oceans (one is off the coast of Western Australia). These were installed as part of the Comprehensive Test Ban Treaty Organization measurement program. These arrays would be well suited to determining vessel-specific ship noise if linked with AIS or similar information. It was noted by another participant that there are commercial organizations such as QinetiQ that run fully instrumented noise ranges on behalf of the military and are allowed to sell spare capacity on the range for commercial purposes. The signal processing and range design are quite important to achieve a successful signature recording.
- One participant noted in response to this point that it can be argued that the much higher density of shipping in the Northern hemisphere, bottom-mounted hydrophone arrays (decommissioned or otherwise) would provide a rich source of data to be pursued. That said, although some of these data have been declassified for biological studies (http://www.dosits.org/gallery/tech/pt/sosus1.htm), much of the information (particularly regarding the spatial relationships among recording nodes, dimensions that are central to accurate localization of sources) remains limited in its general

accessibility. As indicated, this is not likely to be a timely source of data. It is also important to note: the only good forecasting model will have to apply an "average" noise profile to individual ships tracked through AIS and Long Range Identification and Tracking (LRIT) and then predict what the collective contribution of ships over near and distant ranges. Furthermore, there remains a question as to whether noise has to be tied to a specific ship. Perhaps the Correspondence Group should be focus more broadly and work on solutions based on certain basic vessel categories or operating conditions.

- Another participant noted that there are two types of noise monitoring required:

  .1 to establish a ships signature – which is best done on a purpose built range; and

  .2 to enforce any legal requirements for noise reduction which requires a completely different capability and could be done using the limited hydrophones available supplemented with systems being put in place in MPA.

- Another participant stated that these ideas are sound but again raised the question of resolution, one that is now being faced by several standard committees focusing on measurements for underwater noise from ships: how much accuracy is needed to address the management question, how should measurements be conducted to ensure that level of accuracy, and how can we ensure that standardized and thus comparable measurements are made? One response to these questions stated that the accuracy required will be dictated by the severity and range of impacts experienced by the receptor—current impact criteria do not have a sensitivity dimension.
- Another participant, in response to the latest round of questions from the Correspondence Group, stated that measurement should be of individual ships. This can be done on a noise range. Alternatively, measurements of opportunity are possible using sonar buoys or hydrophones and this should be done where background noise is minimal. They stated that noise that one is trying to measure needs to be 10 db above background. Additionally, this participant noted that calibrated measurement systems to environmental parameters of location (e.g., water depth) is needed.
- Another participant agreed that it was very important to correlate measures of generated sound with general information on the ship characteristics and general information concerning the mission, for single ship study, as well as forecast of ship traffic effect.
- Another participant agreed that research should correlate measures of generated sound with general information on the ship characteristics and its mission, for a single ship study, as well as forecast of ship traffic effect.
- Yet another participant stated that it should be made clear that it is necessary to understand the characteristics of an individual ship in a known configuration, measured on the beam aspect, and at a known distance so that representative source levels can be generated by correcting back to 1 m. Seabed hydrophones and other methods can give an understanding of the noise levels in an area, and the statistical variability with the time and season, etc., but not the characteristics of individual ships. The variable distances, differences in propagation loss, the vertical directivity of the ship radiated noise and the unknown ship state prevent the determination of individual ship noise levels.

5 One participant stated that there should be a study of the effects of noise reduction techniques/strategies on different parts of the frequency spectrum in order to be most effective, efficient, and targeted with our quieting approaches. It was felt by this participant that the impact of noise must be known to determine the most important noise sources.

6 It was thought by one participant that if medium speed diesels are treated in an appropriate way, further reduction might be limited by the contribution of the low speed engines (Note: "medium" and "low" speed engines may require further definition as we go forward; however, one participant stated that the definition of low and medium speed engines are as follows: Medium speed engines are 4-stroke-cycle diesel engines either driving a propeller via a reduction gear (300 to 600 rpm) or a generator (600-900 rpm). A low speed engine is a 2-stroke-cycle diesel engine directly driving the propeller (60-150 rpm). In shipbuilding, this difference is quite clear). This participant felt that their underwater noise contribution is not well known because it is masked by propeller and medium speed diesel noise. Structure-borne noise measurements, however, show that they may limit substantial reduction of overall noise. This also requires research. Noise reduction measures are very limited as of the size of these engines (hundreds to thousands of tons). One participant disagreed with this stating that noise reduction measures must be determined by the impact made on the receptors present. There could be a highly sensitive receptor still being impaired by a quiet ship if the environmental circumstances were right.

- One participant agreed with the need to base noise reduction measures on the knowledge of the impact made on receptors. This implies that most of the research work on technological aspects should be strongly linked to research achievement on the biological side to understand reception mechanisms and subsequent effects on receptors. An accurate mathematical modelling may be helpful in the development of a powerful prediction methods on both sides.

7 Another participant felt that investigations into propeller-induced radiated noise of commercial vessels should be extended and supported by further research. One participant thought that this should not be done before an exhaustive literature review is undertaken to understand where the gaps in knowledge are.

8 One participant stated that we need (1) to correlate measured noise data and observed cavitation phenomena; (2) to correlate cavitation phenomena and geometrical design counter measures, therefore detailed numerical and experimental investigations have to be foreseen; (3) detailed full scale measurements and that the frequencies contributing to the noise have to checked carefully; (4) to check if onboard measurements can give us the answers we need; and (5) to combine model tests and numerical calculations. This participant noted that noise measurement can be done at Hamburg Ship Model Basin (Hamburgische Schiffbau-Versuchsanstalt), SSPA Sweden AB, MARIN (Maritime Research Institute Netherlands) and the David Taylor Model Basin.

9 One participant noted that we still have to identify ship types with the most urgent need for noise reduction. Therefore in order to measure and classify ship noise levels, we should be able to cluster ship types, including machinery or loading conditions, to establish the correlation to their acoustic signature. If we do not follow this approach, we will be acting only on assumptions and not on tangible facts. All measurement campaigns on individual ships are often either inconsistent in themselves or not comparable with each other. Another participant felt that in addition to propeller design and other information listed, the following information should be collected: vessel characteristics, draft/trim of the vessel, loading conditions, propeller type: fixed vs. CRP, propeller RPM, and hull & propeller condition.

- This participant also noted that there is still a need for proven data and apportionment for the overall noise emitted by a cargo ship: there is still no clear evidence of how much of the sound power is emitted by which part of the ship or by which phenomenon, and in which frequency range dominates which effect. This participant stated that it is not always the propeller that is responsible for the total noise. As long as there is no clear distinction which amount of noise is radiated via the hull, research is needed to identify the governing mechanism and potential contribution to the total sound power emitted by the ship.

10 Another participant stated that it is of great importance to investigate propeller designs for a better compromise between efficiency and radiated noise, particularly for controllable pitch propellers. Yet another participant stated that for propellers, beside cavitation (which undoubtedly is a major noise source), we should be able to predict cavitation noise as well as the inherent pressure pulses/fluctuation, that may be potentially reflected by the ship's hull and radiated into the water. Here the methods of computational fluid dynamics (CFD) should support the model basin effort:

- Verification: This participant would appreciate the development of specific standards for measuring underwater noise. However, it was noted that it would be hard to imagine measuring every type of ship, including new builds and retrofits, so we should decide how to provide a “silent ship”:

  -by design/calculation

  -by onboard measurements (structureborne sound, pressure fluctuations) during sea trial, or

  -by real hydrophone measurements—this was deemed critical for verification purposes.

- Another participant stated in this round of comments that a verification approach should be prepared that is commonly accepted and meaningful.

11 One participant stated that it is necessary to strictly observe the frequencies of noise contributions. It is recommended to concentrate on long range (for example > 10 nm) effects where the shipping frequency spectrum dominates over primordial levels below 300 Hz.

12 One participant noted the following polar issues should be areas for priority research:

- Research on the Arctic - One of the key issues about ship noise in the Arctic below 1kHz, is that ocean acidification has, in the past five years, greatly increased the transmissivity of the ocean in the upper water column (where the sound channel is in the Arctic) to sound in this range. Coverage of the Arctic, especially around Alaska, is not well-documented. This suggests that in the future, if this is where the change is greatest, this is where ship noise reduction efforts should be focused, particularly because this is also the communication frequency range of the great whales.

- Research on Azipods – This participant felt that there should be further review of azipods to better understand when, how, and whether noise reduction from these takes place. Because in the Arctic the sound channel is in the upper water column, and new icebreakers and ice strengthened commercial vessels are using azipods, more information on this topic is among the most critical research needs that should be identified in this report. It is possible that the newer icebreaking ships, which have azipod engines, have a more linear, less disturbed flow around the props, and are thus both less noisy, and more efficient for propulsion as well. The new icebreaking cargo ships being built have just such propulsion systems.

- Research on ship loading – Some icebreakers can have very different loads, mostly of fuel, depending on time during operation (e.g., in McMurdo Sound area full of fuel at beginning of season, not so much at end). More study on what ships, or what loading levels/variation effects on noise are would be useful.

- Research for prop depth – Icebreaker props are fairly deep: 33.5 feet down already. This is in part to avoid ice. In building a new ship, is it possible to make them deeper and would this result in them being quieter?

- Research for retractable keels – Some of the newer research ships, including icebreakers, have retractable keels. The keels are raised in ice, but lowered in open water to reduce ship roll due to rounded hull design required for optimal icebreaking. Does a retractable keel reduce noise due to ship roll significantly? Is the sound reduction only due to roll reduction effects on water moving around the hull or is it more due to water movement increased laminar flow around the props?

13 One participant asked whether there is a potential for noise reduction by getting away from controllable pitch propellers such as electric (i.e., diesel generators) drives fixed pitch propeller. This participant stated that this is like pods but perhaps they can be put onboard and then isolated. Generally the luxury cruise liner industry does this for minimizing sound onboard, so there is already technology in use on liners and military vessels. Research may be necessary to determine how underwater radiated noise rather than onboard noise can be reduced.

14 The following research facilities were identified as places where research is being done or could be done on the issue of underwater noise from commercial shipping:

- Hamburg Ship Model Basin (Hamburgische Schiffbau-Versuchsanstalt);
- SSPA Sweden AB;
- MARIN (Maritime Research Institute Netherlands);
- David Taylor Model Basin;
- Australian Maritime Hydrodynamics Research Centre http://www.amhrc.edu.au/ - Collaborative research centre of the Defense Science and Technology Organization, the Australian Maritime College and the University of Tasmania. Range of hydrodynamic research supported by infrastructure including cavitation tunnel, towing tank, integrated marine simulator (shiphandling and ship operations), flume tank, model test basin and high performance computer network;
- Vipac - http://www.vipac.com.au/marine.html - Commercial consultants providing design analysis and sea trial services in the areas of vibration and acoustics and underwater radiated noise;
- University of New South Wales (Mechanical Engineering, Vibration and Acoustics Research Group) – Work on selected aspects of radiated noise;

- QinetiQ – Maritime signature support from initial design and model testing through to acoustic ranging of all in service platforms deployed worldwide and at fixed ranges in the UK. Includes full signature decomposition and analysis and presentation to the customer in an easy to understand informative format;
- British Aerospace;
- BBN (US);
- Lloyds Register ODS – luxury liner noise work;
- INSEAN, the Italian Ship Model Basin; and
- See also annex 5.

15 One participant reiterated their comments stating that we need to go further on the following items:

- Measurement and classification of ship noise levels, link to AIS and ship design/operation data;
- Clarifying the governing phenomena; and
- Preparing a verification approach that is commonly accepted and meaningful.

16 Another participant identified the following main topics where significant research should occur:

- to correlate measures of generated sound with general information on the ship characteristics and its mission, for single ship study, as well as forecast of ship traffic effect;
- Noise reduction measures should be based on the knowledge of the impact made on receptors. This implies that most of the research work on technological aspects should be strongly linked to research achievement on the biological side to understand reception mechanisms and subsequent effects on receptors; and
- Prepare a verification approach that is commonly accepted and meaningful.

17 Another participant stated that they felt that this document on research needs contains useful information on ship noise measurements but some of the apparent differences of opinion relate to different assumptions about the trade offs between absolute accuracy, relative precision and number of ships measured. At one end of the scale, dedicated noise measurement ranges can make very accurate absolute measurements but only of a limited number of vessels. At the other extreme, bottom mounted hydrophones together with AIS have the potential to collect measurements from a large number of vessels but with much lower accuracy.

- This participant continued, saying that for some purposes a set of relative measurements of a number of vessels may be adequate, recognizing that these may not be directly comparable with measurements from other areas. As more data become available from the different types of measurement systems there will be a need for an assessment of the most appropriate methodology to address specific questions taking into account achievable sample sizes, accuracy and precision. These assessments will be assisted by experiments involving simultaneous measurements using different systems.

18 Finally one participant indicated that particular emphasis should be shown for research and studies focused on demonstrating the efficiencies and operational cost savings that are achievable through the use propellers designed to reduce radiated noise.

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ANNEX 5

MODEL BASINS

Model Basins				
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UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

October 6, 2009

Dear Sir or Madam:

The United Nations' International Maritime Organization (IMO), under its Marine Environment Protection Committee (MEPC), has recently formed a correspondence group (CG) to address the issue of incidental underwater noise from commercial shipping and its potential impacts on marine life. This has been identified as an issue of high priority within MEPC. This international CG comprised of scientists, engineers, industry representatives, managers, and conservation groups, is tasked with *identifying* and *addressing* means of reducing the incidental introduction of noise from commercial shipping operations into the marine environment. Our goal is to develop practical, effective guidance on viable technical solutions to reduce the levels of underwater noise produced by transiting commercial ships. As you can see from our attached report from April (2009), we have considered this issue in considerable detail and have benefited from the input of subject-matter experts. From these deliberations, it is obvious that this is a large and complex issue, but one in which there seems to be some promise of success in certain areas. We have concluded that the most appropriate initial efforts should focus on means to reduce propeller cavitation for various classes of commercial vessels, with particular emphasis on low-frequency (less than 300 Hertz [Hz]) underwater radiated noise.

To proceed with the goals of the CG, we are now seeking the expertise of those directly involved with ship design and development. We are aware that some aspects of ship performance are optimized prior to building by undergoing thorough evaluations at model basins. While we further understand that propeller performance and hull design play key roles in model basin work, we are unclear as to whether radiated noise resulting from different design configurations are explicitly measured during optimization trials. This letter seeks clarification as to whether your facility collects data in connection with noise and vibration prediction associated with model trials, and, if so, how these data are used to optimize ship designs. In particular, we are interested in any empirical information that you could provide that would assist the CG in quantifying potential reductions in cavitation and thus low-frequency acoustic emissions (<300 Hz) resulting from optimizing propeller, hull, or other ship features. Is it possible to extend your prediction abilities to the frequency range <1000 Hz with your current equipment? Further, will any of these reductions be expected to result in any increase in fuel efficiency or reduction in greenhouse gas emissions or have other technical or economical advantages and disadvantages?

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

If your facility has identified design features that are likely to or known to reduce incidental noise production in final builds, it would be greatly appreciated if you would be willing to share this knowledge with us to report back to the CG. We fully understand that the proprietary nature of some data would need to be taken into consideration. Our first goal, in opening this dialog, is to better understand how extensively underwater incidental noise production is currently being evaluated when designing new builds for different commercial ship types, and whether model basins could provide suggestions for ways to evaluate the acoustic consequences of designing ships with better fuel economy and/or higher emission standards.

Thank you in advance for your time, consideration, and feedback.

Sincerely,

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Attachment:
MEPC 59/19 Report of the Correspondence Group

SUMMARY of MODEL BASIN responses to IMO Correspondence Group on Vessel Quieting request for information

Overview/Chronology

Members of the United States contingent of the IMO Correspondence Group on Vessel Quieting developed a written request for information to model basins and other research and technological facilities regarding technical information on vessel quieting technologies. Specifically, this letter asked for information regarding quantification of low-frequency noise reduction from optimizing propeller, hull or other designs, as well as any information related to increased efficiency or reduced emissions. This letter, sent and co-signed by Drs. Leila Hatch and Amy Scholik-Schlomer (from the U.S. National Oceanic and Atmospheric Administration), was sent on 6 October 2009 to 90 scientists or R&D facilities in 26 nations.

As of 24 November 2009, a total of six responses have been received in response to this request for information, four of which include substantive technical information. Generally, these responses were supportive and consistent with the report of the Correspondence Group from MEPC 59 (MEPC 59/19) which was attached to the transmission letter. The below table summarizes these responses, which are provided in their entirety in the subsequent section. Some of the most important points raised in the four substantive responses include the following:

- Structural vibration induced by propeller movement (causing stern plates to resonate as a function of limited clearance from prop blades) and other on-board machinery is an important consideration in engineering efforts to reduce radiated noise.
- The difficulty was noted for many test facilities to accurately assess low frequency radiated noise, where it is considered and assessed, because of high ambient noise (within the testing enclosures) at low frequencies; this masks accurate measurements.
- Design features for cavitation noise reduction are numerous and can be subdivided into (1) hull line design; (2) appendage design; (3) propeller design; and (4) retro-fits.
- Researchers in the Netherlands have observed a 50 Hz maximum in hull pressure fluctuations resulting from propeller-induced vortices; this may be related to the "hump" seen in the radiated noise spectrum at this frequency.
- Optimal design of propellers from a quieting perspective is slow moving, large-diameter, non-cavitating propeller with many blades (with reduced propeller loading, though this decreases efficiency) in a uniform flow; obviously there are practical and engineering limits to this.
- Optimum propeller design is usually a trade-off between efficiency and cavitation performance; high efficiency and thus low fuel consumption has usually the highest priority among commercial ship-owners.
- Optimizing hull design can both increase the hull efficiency and achieve a smoother wake field (inflow) which gives the propeller better acoustic performance, although load carrying capacity, port and fairway restrictions can be limiting.

TABLE OF RESPONSES AND SIMPLE SUMMARY OF CONTENT

Responder (Organization)	Date Received	SIMPLE SUMMARY
Robert Beck (Naval Architecture and Marine Engineering; University of Michigan)	**7 Oct 09**	Nothing substantive in this response. Dr. Beck just indicates that he has forwarded the request for information to Prof. Nick Vlahopoulos, who is "the department's expert on acoustics". Dr. Vlahopoulos has yet to follow up with a response.
Z. Zong (Towing Tank of Dalian University of Technology, China)	**8 Oct 09**	Dr. Zong leads the towing tank of Dalian University in China, which measures shipborn vibration and noise, as well as underwater acoustics (radiated noise). He essentially agrees with the conclusions of the report and of the focus of the correspondence group on cavitation. However, he also notes that another design issue that is often overlooked is the relatively little clearance allowed between the propeller and the hull of the stern. He indicates that this can cause resonance of the structural plates of the stern, resulting in significant radiated underwater noise. Structural vibration induced by propeller and machinery noise is an important consideration in engineering efforts to reduce radiated noise.
Mary Williams (NRC Institute for Ocean Technology)	**9 Oct 09**	Nothing substantive in this response. It just indicates that NRC-IOT does not have expertise or experience in the field of vessel quieting. Subsequent transmissions could exclude them from inclusion.
Johan Bosschers (Research and Development, MARIN, Netherlands)	**28 Oct 09**	This group in the Netherlands (MARIN) is involved in several projects directly related to the IMO Correspondence Group, specifically far-field radiated propeller cavitation noise and broadband hull pressure fluctuations generated by cavitating propeller vortices. They confirm that noise is not considered in the design process for most vessels. They also note the difficulty in many test facilities to accurately assess low-frequency radiated noise and that there is significant energy in radiated noise and hull pressure fluctuations at higher frequencies (> 1 kHz). Like Dr. Zong, they also note the importance of considering hull vibration and resonance from propeller motion; they have observed a 50 Hz maximum in hull pressure fluctuations which may be related to the "hump" seen in the radiated noise spectrum. They indicate that there is a non-liner relationship between hull pressure fluctuations and far-field radiated noise, and that some information exists (seems classified or proprietary) on the relation between (non-uniform) ship wake fields, propeller geometries and hull pressure fluctuations, as well as on the influence of propeller geometry and efficiency (note: seems like we should follow up this last one). They segregate the design features for cavitation noise as: hull line design; appendage design; propeller design; and retro-fits.

Manfred Mehmel (Potsdam Model Basin)	**2 Nov 09**	The Potsdam Model Basin works in ship hydrodynamics with special niches in designing propulsion systems and computational fluid dynamics. They have focused on reducing pressure pulses in the wake field to minimize hull vibration and they have some capabilities to measure very low frequency noise. They provide some useful background information on underwater acoustics related to propulsion systems (see below in detail). They also reiterate previous conclusions that the optimal design of propellers from a quieting perspective is slow moving, large-diameter, non-cavitating propeller with many blades in a uniform flow. They note that for quiet vessels, other sources on the ship and the impact of waves on the hull can contribute to radiated noise.
Jan Hallander (SSPA Sweden AB)	**9 Nov 09**	SSPA is one of the major model basins in the world for testing and optimizing commercial ships; they also have experience in testing naval vessels and underwater vehicles where radiated noise is a very important issue. [This is verbatim because I thought interesting in light of something Kathy said recently: "In addition to model testing we assist our customers with advisory, calculations and simulations at all stages of the design process. In some projects we are assisting the customer in developing a new concept before contracting a shipyard while in other projects we are assigned by the customer just for validation and verification."]. Optimum propeller design is usually a trade-off between efficiency and cavitation performance; high efficiency and thus low fuel consumption has usually the highest priority among commercial ship-owners. Where radiated noise is an important criterion, cavitation can be avoided by lowering the propeller loading, but this comes at the cost of lower efficiency and thus higher fuel consumption. Optimizing hull design can both increase the hull efficiency and achieve a smoother wake field (inflow) which gives the propeller better acoustic performance, although load carrying capacity, port and fairway restrictions can be limiting. For a standard commercial ship, there are drivers to reduce underwater radiated noise, but they do care about hull vibrations for interior noise and/or structural fatigue. There are standard measurements for monitoring hull pressure pulses. In terms of underwater low frequency radiated noise, the prediction of radiated cavitation noise is more complicated than just applying scaling laws to model scale measurements from test basins for several reasons including where the measurement is made (close to the source) and the fact that some of the noise is radiated directly into the water and some is radiated secondarily through the hull. The relationship between scaled models and full scale far-field noise fields will differ for different ship types. They conclude that the acoustic consequences of designing ships with better fuel economy will probably be marginal since there are requirements on pressure pulses and vibration.

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