Underwater Radiated Noise

MAN Energy Solutions
Future in the making

Propeller & Aft Ship:
Minimizing underwater noise emissions

Future in the making

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Regulations and propeller challenges

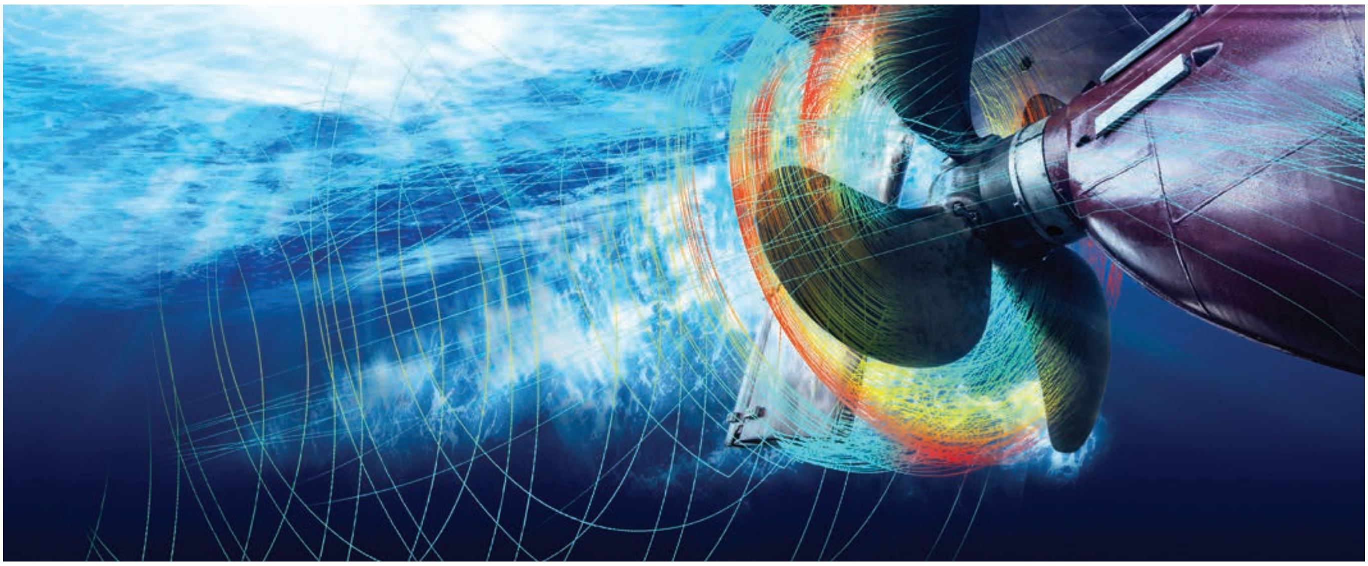
Upcoming regulations regarding Underwater Radiated Noise (URN) levels may conflict with our aim to reduce greenhouse gas emissions. In this short paper, we explain why this is the case and how the Propeller Business Unit's Hydrodynamic R&D group is turning this challenge into solutions and customer benefits.

Underwater Radiated Noise (URN)

- Shipping noise disturbs the communication, and therefore the living conditions, of mammals, fish and marine life.
- Propellers are a major source of URN, especially as a result of cavitation.
- Cavitation: The phenomenon in which the pressure of the water reduces to below the water's vapor pressure, leading to the formation of small vapor-filled bubbles.

With "Moving big things to zero" we've outlined our mission to reduce greenhouse gas emissions in key sectors of the global economy. Green ships sailing the ocean and calling in at harbors is a great vision, but we need to have a look under the water surface as well.

The adverse impact that underwater radiated noise (URN) has on our ecosystem is not widely known, but the impact on our ecosystem is indisputable.



Harmful effect on marine fauna

Imagine a motorcycle racing through the canteen while you are having lunch or a jackhammer ripping up the floor in your office while you are trying to hold a disussion with your colleagues – this would be quite disturbing.

Shipping noise has exactly the same effect on marine fauna.
It disturbs the communication of marine mammals and fish. As you see in Fig. 1, the frequency range of shipping noise is usually between 10 and 2,000 Hz. This is more or less the same range fish and marine mammals use for their communication. In other words, too excessive levels of URN reduce their abilities to settle and prosper.

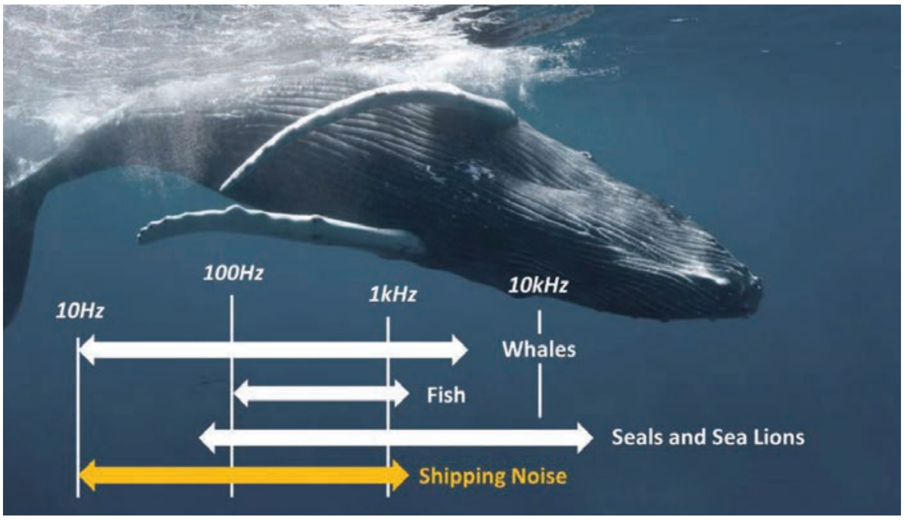


Fig. 1: Frequency range used by fish and marine mammals for communication vs. shipping noise frequency range

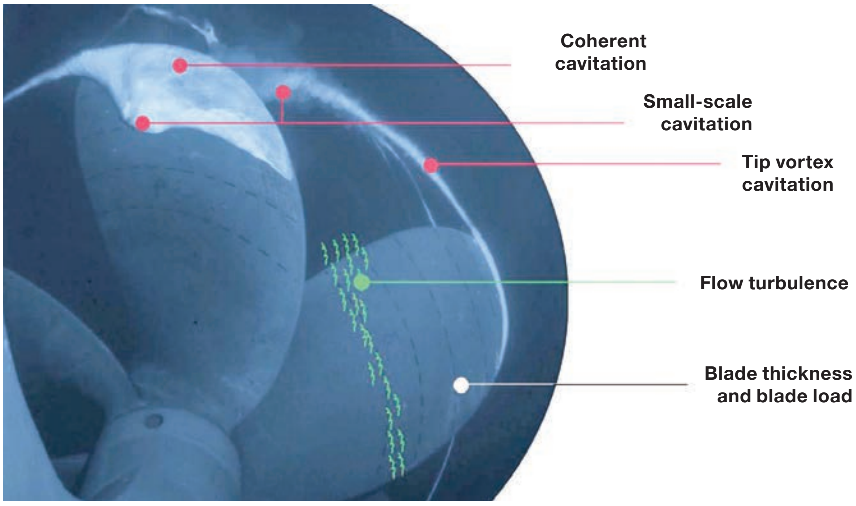


Fig. 2: Different mechanisms of URN generation. Strongly developed sheet cavitation near the blade tip, tip vortex cavitation, and small-scale cavitating structures due to break-up of coherent cavities

For military applications, underwater radiated noise (URN) has always been a topic of interest, and this issue is becoming increasingly important for the merchant fleet as well. Indeed, we are still far from seeing international, standardized rules regarding URN, but recent activities by the IMO, the European Union and several classification societies indicate that regulation will happen sooner rather than later.

The propeller as major source of URN

In particular, the propeller is a major source of URN. Here, different flow features, such as flow turbulence, load and thickness of blades contribute to noise. However, the effect that dominates all the others is cavitation.

Cavitation arises if the pressure in the fluid falls below its vapor pressure. In that case, the liquid begins to evaporate and forms bubbles and cavities filled with water vapor. For most propellers in operation, regions of low pressure appear on the suction side of the blade near the propeller tip and in the core of the trailing vortices. It is no surprise that cavitation will develop in these regions (see Fig. 2). These cavitating structures undergo permanent changes in form and volume – which contributes massively to URN.

The solution seems to be simple: when the extent of cavitation is reduced or cavitation is avoided completely, URN should no longer be an issue. That is true, but, as we will see next, the situation is more complicated than that.

Minimizing underwater noise emissions

- Dilemma: in conventional propeller design, it is not possible to decrease URN levels arbitrarily without sacrificing efficiency, increasing fuel consumption and emissions.
- Possibility to extend the scope of design process by including other components of the propulsion system, e.g. rudder, rudder bulb, struts etc.
- Holistic design process: includes prognosis for cavitation, URN levels and efficiency and takes into account interaction between components of the propulsion system.

Every percent counts

Efficiency is an important criterion when a propeller is designed for a vessel. Evidently, this is a particularly significant design objective when we want to reach our ambitious goals of reducing greenhouse gases. From an economic point of view, efficiency will become even more important in the future when e-fuels are more widely used, since these fuels are more expensive than conventional fossil fuels.

The design conflict

We already know the importance of designing for efficiency, and have seen that reducing URN levels is another important design objective. However, these two design objectives are in conflict.

The physics of propeller flow mean that it is thus not possible to decrease URN levels arbitrarily without sacrificing efficiency.

Briefly, in order to reduce the amount of cavitation, and thus URN levels, it is necessary to control regions of extremely low pressures on the blade. This can be done either by removing load from the blade tip or by increasing the area of the blades so that the blade load is distributed over a larger surface. Both solutions, however, lead to a loss of efficiency due to a less favorable load distribution and increased surface friction losses.

The opportunity

Within the conventional propeller design process, the blade designer seeks for increased efficiency while reducing cavitation as much as possible. As we saw, at some point, there will be a boundary, where it is no longer possible to improve one design objective without negatively impacting the other. This boundary is called the Pareto front (see figure 3, left-hand side). At this point, the customer must decide which is more important: reducing URN levels or increasing efficiency.

It is possible, though, to extend the scope of the design process by including other components of the propulsion system such as for example, the rudder, rudder bulb, struts (see figure 4) or by considering alternative propeller concepts, such as the efficient Kappel 2.0 concept.

Additionally, changes to the aft ship geometry can be applied so that the quality of the ship's wake field is improved. By these measures, together with the customer, we can shift the boundary imposed by the Pareto front towards more efficient and less noisy propellers.

This is what we call a "holistic design process" (see figure 3 right-hand side). In order to offer this design strategy to our customers, we have added some new tools to our toolbox: tools allowing us to make a prognosis for cavitation, URN levels and efficiency as well as tools taking into account the interaction between several components of the propulsion system. We will consider these tools below.

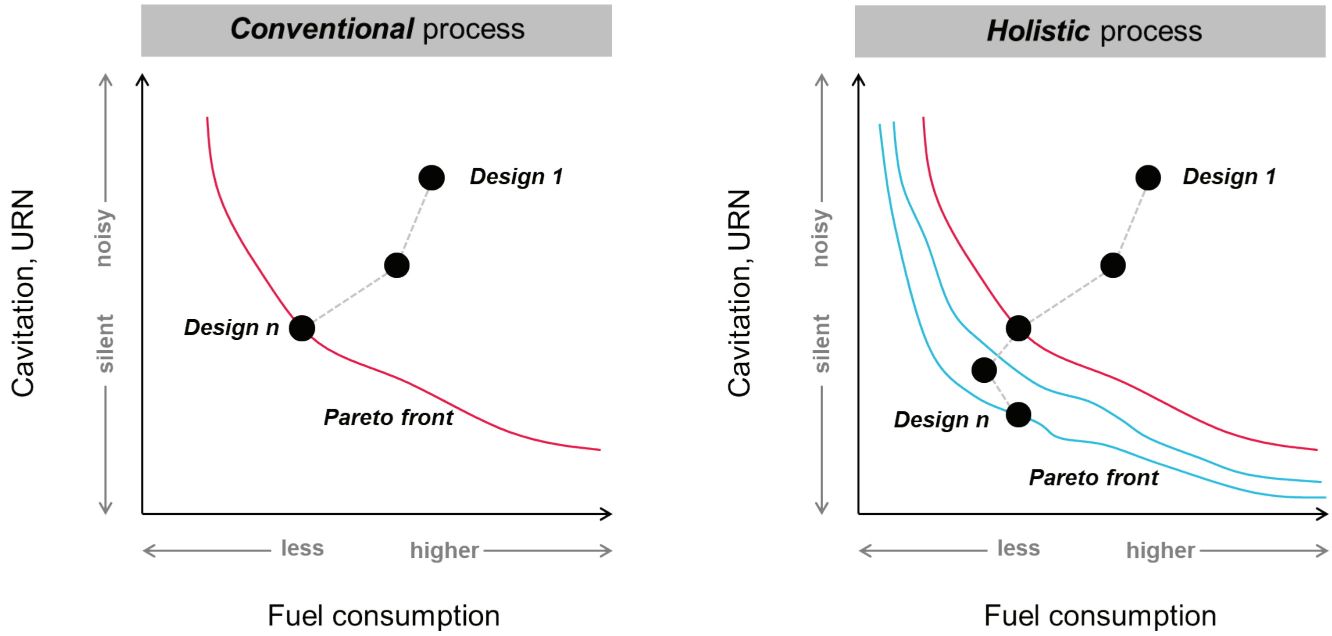


Fig. 3: Conventional vs. holistic design process

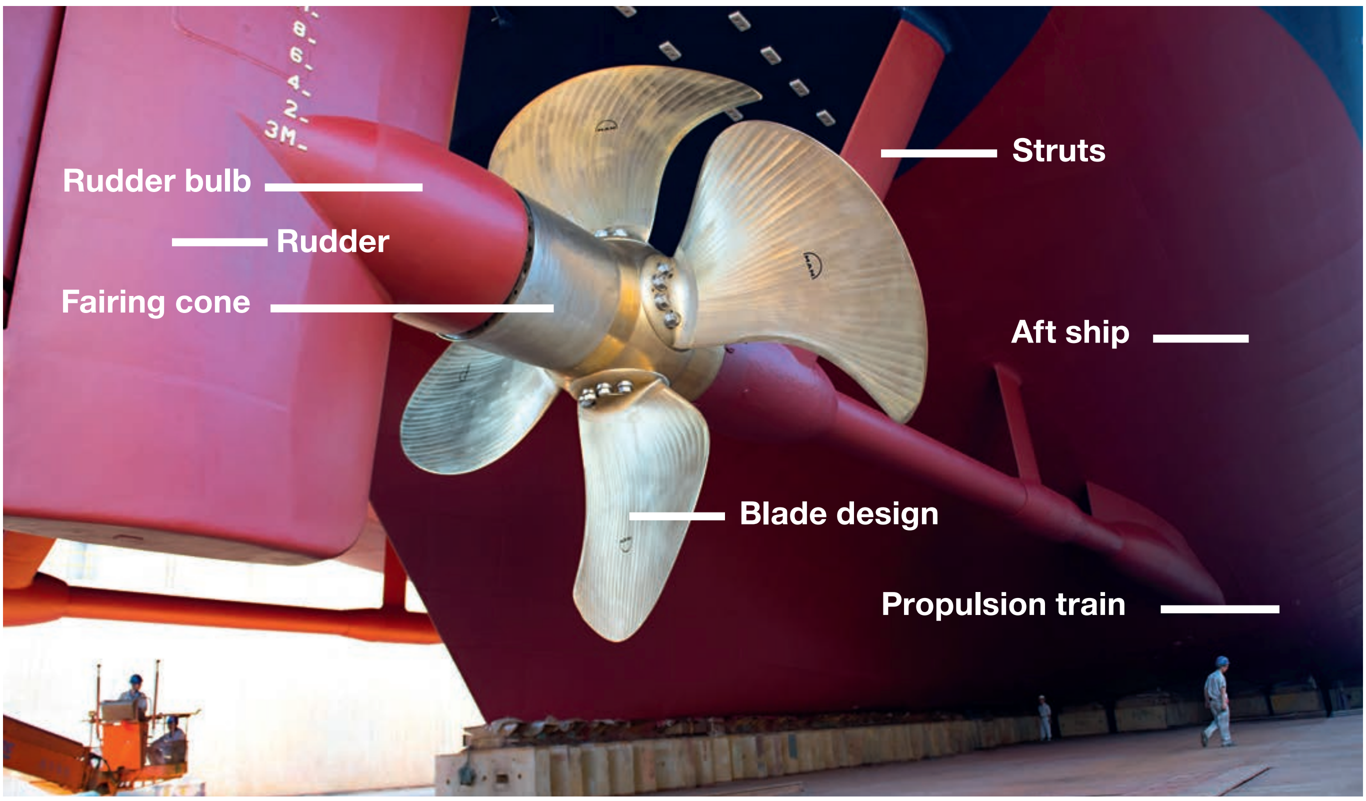


Fig. 4: Components of the propulsion and aft ship system

Our toolbox

Tools and methods

- Computational Fluid Dynamics (CFD): universal tool to create a very detailed model of the propulsion system which captures all interaction effects in the aft ship region.
- MAN Energy Solutions' Hydrodynamics R&D group is developing and implementing concepts that are based on so-called acoustic analogies.
- Basic idea of acoustic analogies: place a number of acoustic sources on the surfaces of the propeller and around it.
- Once we know everything about the flow field around the propeller, by applying acoustic analogies, we obtain information about propeller noise.

Being efficient and silent at the same time: we have previously mentioned why this is important for the next generation of propellers and why this can turn into a challenge. In order to design propulsion systems satisfying these two demands, we need the right tools and we need to know how to use them effectively.

Tools for hydrodynamic analysis of propulsion systems

Propellers operate in close proximity to the ship's hull, the rudder and other appendages. This configuration leads to complicated interactions between propeller, rudder and hull flow, which must be considered when optimizing propulsion systems in a holistic manner.

Computational Fluid Dynamics (CFD) is a powerful and universal tool making it possible to create a very detailed model of the propulsion system and inherently capturing all the interaction effects in the aft ship region. An experienced user will be able to generate quite accurate results.

However, there is a price to pay: CFD is based on numerically solving the Navier-Stokes equations. In order to solve these equations, the entire fluid domain needs to be discretized. Depending on the problem, we are dealing with 10 to 50 million control volumes. The computational cost of these methods is very high, and it can take up to a couple of days before we see results – too long to be used as the only tool in our daily business.

Panel codes (figure 5) can be seen as fast alternative to CFD. These methods are based on a simplification of the flow model. The resulting equations are much easier to solve and only the surface of the body needs to be meshed. Panel codes can deliver results in a couple of minutes – but the level of detail that can be achieved is lower. Furthermore, not all of the interaction effects outlined above are captured.

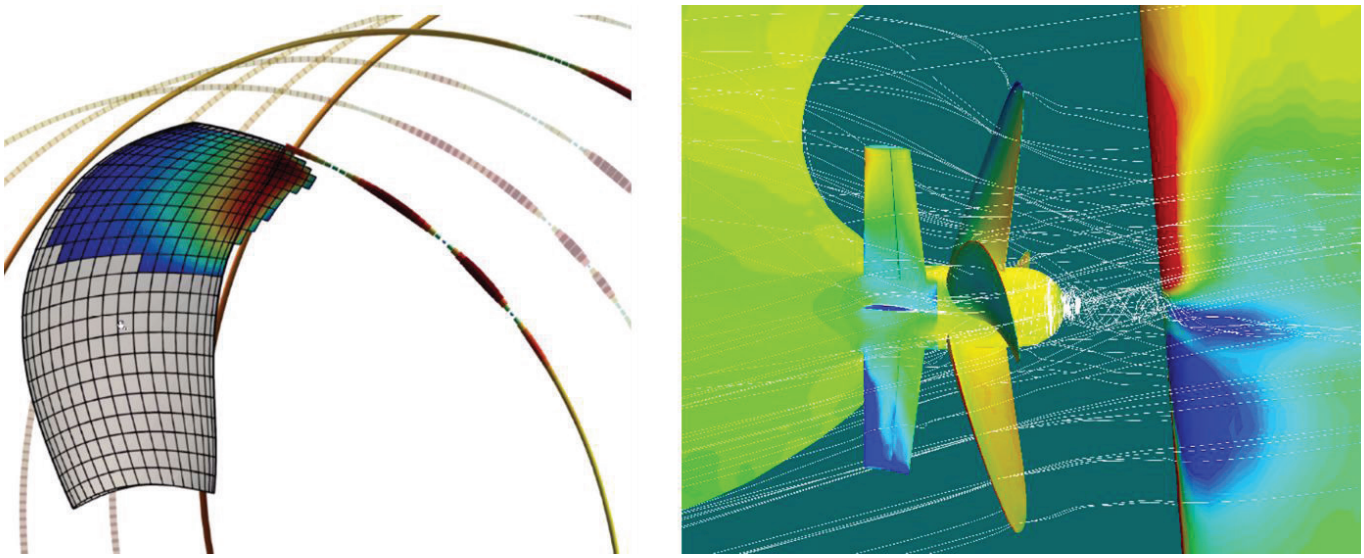


Fig. 5: Example simulation results obtained by our tools for hydrodynamic analysis.
Left: Sheet and tip vortex cavitation predicted by the in-house panel code ESPPRO; right: CFD simulation of a propulsion system.

Which tools are used in the different phases of a project depends on the scope of the project, the time available, prior knowledge and the designers' experience. Based on these parameters, our designers make a careful selection to ensure the most effective use of our resources in the design and optimization process.

Recent research in our group addresses developing hybrid methods, i.e. a combination of CFD and simplified flow models, where CFD is employed to increase the accuracy of low-fidelity tools.

Numerical methods for propeller noise

So far, we have explored how to simulate the hydrodynamic flow field around the propeller. How do we take into account propeller noise?

MAN Energy Solutions' Hydrodynamics R&D group is developing and implementing concepts that are based on so-called acoustic analogies. The work is focused around an Industrial PhD project in collaboration with universities and research centers.

The basic idea behind the method is to place a number of acoustic sources on the surfaces of the propeller and around it (see Fig. 6). The strengths of these sources is then exclusively determined by the quantities of the hydrodynamic flow field, i.e. pressure, velocities, temporal change of cavitation volume – all of which are already known from either CFD simulations involving commercial software or in-house panel code simulations. In other words, once we know everything about the flow field around the propeller, by applying acoustic analogies, we obtain information about propeller noise. The extra computational cost is therefore very low.

This approach is quite promising and has already been introduced in commercial projects with high demands regarding underwater radiated noise.

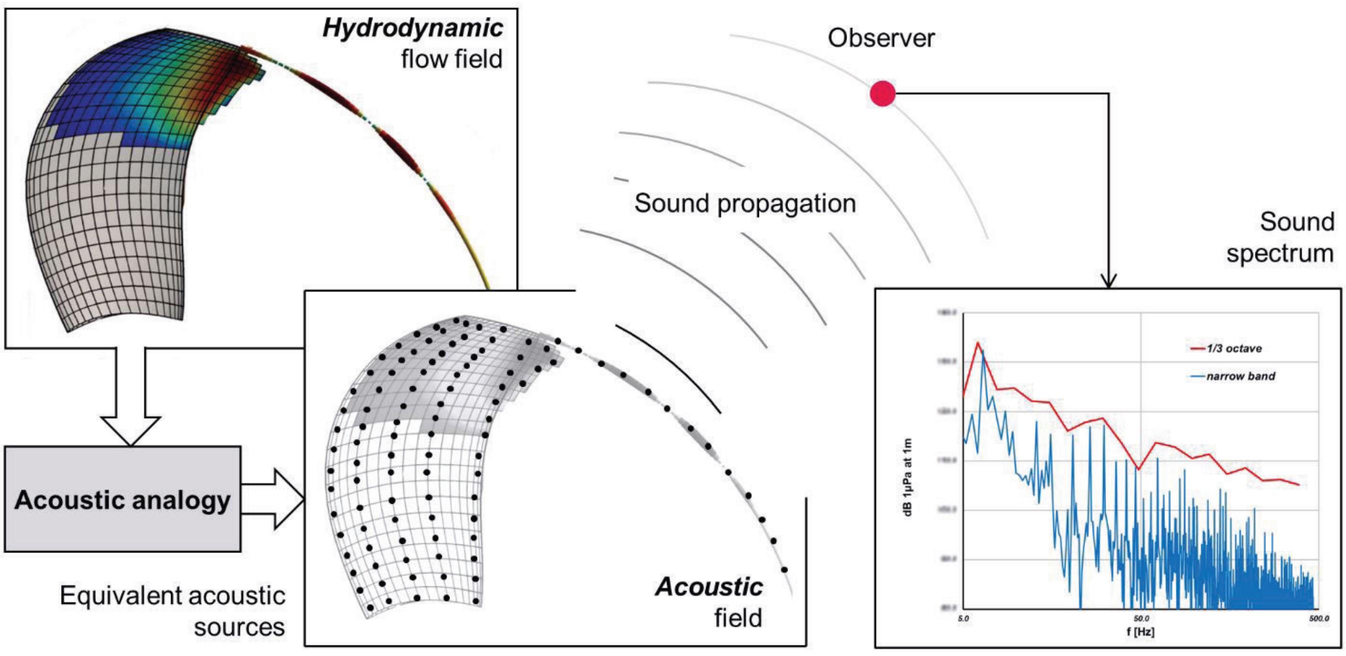


Fig. 6: Basic principle of propeller noise prediction using acoustic analogies:
Starting from the hydrodynamic flow solution over equivalent acoustic sources to a sound spectrum.

Rules, guidelines and support

Currently there is no mandatory regulation relating URN to ships. Many projects and initiatives, however, are ongoing at various levels.

International Maritime Organisation

IMO guidelines for new and existing vessels are of non-mandatory nature. When the revised guidelines were published by the IMO in August 2023, a three-year experience-building phase (EBP) started, which will be used to collect data to evaluate the effectiveness and the level of voluntary uptake by shipping companies.

Classification societies

On the general level, we recommend shipowners and operators to seek support from classification societies, for conducting the baselining and setting the noise reduction targets. Also, when choosing the relevant measures to achieve the set targets, classification societies may be of assistance.

Seven classification societies have already created "silent class notations" and shipowners may also want to consider obtaining such notation for their vessels.

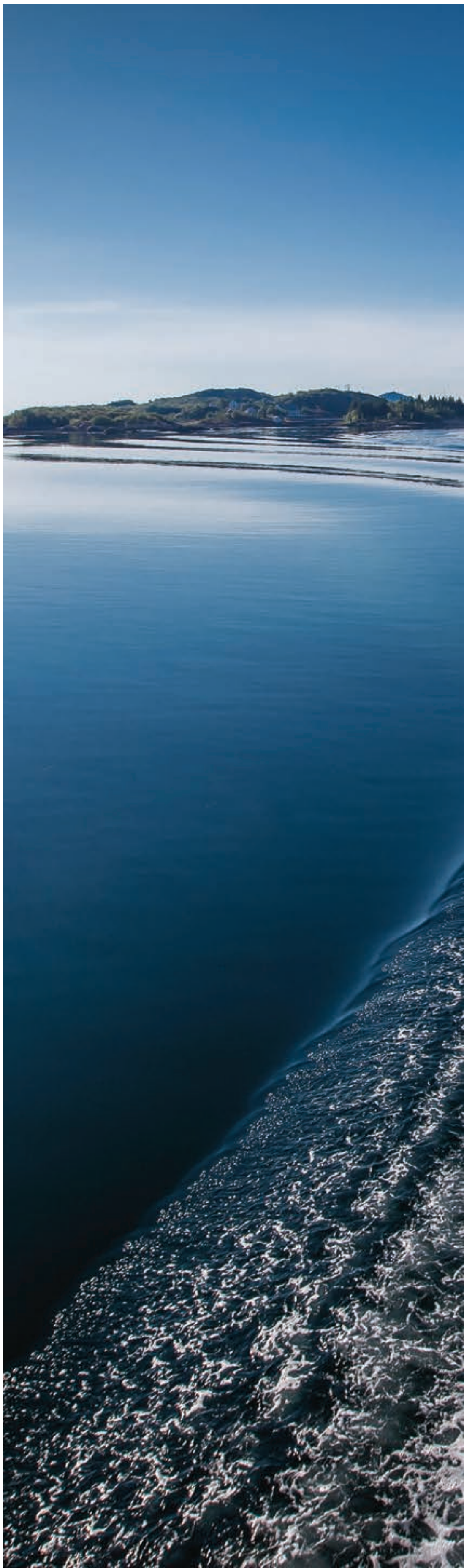
Classification society	Name	Year
DNV	SILENT (5 class notations)	2018
Bureau Veritas	NR614 Underwater	2017
Lloyd's Register	ShipRight (3 class notations)	2018
ABS	Underwater noise (2 class notations)	2018
CCS	Guidelines for ship URN	2018
RINA	RINA DOLPHIN (2 class notations)	2019
Korean Register	Guidances for Underwater Radiated Noise (2 class notations)	2021

Fig. 7: "Silent class notations" from seven classification societies.

Contact us

At MAN Energy Solutions, we closely follow the development and shall be pleased to support on a detailed level for the individual cases regarding optimal noise suppression means and measures in relation to our propulsion systems, propellers and aft ship systems.

For more information, please go to our Propeller & Aft Ship website – or contact us directly at: sales-frh@man-es.com



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