DISCUSSION

A REVIEW OF PRACTICAL METHODS FOR REDUCING UNDERWATER NOISE POLLUTION FROM LARGE COMMERCIAL VESSELS

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COMMENT

Do Ligtelijn, General Manager R&D – Hydrodynamics, Wärtsilä Netherlands BV

The paper provides an interesting and rather complete overview of the reasons for reducing shipping noise and the possible ways to achieve this. It is in particular interesting to note that the majority of noise impact is probably caused by the noisiest 10% of ships, and that the ambient noise level in the oceans increased by around 20 dB compared to pre-industrial conditions.

The relation found between ship speed and radiated noise level, although of course probably too simple, may indeed be a practical way to judge the effects of noise mitigation measures, and allows for instance a first estimate to be made of the effect of energy saving measures to noise emissions, at least for fixed pitch propellers (FPP's). The efficiency of FPP's remains almost unchanged when reducing ship speed (at least for most displacement vessels), whereas the cavitation number increases with the square of the rotational speed, thus reducing cavitation and its radiated noise rapidly.

For controllable pitch propellers (CPP's) the situation is more complex. Many CPP's are running at constant rotational speed over the entire power range, governing the power absorption of the propeller by the pitch of the blades. Contrary to what happens with FPP's, slow steaming for CPP's at constant RPM means significant decrease of efficiency (see reference), whilst the cavitation number remains constant and low. Due to the unfavourable blade pitch at lower powers cavitation may switch from the back to the face side of the blade and the cavitation noise level may actually increase when lowering power. It is noted that slower steaming not only occurs for economic reasons, but also in areas of dense traffic, many obstacles (islands, off shore installations) and harbour approaches. For future installations that have to comply with the coming underwater noise regulations it is advisable to operate CPP's as much as possible like FPP's, using the CPP-mode only when needed, like during manoeuvring or other specific operating conditions.

In section 3.7 the paper mentions that application of a Costa Propulsion Bulb would reduce the noise level by 5 dB. However, this noise reduction is attributed in that paper to a system of which a rudder bulb is only one part of the system. In the described system the propeller hub cap is elongated till close to a rudder bulb, eliminating therewith the (cavitating) hub vortex. The noise reduction is then obtained by designing the propeller with a different radial loading distribution, allowing more thrust load near the hub (as there is no risk for hub vortex cavitation), and reducing loading at the tip, thereby reducing cavitation at that part of the blade.

Takeo Nojiri, MOL Techno-Trade Ltd., Japan

I appreciate being given the opportunity to comment on Dr Leaper and Dr Renilsons' insightful paper. The comments that I will make are based on my experiences of underwater noise project in Mitsui Engineering and Shipbuilding Co. Ltd., and R & D project of PBCF (Propeller Boss Cap Fins) in MOL Techno-Trade, Ltd.

As Dr Leaper and Dr Renilson mentioned in the paper, the noisiest and most annoying underwater noise radiated from vessels will generally be line spectrum one in low frequency range. This line spectrum noise will generally be caused from propeller cavitation. In case of propeller operating in ship wake non-uniform flow, the cavitation noise will consist of low frequency line spectrum at blade frequency and its harmonics, line spectrum in mid range if singing is exist, and wide band continuous spectrum noise from mid to high frequency. The biggest component will be the line spectrum noise at 1st blade frequency in most cases. This blade frequency noise would be coming from the cavitation volume change during the rotation of propeller blade in non-uniform flow.

On the other hand, the pressure fluctuation at blade frequency and its harmonics would possibly be predicable from the cavitation volume change of propeller blades during its rotation. This methodology is known as the surface force analysis to estimate and reduce the hull vibration.[56, 57] As my suggestion, this methodology would be helpful to predict and study the reduction of the blade frequency underwater noise radiated from the large commercial vessels. Radiated noise from controllable pitch propeller (CPP) will be much affected from its control mode. In case of pitch control with constant revolution, it will be noisier in low speed including bollard condition than normal speed running.[58, 59]

PBCF is a well proven fuel saving device. To the present time, PBCF devices have been fitted to more than 2,000 vessels around the world. The PBCF device works by improving the flow around the propeller boss.[60, 61] Looking into the flow around the propeller boss, the water flow is accelerated and twisted when it passes through the propeller disc. Further, close to the hub the blade root vortices are also present. These coalesce with the general twist in the flow induced by the blade downwash to produce a very strong vortex aft of the boss. This strong hub vortex is normally resulted in hub vortex cavitation. When the PBCF device is installed, the strong down flows from propeller blade trailing edge are rectified by the PBCF fins and the hub vortex, i.e. hub vortex cavitation, is distinguished. As a result, not only the propeller efficiency will increase but also its radiated noise will be reduced. This is confirmed by the model test in cavitation tunnel.[62] Although the quantitative investigation on noise reduction by PBCF are limited, its noise reduction effect will be undoubtedly, as distinguish of hub vortex cavitation by PBCF is well confirmed by lots of model tests.

Robert Walsh, President, Ship Propulsion Solutions, LLC

In the Maritime Reporter & Engineering News, March 2009, Dennis Bryant wrote "It is somewhat ironic that so much attention has been focused on certain marine noise issues when more significant threats to marine mammals, such as fishery by-catch, have proven less controversial." Even if technical guidelines for ship quieting technologies are non-mandatory they could possibly result in another economically sub-optimum approach to ship design similar to that of EEDI, looking to minimize Green House Gases, which encourages construction of larger, slower moving ships resulting in reduced trading flexibility. For existing ships it seems that a 90/10 rule applies, i.e. a small percentage of ships (poor designs) contribute to the noise problem because of propeller cavitation, and most probably with cavitation occurring on the outer radii of the blades. If improving these bad actors can be tied to improving operating efficiency by achieving fuel cost reduction then a solid economic incentive would exist for change along with the secondary benefit of noise reduction. What is happening around the propeller hub may less likely be cavitation and more likely disrupted flow with rotational losses that have lower noise levels than that resulting from cavitation. Measuring fuel savings would seem to be more practicable than the challenges faced when making full-scale noise measurements, as stated in Section 3.4 of the report: "For all these designs of propeller(s), noise measurements are required to verify whether claimed improvements in efficiency are matched by reductions in noise." The paper cites several innovative propeller designs and other stern-appended hydrodynamic energy saving devices (ESDs); however, up till now, none of these devices have had their benefits for full-scale ships correlated with noise reduction, but only for propulsion efficiency improvement. With new ships being designed to meet the mandatory, synthesized EEDI requirements achieving highly efficient propellers without cavitation should be possible. For existing ships improving propulsion efficiency by retrofitting more efficient propellers and ESDs should also be cost-beneficial when driven by today's high fuel costs. The overall result should be less underwater noise.

Dr Dietrich Wittekind, DW-ShipConsult

The paper is a comprehensive and complete overview of design aspects of propellers. The following comment is limited to the feature of propeller generated noise which is dominant in long distance noise propagation.

The spectrum of background noise from shipping features a broad band hump peaking at around 50 Hz, Figure 1. It is shown that this characteristic is a feature of the individual ship which clearly becomes more prominent with increasing severity of cavitation but without frequency shift [32, 36: Figure 1].

The exact cause of the feature has never been investigated. It is broad band in character, it is not in conflict with vibration requirements on board and too low in frequency to be critical in view of on board acoustics. Therefore, it is not in focus of ship and propeller design.

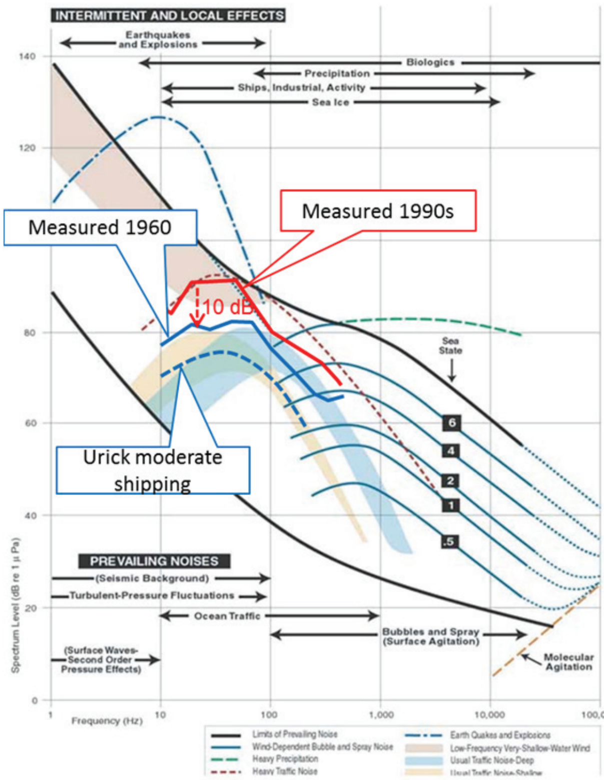

Figure 1: Standard and measured spectra from shipping displaying a maximum at around 50 Hz

Background graphics adopted from "Ocean Noise and Marine Mammals, Nat'l Acad. Sci., 2003; Inserted curves from 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.

It is further observed that not all ships feature such a pronounced spectral behaviour or have the maximum not at around 50 Hz but rather at e.g. 70 to 80 Hz, Figure 2. Research work can be done in cavitation tunnels so do not require full scale ships in much of the basic research [32].

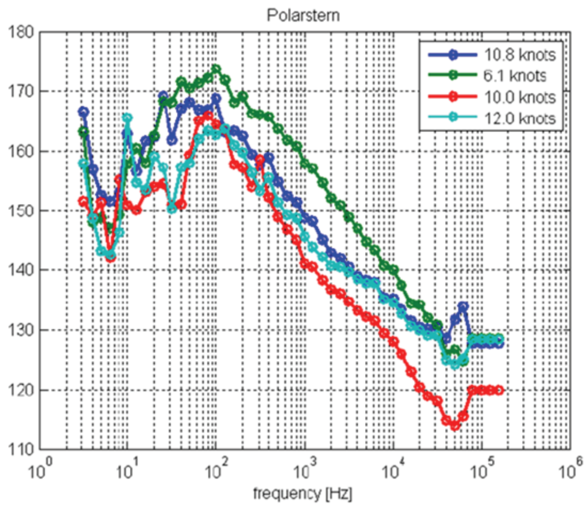

Figure 2: Radiated noise of research icebraker Polarstern from Kraus, Umweltwirkung schnell fahrender Schiffe (Environmental Effects from fast Vessels), Workshop GAUSS, Bremen, 29. 4.2008 http://www.gauss.org/img/pool/D_Kraus_Hochschule_Bremen.pdf

Along with such work relationships addressed in the paper can be quantified as for example the effect of propulsion in ballast condition. By tendency the propeller is relieved compared to deep draught conditions and therefore changes its cavitation behaviour, at the same time is working under reduced static pressure further enhancing cavitation severity. On the other hand closer vicinity to the surface reduces low frequency noise radiation particularly in the near horizontal directions.

The relationship of noise radiation related to ship and propeller design and operating condition has to be taken up by naval architects, propeller designers and acousticians in unison. Quick results can be expected but development of a systematic design process to observe noise radiation and propulsion efficiency at the same time will take a longer time. Funding of such work, is not yet provided. It should be kept in mind that low noise design of ships has an effect in the environment only after decades due to longevity of ships.

For a more detailed description of the character of low frequency broad band propeller noise see Wittekind, D. Der steigende Lärmpegel in den Weltmeeren – eine Herausforderung für die Schiffstechnik?(The Increasing Noise Level in the Sea – a Challenge for Ship Technology?) Jahrbuch der Schiffbautechnischen Gesellschaft 2009 (in German: English translation available at author)

AUTHOR'S RESPONSE

Since we wrote our paper, a new study (Rolland et al. 2012) has found that a 6dB reduction in shipping noise in the Bay of Fundy was associated with decreases in stress hormones in the North Atlantic right whale. It is not a surprise that shipping noise may be associated with chronic stress in whales but it is encouraging that a measureable improvement can result from a modest noise reduction. Such reductions are likely cost effective and achievable for most vessels and particularly the noisiest ones.

We thank the four authors for some very informative comments on our paper and for drawing our attention to additional information of which we were not fully aware. We agree that measuring fuel savings is easier than measuring noise as suggested by **Mr Walsh**. We also believe there is scope for optimising noise reduction as part of measures to save fuel. However the two may not equate directly, particularly since only a tiny proportion (typically around 10^{-6}) of the propulsion energy is lost as noise. We support the suggestion by **Dr Wittekind** for collaborative work between naval architects, propeller designers and acousticians, and particularly the development of a systematic design process to observe noise radiation and propulsion efficiency simultaneously.

There remains a need for more noise measurements both at full scale and in cavitation tunnels. The responses highlight this in different ways. Two of the commentators (Mr Walsh and **Mr Ligtelijn**) note that the noisiest ships contribute the majority of the problem; the International Maritime Organization (IMO) has already recognised the need to identify these vessels. Wittekind draws attention to an unexplained broad band hump in noise signatures peaking at around 50Hz. He notes that the exact cause of the feature has never been investigated. This is at a frequency that is of concern for large whales and investigation of the factors that contribute to noise around this frequency may help to reduce levels. He also suggests factors that may affect noise output for a vessel in ballast. We would add to that the effects of trim and loading to the wake into the propeller. Predicting the effects of these factors on noise may require full scale measurements.

We are not sure about the cause of the noise from the propeller hub as suggested by Walsh. Certainly cavitation can be observed when testing models in a cavitation tunnel. This is clearly an area where more research is required. However, we agree with Walsh that there is not enough evidence that hydrodynamic energy saving devices will also reduce radiated noise for all the cases where they increase efficiency. This needs further work to ensure that increased efficiency for the 'poor' ship/propeller combinations could also reduce underwater noise.

Both **Mr Nojiri** and Ligtelijn note the potential for increased noise at slow speeds from controllable pitch propellers (CPPs). Ligtelijn draws attention to the fact that slower steaming occurs for navigational as well as economic reasons such as in areas of dense traffic, close to obstacles and harbour approaches. This may sometimes occur in particularly environmentally sensitive coastal areas. Hence there is also a need to address noise output from vessels with CPPs, particularly when slow steaming.

We appreciate the considerable information provided by Nojiri on Propeller Boss Cap Fins; and note that for this technology there is also a need for actual measurements of the noise reductions that are likely to be achieved. We agree with him that PBCF may reduce noise as well as increase efficiency. We thank him for his additional reference, however, there needs to be more work to optimise noise reduction. This feature of the PBCF could become an important selling point if the appropriate research demonstrated nosie reduction. The mechanism described by Ligtelijn by which the Costa Propulsion Bulb may reduce noise also shows good promise for substantial noise reduction. It would be interesting to see further information on this and whether similar comments may also apply to the PCBF.

In summary there seems to be widespread agreement that noise can be reduced alongside efficiency measures, and the need is now for focussed research addressing the issues highlighted in our original paper and the four commentaries. We are greatly encouraged by the level of interest in the subject and also hope this will be of value to the IMO correspondence group currently developing technical guidelines for minimising underwater noise from commercial shipping.

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