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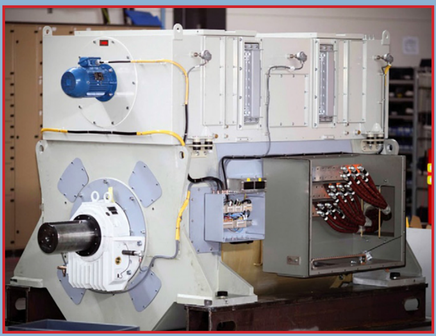

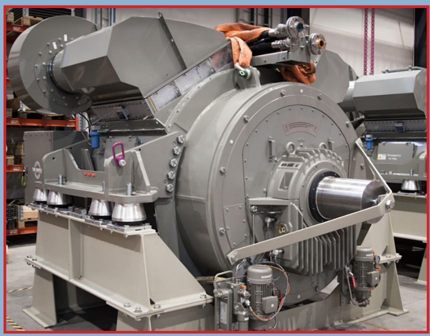

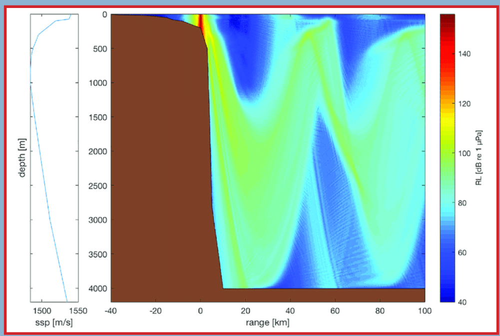

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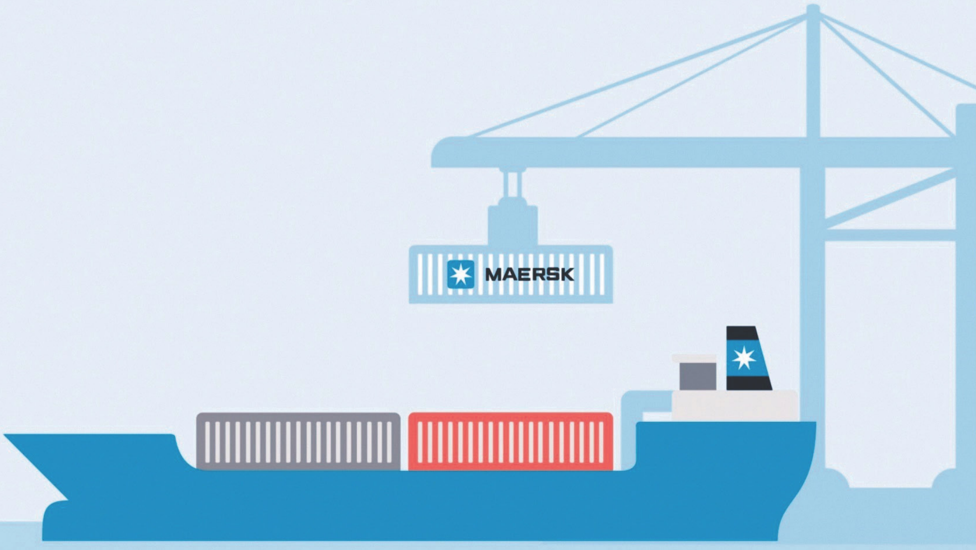

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EDITORIAL

When a man is out of sight, it is not too long before he is out of mind.
- Victor Hugo

The Baltimore Bridge allision and the unsafe seas continue to hog maritime news limelight. The Bridge collapse has become an object of FBI investigation with a criminal complexion. The Bridge was supposedly 'fracture critical', (implies that if any component of the main structural frame fails, most of the bridge will go down). There are many such bridges in the USA and bridge collapse due to vessel allisions with loss of lives are on record. The collapse brings forth the woes of lives lost, disrupted port operations/trade, economic losses and rebuild constraints etc.

Next the vessel… it is reported that the vessel has an allision history and recorded deficiencies concerning propulsion and auxiliaries. The initial information looks at loss of power and actions to avoid the mishap etc.; however, a clear picture is yet to emerge. Evidence of inconsistent power supply 'even before leaving port' makes the case to point a finger at the 'negligent vessel manager' taking out the ship in an unseaworthy condition. Crew incompetence, non-adherence to SoPs, maintenance failure will count for other pointing fingers. The professional fraternity feels that the dog whistles in all the actions obviously will lead to criminalisation of the seafarer (read, concerned ship's personnel).

And another area where the poor seafarer faces perils is the hot spots around Suez … the Red Sea/Straits of Hormuz. It is worth mentioning that 3 papers from India are going to IMO's Legal Committee. The issues in focus are maritime security, conflicts, piracy attacks and seafarer contract terms amongst others. Given the high stakes, India has a greater responsibility to take up representations at the IMO. The 'human rights at sea', an Indian initiative with the Human Rights Commission needs and a good visibility and support. The challenges of fly-by-night operators, non-ownership behaviour of ship-owners during incidents, singling out the accountability on the ship's personnel alone, post-incident incarcerations in alien jails need to be discussed with data and addressed. To recall, the seafarers were the last in the scheme of things during the pandemic periods. As the land's end disappear, the sailor turns to his loneliness. The seafarer would be out of the stakeholders' minds as things return to normalcy. The principals need reminders from time to time. Else, it will be in the blues… out of sight and out of mind.

In this issue…

Under water radiated noise from sailing vessels has been a topical discussion. Palaniappan and Dr. Vedachalam look with this two-part series. In this Part A, the Authors start with explanations on the hearing mechanism of fishes and pitching for control of underwater noise. This is followed by discussions on the modelling and class notations for silent ships. The propeller cavitation, frequencies, sources and ship equipment (including podded propellers) are good takeaways. The tail-section of this first part settles with talks on technological maturity of systems. This is another educational read.

Prabu Duplex returns with his maintenance discussions. Presenting a case for shipboard predictive maintenance, a component selection procedure is put forth. Prabu Duplex projects the cases juxtaposing two companies, one composed of world's top geologists and the other offers support services to harbour pilots. Company 1 operates survey vessels and its requirements stem from this profile and Company 2 has smaller crafts, tenders, pilot station vessels etc. The maintenance complexion depend upon the equipment's criticality etc. From thereon, each Company's operations and needs are discussed. The 4-Quadrant approach to component maintenance is an interesting proposition for Technical Superintendents to mull about.

Under Technical Notes, Dr. Punit Kumar and Dr. Sanjeev Kumar Varshney talk on moving ships using kites. In Competency Corner, alternator maintenance talks continue. MER Archives from May 1984 capture a few interesting topics: medium speed engines burning fuel oils; structural survey of oil tankers and a few Postbag discussions.

While you sweat and cool in the hot climate and campaigns, here is the May issue. May the coming times bring some rains and rational rulers.

Dr Rajoo Balaji
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MARINE ENGINEERS REVIEW INDIA

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Silent ships – Importance, Policies and Technology Trends: Part A

M. Palaniappan & N. Vedachalam

Abstract

An eco-friendly maritime transport is the key to sustainable development. Shipping is a major contributor for the ambient noise in many ocean regions that has been reported to be increasing at the rate of 3db/decade. As it is found to have a detrimental impact on a wide range of marine life, the International Maritime Organization (IMO) and International Association for Classification Societies (IACS) have published guidelines on vessel quieting technologies and methods for newly built, as well as existing vessels, for reducing the on-board noise, noise radiated to harbour and under water radiated noise (URN). This part discusses the impact of anthropogenic noise on marine ecology, propagation pattern of ship URN in shallow and deep-oceans, noise sources, regulations for silent/quiet ship notation and the maturing URN reduction technologies.

Part B of the article describes the effective mitigation techniques for bubble sweep down, which helps to significantly improve the multi-beam sonar performance in hydrographic/research vessels. The modified forward hull geometry, first-of-its-kind hydrodynamic re-design approach for creating an effective bubble diverter is explained using numerical models.

Introduction

The global fleet of more than 94,171 ships including passenger vessels, containers ships, tankers, gas carriers, bulkers, dry and cargo carriers, with a consolidated Dead Weight Tonnage (DWT) of ~2 Billion Tons contribute to ~90% of the global trade. The UN SDG 14.1 aims to prevent and reduce marine pollution of all kinds significantly by 2025; and Goal 14.2 targets to manage and protect marine and coastal ecosystems from adverse impacts in a sustainable manner by strengthening their resilience and acting for their restoration in order to achieve healthy and productive oceans.

In line with the UN SDG objectives, IMO has enacted various policies including switching to cleaner fuels, implementing Energy Efficiency Design Index (EEDI) for the newly-built vessels, Ship Energy Efficiency Management Plan (SEEMP) for operating vessels, autonomous operations and silent/quiet configurations **(Figure. 1)**.

Earlier, Underwater Radiated Noise (URN) has primarily been a concern for vessels engaged in anti-submarine warfare (ASW), mine counter-measure and oceanographic research. The rising level of anthropogenic URN in the ocean, largely contributed by container ships, dry bulk and liquid tanker vessels (75% of the energy associated with URN) affects fisheries, research, emergency response and offshore activities where noise disturbs communication with subsea equipment. The presence of URN reduces data quality and decreases the operational range and accuracy of underwater sensors such as echo sounders, acoustic positioning systems, acoustic communication systems and towed arrays. Thus policies are being enacted for reducing the URN through appropriate vessel quieting technologies.

“The rising level of anthropogenic URN in the ocean, largely contributed by container ships, dry bulk and liquid tanker vessels (75% of the energy associated with URN) affects fisheries, research, emergency response and offshore activities where noise disturbs communication with subsea equipment”

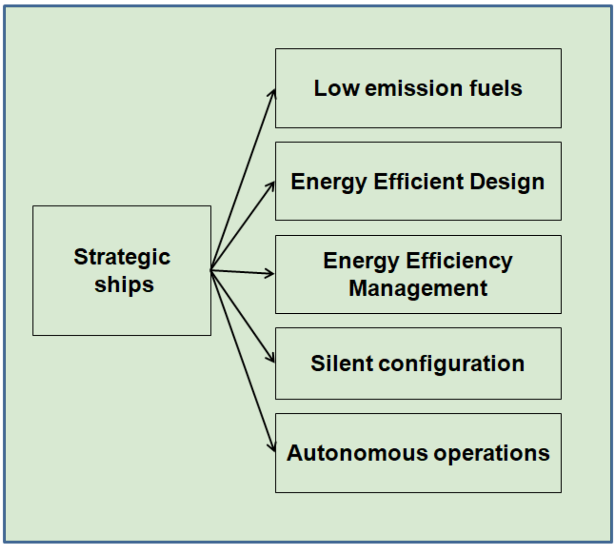

Figure. 1. IMO's eco-friendly initiatives for strategic ships

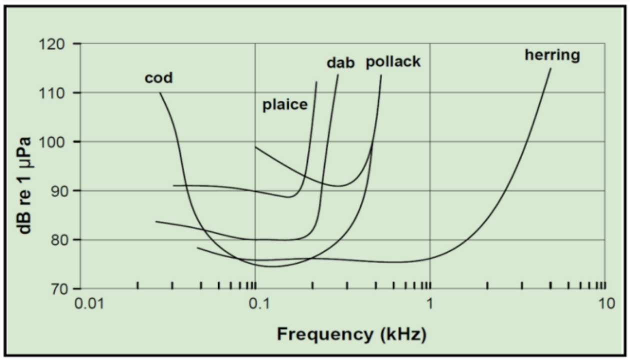

Figure. 2. Audible spectrum of fishes

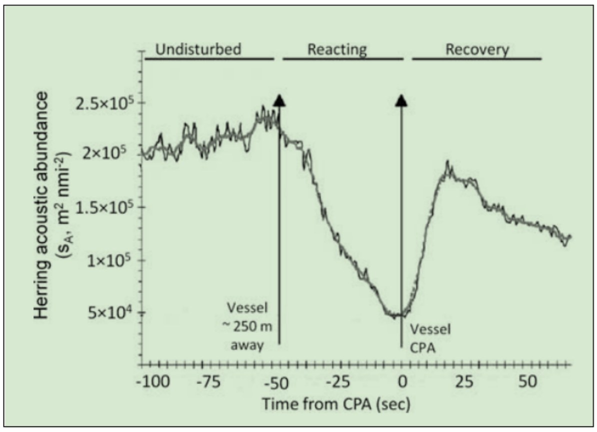

Figure. 3. Influence of URN in Atlantic Herring zones

Impacts of ship URN on marine ecology

As a vessel travels through different environments, from coastal to offshore waters, its URN field changes based on the water depth, temperature profile, bathymetry and seabed properties. The directionality of the noise field is highly variable. In shallow waters, the propagating noise repeatedly interacts with the water surface and seafloor, where it is reflected, scattered, and partly absorbed. In deep waters the directionality is dipolar (i.e. strongly downward) and interactions and hence acoustic energy losses at the seafloor and sea surface are reduced. The noise traveling in deep-ocean easily couples into the deep sound channel [i.e., Sound Fixing And Ranging (SOFAR) channel], where it can traverse entire oceans with very little acoustic energy loss. The noise from ship traveling over sloping bathymetry can enter the SOFAR channel with just one seafloor reflection. The noise fields, depending on its intensity, influences the behavioural responses in animals, creates acoustic interference (i.e. masking), temporary or permanent shifts in hearing threshold (TTS, PTS), masking of communication and echolocation sounds and produces stress.

The audible range of the fishes is depicted in **Figure. 2.** The lower the thresholds (y-axis), the more sensitive the fish is to the frequency. The lower frequency components of URN are sensitive to mysticetes (i.e. baleen whales) and higher frequencies (tens of kHz) influence odontocetes (i.e. toothed whales, dolphins and porpoises).

Due to the effects of ship URN, fishes avoid approaching vessels and this creates bias in fishery surveys. The reaction to ship arrival, due to URN, is found to occur at separation distances of more than several hundred meters. The mean backscatter of Atlantic herring measured by a stationary echo-sounder as the aggregation is approached and then passed by a research vessel suggests that the stimulus propagates well ahead of the vessel **(Figure. 3).**

Given the potential impacts of avoidance reactions on abundance estimates, various experiments have been conducted to characterise the impacts of vessel-induced fish reactions on acoustic abundance estimates relative to undisturbed states. The quantitative comparisons of fish backscatter from undisturbed fish and during vessel passage for various species is depicted in **Figure. 4.** The symbols indicate the mean ratio of an abundance measurement made during vessel passage to the undisturbed abundance (VA).

Fishes detect sound with paired inner ears **(Figure.5),** located in the cranial cavity lateral to the brain at the level of the medulla, that closely resembles ears found in other vertebrates. Since a fish's body is the same density as water, there is no need for any external structures (external or middle ears) to carry sound to the sensory regions of the ear. The ear consists of three semi-circular canals and associated sensory regions (ampullae) that are primarily involved in detection of angular acceleration and three otolith organs (saccule, lagena, utricle) that are involved in hearing and positional senses. There is very substantial variation in the morphology of the ears of fishes and particularly in the regions associated with hearing, leading to the suggestion that there is very substantial diversity in hearing mechanisms (and potentially capabilities) in different species.

The auditory parts of the ear, the otolith organs, each have a sensory epithelium that lies in close contact with a dense calcium carbonate structure, the otolith. The sensory epithelium (often referred to as a macula) has many sensory hair cells that are very similar to those

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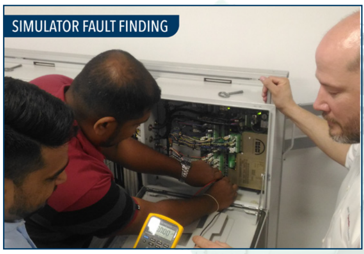

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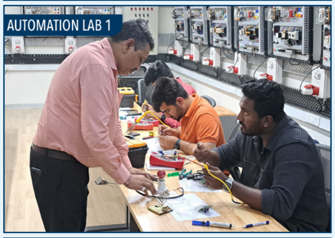

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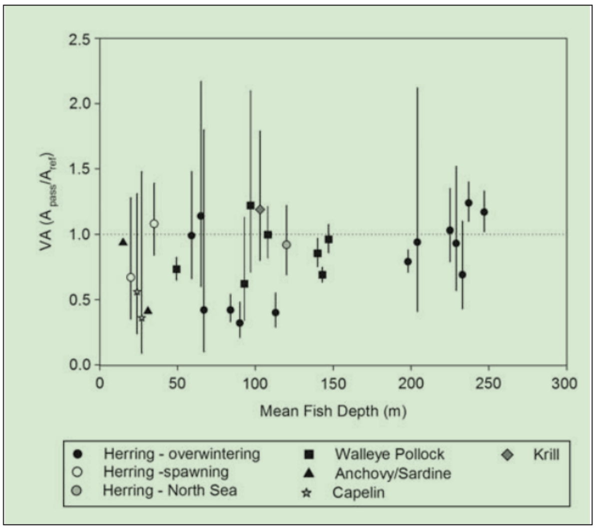

Figure. 4. Impacts of vessel-induced fish reactions

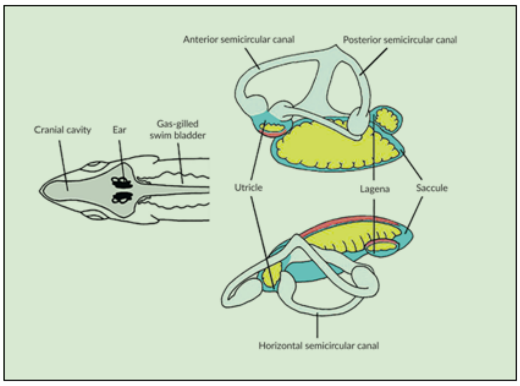

Figure. 5. Construction of fish hearing system

found in the mammalian ear. When a fish is exposed to particle motion, the body, along with the sensory cells, moves with the water, while the far denser otoliths move at a different amplitude and phase. This results in bending of the cilia on the apical surface of the sensory cells, releasing a neurotransmitter and sending a signal to the brain through an afferent neuron. The sensory hair cells are morphologically polarised and the response of an individual cell changes with bending in different directions. Thus, each cell is directionally sensitive. These hair cell orientation patterns, which vary in different species, show graded responses to particle motion from various directions, thereby enabling a fish to determine direction by comparing information from different receptor groups.

The swim bladder (and other gas-filled cavities) potentially plays a major role in the hearing function of fishes. The gas within the swim bladder is compressible and undergoes changes in volume in response to fluctuating sound pressures. **This results in the swim bladder serving as an acoustic transformer, translating sound pressure into re-radiated particle motion.** This produces higher levels of particle motion at the ears that stimulates the otolith organs. Any increase in the level of ambient ocean noise results in a rising of the auditory threshold and a decline in the ability of the fish to detect, locate and recognise particular sounds. Critically, the masking of biologically relevant sounds occurs not only as a result of increases in natural ambient sea noise (caused by wind and rain) but also by anthropogenically induced noise. The frequency and amplitude of the ocean ambient noise is shown in **Figure. 6.**

However, fishes that do not hear well may be less likely to have their hearing sensitivity affected by masking noise, since the lowest sound level they can detect may be above the level of the background noise. The influence of masking in *Gadusmorhua* and *Salmo salar* by ambient noise is described in **Figure. 7.** The thresholds were determined using a pure tone signal at a frequency of 160 Hz. The ambient noise is expressed as the spectrum level at that same frequency (dB re 1 µPa/Hz). Closed symbols, thresholds to natural levels of ambient noise; open symbols, thresholds to anthropogenic noise. The thresholds in *S. salar* were only influenced by high noise levels, above the natural ambient levels of noise.

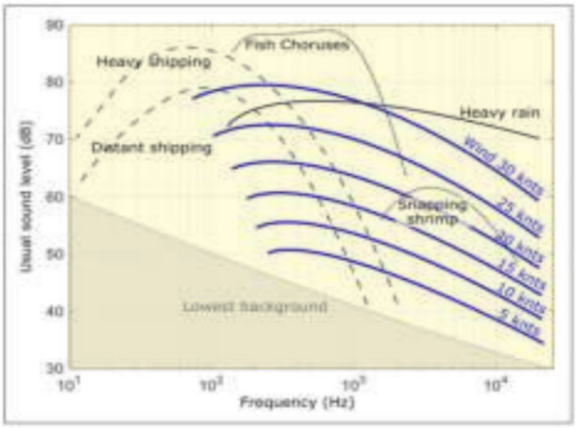

Figure. 6. Sources of ambient noise in the ocean

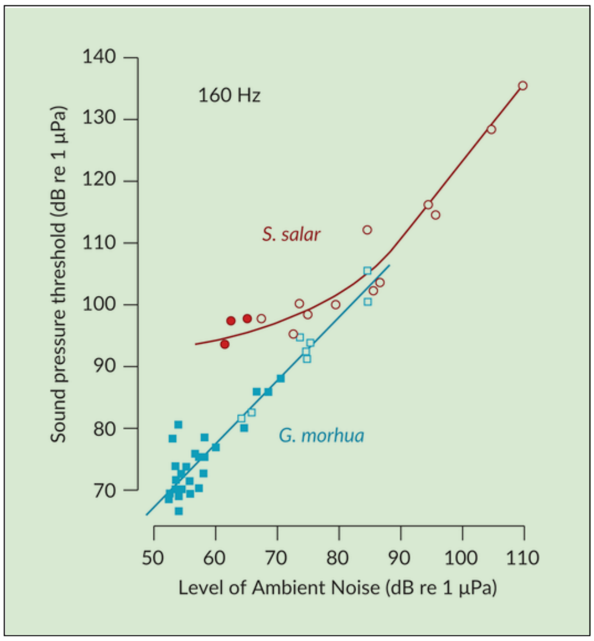

Figure. 7. Influence of masking by ambient noise

Higher levels of URN results in mortality, temporary hearing impairment, physiological changes, changes in behaviour and the masking of biologically important sounds. There may be significant consequences to individuals and populations as a result of changes in behaviour, including impairment of spawning, interference with foraging and feeding, or disruption of migrations and habitat selection. The U.S. National Marine Fisheries Service (NMFS), as well as other agencies, currently uses 150 dB re 1 μPa (rms) as the sound pressure level that may result in onset of behavioural effects, the level above are expected to cause temporary changes in behaviour and these might include startle responses (though startle is not defined and has broad meaning to fish biologists), feeding disruption, area avoidance, etc. However, investigating responses to sounds of short duration, responses to continuous or repeated exposure, needs to be studied in detail. The consequences of higher URN in various animals are summarised in **Table.1.**

Table. 1. Influence of higher noise in marine species

Animal type	Mortal injury	Recoverable/ Impairment injury	Temporary Threshold Shift (TTS)
A	>219 dB	>216 dB	>>186 dB
B	210 dB	203 dB	>186 dB
C	207 dB	203 dB	186 dB
D	210 db	-	-

A: Fishes with no swim bladder;
B: Fishes with swim bladder not involved in hearing;
C: Fishes with swim bladder involved in hearing;
D: Sea turtles, eggs and larvae.

Propagation of ship URN in shallow and deep-oceans

The URN source levels vary based on the ship class due to variability in design, maintenance, and operational parameters such as speed **(Figure.8).** The overall broadband noise spectrum of URN ranges from a few Hz to over 100 kHz.

Modelling and simulation software are available for analysing the acoustic signal propagation in the ocean. They include Bellhop, DESERT, SUNSET and NS2. Bellhop is based on beam tracing approach for predicting the acoustic pressure fields in ocean environments. Beam tracing is done using geometric and physics-based spreading laws to determine the beam coordinates during the propagation. The inputs for the simulation tools include specifications of the directional pressure sources, location-specific sound velocity profile and the geo-acoustic properties of the boundary zones. The simulation outputs include transmission loss (TL), Eigen rays, arrivals and received time-series.

Seafloor is modelled with properties as hard and dense limestone

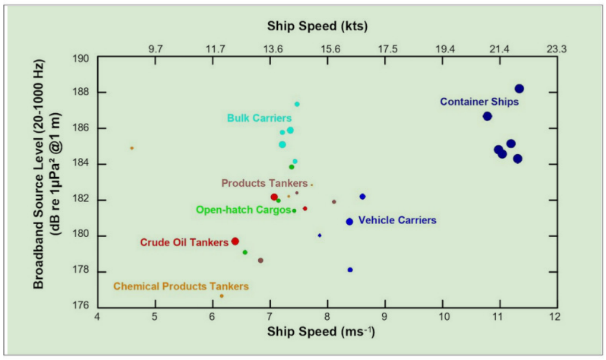

Figure. 8. URN from various vessels

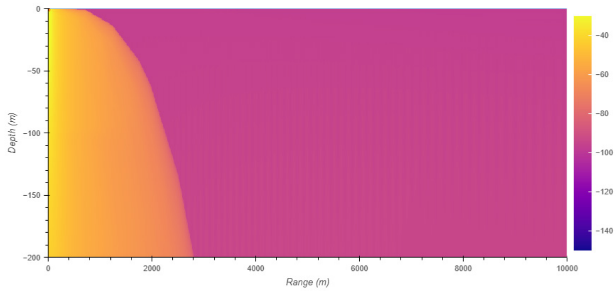

Figure. 9. Sound field due to 185dB-2 kHz surface source located at 200m water-depth location

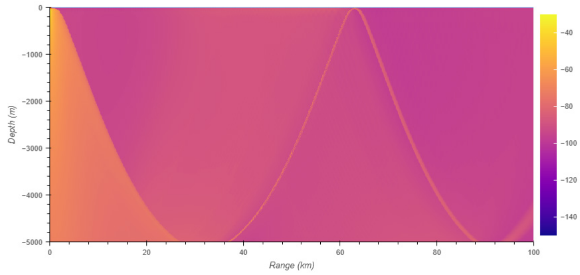

Figure. 10. Sound field due to 185dB-2 kHz surface source located at 5000m water-depth location

Modelling and simulations are carried out using modelling and simulation software Bellhop for a source with power level of 185db at 2 kHz located at the sea surface. **Figure. 9 and 10** shows the simulation results for when the location water depths are 200m and 5000m, respectively.

Figure. 11 depicts the simulation results of the RAMGeo in AcTUP V2.8 software (done by Australian Centre science and Technology) showing the noise field when a cruise ship with a source level of 191 dB re 1 μPa m passes over the continental slope with the indicated sound velocity profile.

Seafloor is modelled with properties as hard and dense limestone. Dipole radiation pattern (in which most energy radiating downward) is visible. The sound energy propagates poorly into shallow water (with received levels

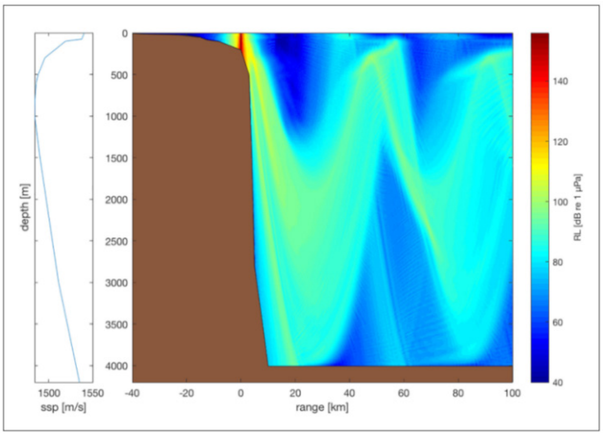

Figure. 11. Sound field of191dB when ship passing over a continental slope

rapidly decreasing with increasing range) propagates well with reduced losses into deep water.

Silent/Quiet Notation for ships

The evolution of the standards for reducing the ship on-board noise, noise radiated to harbour and URN are summarised in **Table. 2.**

DNV issued the world's first underwater noise notation in 2010, the SILENT class, for various vessels **(Table. 3). The intention of the notation is to provide owners of acoustically sensitive vessels with concise and realistic criteria for underwater noise emission, and to provide environmentally conscious owners an opportunity to demonstrate a low environmental foot print.** Ship noise measurement standards include, DNV Silent URN measurement procedures, ANSI/ASA S12.64-2009 and ITTC recommended procedures for URN from ship reference 7.5-04-04-01.

The allowed frequency band for various silent classes is shown in **Figure. 12.** The stringent level of URN requirement in the SILENT class notation is SILENT-R for research vessels. In 2019, DNV-GL awarded Silent-R to the DONG FANG HONG 3 scientific research vessel. The first

DNV issued the world's first underwater noise notation in 2010, the SILENT class, for various vessels

Table. 3. Classification of vessels based on noise levels

Class	Vessel
A	Vessel using hydro-acoustic equipment
S	Seismic vessels
F	Fishery vessels
R	Research
E	Environmental

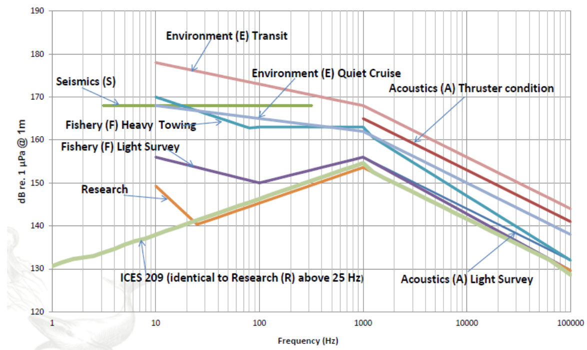

Figure. 12. Frequency range for various silent class vessels

DNV Silent-E class notation was awarded to a merchant vessel and LR2 crude oil tanker new- build. ONEX Peace, an Aframax tanker built by Hyundai Samho Heavy Industries has become the world's first merchant vessel to receive DNV's SILENT-E notation. DNV's CG-0313 standard provides measurement procedures for URN and external airborne noise emissions.

Sources of ship URN and noise reduction technologies

The various sources of ship-based URN **(Figure. 12)** and the methods recommended to reduce are summarised in **Table. 4.** The IMO and IACS agencies recommends propellers design to reduce cavitation by appropriate selection of propeller diameter, number of blades and pitch to reduce generation of URN.

Table 2. Standards for regulating the ship noise

Period	Noise (On-board)	Vibrations (On-board)	Noise radiated to harbour	URN
1974	SOLAS regulation	-	-	RESWCC3-068
1975-81	IMO A 343, A 468			
1984		ISO 6954		
1990	Comfort class notations	-		
2001			ISO 2922	
2002-06	ILO convention to fishing sector		ISO 14509-2	ICES-N 209
Post 2007	IMO A 468 revision 85dB-80db(A)		ISO 14509-1	DNV Silent class

Table. 4. Generation of URN and methods of reduction (Figure. 13)

URN source	Methods to reduce
Propeller noise	Due to cavitation and depends on propeller design and hull shape, electric propeller
Rotating machinery	Engine vibration levels, Foundation stiffness, resilient mountings
Hull	Hull smoothness and coatings

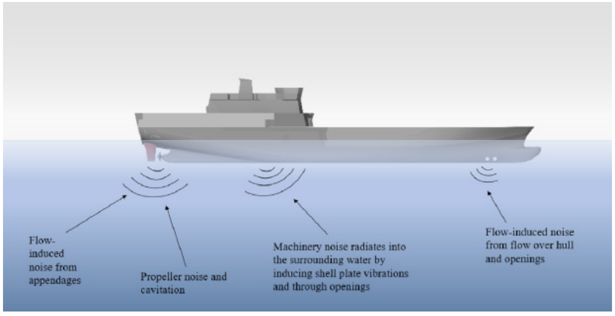

Figure. 13. Sources of ship URN

The shape of a ship's hull and the resulting wake affect the propeller performance and resultant URN. Hence hull and propeller design together reduces URN. Larger machinery such as engines, turbines and diesel generators also have a greater influence on URN production and hence to be mounted on vibration-resistant mountings.

Propeller, Hull form and Machinery

Propeller noise is classified into cavitating and non-cavitating, with cavitation noise tending to dominate at higher vessel speeds (>8 knots). For a non-cavitating propeller, tip vortex noise is the dominant source if the propeller is operating in a uniform flow. Propellers also produce trailing edge and leading edge noise, as well as noise from the hub. Trailing edge noise results from the convecting turbulent boundary layer over the trailing edge, where the fluctuations scatter as acoustic waves. This can be broadband or narrowband, depending on the factors such as the Reynolds number and the thickness of the boundary layer relative to the edge thickness. This can also lead to propeller singing, where a fluid–structure interaction leads to a high-pitched tonal sound being produced. This occurs when the dominant vortex shedding frequency matches with the natural frequency of the blade. Leading-edge noise results from unsteady and turbulent flow interacting with the leading edge of a lifting surface, which induces pressure fluctuations and hence noise. Low frequency tonal noise occurs as a result of the propeller rotating through a spatially-varying wake field which can lead to cavitation, as well as non-cavitating noise.

Propeller noise is classified into cavitating and non-cavitating, with cavitation noise tending to dominate at higher vessel speeds (>8 knots)

Low frequency cavitation noise tends to be due to attached cavitation bubbles oscillating as the propeller rotates through a spatially varying wake field, whereas detached cavitation and vortex cavitation tend to increase noise levels at higher frequencies. **Vortex cavitation can occur at the tip and the hub. Tip vortex cavitation is often the first to occur and arises due to the low pressure in the tip vortex core.** This type of cavitation is very sensitive to the particular dynamics of the tip flow and also the water quality, which refers to the size and distribution of nuclei in the water. Hub vortex cavitation occurs when the pressure in the hub vortex drops below a certain point, which is again dependent on the water quality as well as the dynamics of the vortex itself.

Sheet and bubble cavitation can occur when the pressure drops below the cavitation inception point at, or close to, the propeller blade. This will typically occur on the suction side, but can also occur on the pressure side in off-design conditions or for controllable-pitch propellers operating at reduced pitch. Bubble cavities originate at the blades but travel with the flow, and have historically been associated with high noise levels and erosion. Unstable sheet cavitation leads to cloud cavitation, which tends to lead to a large increase in the URN levels. Sheet cavitation is found to increase the noise levels at blade rate harmonics and also at higher frequencies, where the increase in broad-band noise is due to splitting and collapse of bubbles. Noise is produced by growth, oscillation and collapse of cavitation bubbles, as well as by splitting and coalescence. Cavitation bubble collapse can produce noise several orders of magnitude higher than the noise associated with growth, oscillation and splitting.

Applied to flow control at the stern of a ship, vortex generators could be used to transfer momentum towards the top of the propeller plane, increasing the axial velocity and reducing flow separation.

Figure. 14 Vortex generators fitted upstream of a propeller

Demonstrations indicate that placing a vortex generator on the hull upstream of the propeller reduced flow separation at the top-dead-centre location, which led to a decrease in the amplitude of the pressure fluctuations at the blade-rate harmonics. As well as being a mature technology within the aerospace industry, vortex generators have undergone successful full-scale trials on board ships, indicating a high level of maturity **(Figure. 14).**

> *The flow over the hull and appendages also produces URN, and this generally becomes more prominent at higher speeds*

The flow over the hull and appendages also produces URN, and this generally becomes more prominent at higher speeds. Both leading and trailing edge noise will be produced by appendages such as the rudder and stabilizer fins. Interaction noise arises when turbulence from the flow over one structure interacts with another.

For example, the unsteady turbulent flow from a propeller interacts with the rudder, inducing pressure fluctuations on the rudder surface. Hydrofoils produce trailing edge noise, tip vortex noise, and may also cavitate. Noise from openings arises from pumps used within systems directly connected to the sea, and from the flow over the openings and sea chests. Other machinery including generators, pumps, and heating, ventilation, and air conditioning (HVAC) contribute to the overall sound radiated into the surrounding water. The level of URN resulting from on-board machinery is therefore very specific to the type and size of the vessel, as well as the mounts used for individual engines, generators, etc.

Podded propeller

A podded propeller is a streamlined, roughly cylindrical pod with a propeller attached to one end (usually the front end) that is suspended from the bottom of the ship. The pod, which contains the electric motor driving the propeller, can be designed to swivel in a circle so as to direct the propeller's thrust in any direction and thereby steer the ship. A podded propulsor eliminates the need at the stern of the ship for a lengthy, exposed horizontal shaft leading to the propeller and a rudder for steering the ship. **Figure. 15** (top) shows a conventional propeller/stern arrangement with horizontal shaft, strut, propeller and rudder. The bottom one is a propeller /stern arrangement with rotating pod propulsors and no rudder.

With podded propulsors, there are fewer exposed components to create drag (i.e., resistance to forward movement), and the propeller encounters a more uniform water flow, increasing its efficiency (which is its ability to use its RPMs to create thrust). Using podded propulsors can improve a ship's manoeuvrability by permitting a tighter turning radius and by giving it the ability to change the ship's direction of movement or its orientation even at very low speeds. Podded propulsors might also offer certain advantages in terms of maintenance and repair, since the pod can be detached and quickly repaired or replaced by a like unit without need for cutting an opening into the ship's hull and working around other equipment. Various types of motor include synchronous, induction, permanent magnet, super-conducting synchronous and homo-polar types. Podded propulsors has a low acoustic signature as there are no shaft components and bearings.

Low-noise electric motors

In the past, DC motors were used exclusively, since, in addition to the good low-speed torque characteristics, they produced very smooth torque, causing less URN compared to AC motors. With modern frequency converters based on insulated-gate bipolar transistor (IGBT) technology, a very low level of current ripple can be achieved. Nowadays, when combined with properly designed AC motors, this has enabled electric drives based on AC rather than DC technology in silent vessels. Typically, AC propulsion motors have been either

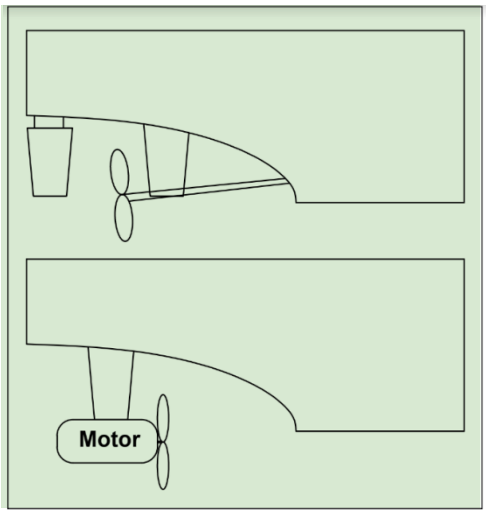

Figure. 15. Configuration of a conventional and podded propulsors

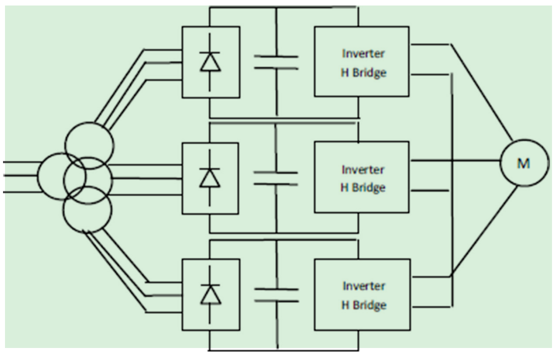

Figure. 16. Multi-level Inverters (MLI) for low noise applications

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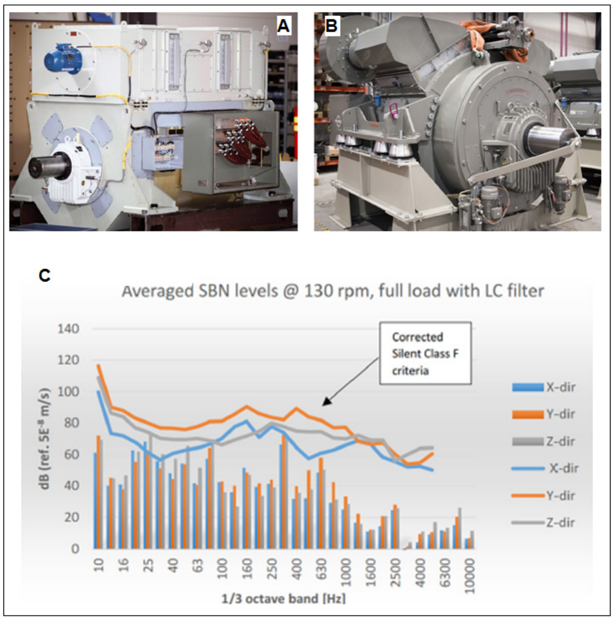

Figure. 17. PM Motors and generators for silent-class vessels

induction or synchronous machines, since they are well-known technology. The drawbacks, however, are reduced efficiency and bigger size and weight. Multi-level inverters (MLI) **(Figure. 16)** produce common-mode voltage reducing the motor winding stresses, produce lesser ship mains distortion and operate at wide range of switching frequencies. MLI can provide multi-stepped output of low frequency or high frequency. The multi-stepped output minimises the harmonic content and a passive filter helps in attaining a sinusoidal output waveform thus reducing the structural-borne noise and audible noise, finally reducing the magnitude of URN.

In addition to the AC and DC drives, Permanent Magnet (PM) motors and generators help to significantly reduce vibration levels and hence URN. In order to minimise airborne and structural-borne noise levels from these PM machines, the electromagnetic vibration level is being reduced by optimising the rotor pole shape and by applying skewing for the magnets. **Figure. 17** shows a 3MW PM generator and 2.25MW PM propulsion motor and its compliance with Silent-F notation. Sleeve bearings were used in both machines to keep mechanical excitations low. Low-speed cooling fans were used to limit audible noise. Resilient mountings or mechanical dampers, were used for connecting the machines to achieve low URN. **Proper electro-mechanical design, combined with the use of resilient mountings and converter-side filtering, results in very low structural-borne noise levels, which can meet even the most stringent DNV Silent F requirements.**

With podded propulsors, there are fewer exposed components to create drag (i.e., resistance to forward movement), and the propeller encounters a more uniform water flow, increasing its efficiency (which is its ability to use its RPMs to create thrust)

Technological maturity and Way ahead

Anthropogenic sound have increased in recent times as a result of increases in shipping, harbour developments, construction and operation of offshore wind farms, tidal and wave energy generation, dredging and cable and

Table. 5. Maturity of URN reduction technologies

Noise source	Technology	TRL
Sheet and bubble cavitation, blade-rate noise	Vortex generator	7–9
Tip vortex cavitation	Water/polymer injection	3–4
	Flexible thread	3–4
	Winglets	4–5
	Roughness applied to tip/ edges	3–4
Hub vortex cavitation	Propeller boss-cap fin/ eco-cap	6–7
Propeller noise (cavitating and non-cavitating)	Energy-saving devices to reduce propeller rotation rate	1–3
Leading-edge and trailing edge noise	Serrated leading/trailing edges	4–6
Tip vortex cavitation, leading-edge and trailing-edge noise	Porous surfaces/edges/tip	3–4
Machinery noise	Passive isolation mounts	9
	Nonlinear isolation mounts	5–7
	Active/hybrid isolation mounts	9
	Acoustic insulation/ mineral wool	9
	Acoustic black hole	3–4
	Aerogels/metamaterial absorbers	3–4
Machinery noise, flow noise in ducts and pipes	Acoustic duct silence	3

pipe laying, seismic surveys for oil and gas and offshore oil developments. A number of research programs have greatly enhanced our understanding of the make-up of ship radiated noise, including the large collaborative EU projects (SONIC, SILENV, AQUO). Such programs have improved our understanding of cavitation noise, machinery noise, and other components, but they have also highlighted the large differences that occur between vessel types and operating conditions.

This provides further weight to the argument that more data is needed across a broader range of ship classes. The signature is often broken down into machinery noise, flow noise, and propeller noise which includes cavitation noise. There are numerous published works of full-scale trials and other experimental studies that demonstrate the levels of noise produced by different vessels, and these also provide details on some of the dominant components. These studies tend to show that low frequency noise (<125 Hz) is dominated by tonal components associated with the main engine firing rates and propeller blade-rate harmonics. Higher frequency noise is made up of machinery noise, propeller and flow noise, and cavitation, but breaking this down into its constituent components is challenging.

> *"Nowadays, when combined with properly designed AC motors, this has enabled electric drives based on AC rather than DC technology in silent vessels"*

However, by targeting each of the individual sources, significant reductions in the overall noise produced should be achievable. Furthermore, by considering the sources individually and examining their physical origins, designs and technology can be developed and applied more successfully to reducing the overall radiated noise levels. An overview of the maturity of the URN reduction technologies in terms of technology readiness level (TRL) is summarised in **Table. 5.** Future research should aim to provide more granularities on the make-up of the acoustic signature of different vessels. This would help to determine which technologies could provide the greatest benefit to reducing the overall noise.

The lack of uptake of noise reducing technology can be attributed to a number of factors. Firstly, there are no legally binding requirements for vessels to reduce noise, and an international agreement on this is likely to still be some way off. Secondly, there remains a lack of data that quantitatively determines the reduction in noise achieved by adopting a particular device. Given the costs of retro-fitting devices or designing new vessels with technology that is perceived to be uncertain and immature, the lack of uptake is perhaps not surprising. Finally, with the exception of devices that also improve energy efficiency, there are currently few economic incentives for ship owners and operators to adopt noise reducing measures. Notable exceptions are the Prince Rupert Port and Port of Vancouver EcoAction programs, where vessels pay reduced harbour fees if they meet certain noise and other environmental criteria.

If programs such as this were implemented more widely, then ship operators would be more incentivised to reduce noise. This should, in turn, encourage more research to mature different technologies and carry out more trials to demonstrate noise-reduction. This creates a virtuous circle, as more visibility of these issues together with more research will lead to a wider take-up across the industry. Developments in acoustic meta materials, and some of the measures for reducing fluid-induced noise and tip vortex cavitation are far less mature, but they have shown much promise in experiments and numerical analyses. Research must continue with a view to maturing these and assessing the integration and operability issues associated with marine vessels. Even though there are a wide range of technologies in different stages of maturity, lack of quantitative data on the effectiveness of many noise-reducing technologies, particularly at full-scale. This makes legislation more difficult to enact and, together with the lack of economic incentives, is limiting the adoption of such technology by the marine industry.

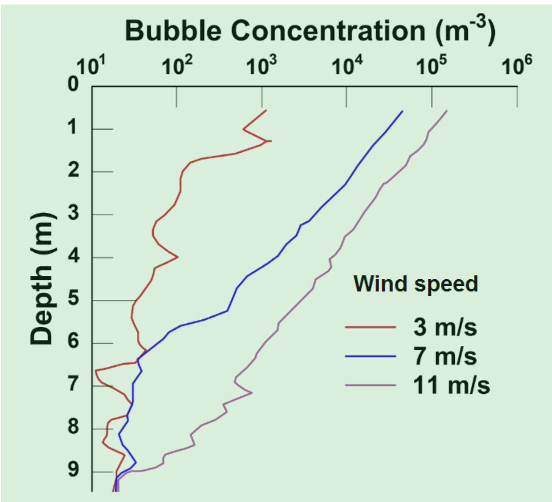

Figure. 18. Mean bubble concentration as a function of depth for various wind speeds

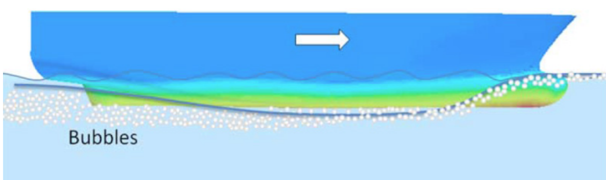

Figure. 19. Representation of BSD path

Further, most classification societies now offer a Quiet Ship Notation to help guide and verify the low signature credentials of a vessel. Certification is normally outlined through 3rd octave target sound pressure levels and tested through the use of full-scale trials, although it is acknowledged that this measurement process is fraught with challenges of consistency and standardisation. Concerted efforts are needed to compare different notations across the different class societies and also to harmonise some definitions and procedures. Thus a global regulatory alignment supported by cross-sector research and development, scaled-up controlled pilot projects, coordinated industry commitments, flexible and modular designs, shall be the key factors required to achieve the silent transition.

Improving Sonar performance in hydrographic vessels

Multibeam sonar (MBS) is a type of active sonar system comprising multiple physical sensors (called a transducer array) that send and receive the sound pulses that map the seafloor or detect other objects in the water column. MBS arrays are usually mounted directly on the hydrographic/research ship's hull bottom keel region. Bubbles created by the movement of the ship and ingested in the natural flow lines across its MBS causes significant acoustic signal loss. As bubbles resonate, they very effectively attenuate (absorb and scatter) sound at a frequency very close to its natural oscillating frequency. In bubbly waters, when the quantity of air is 0.001%, 0.01% and 0.1%, the sound speeds are 1488, 921 and 358 m/s, respectively.

Many processes in the upper ocean determine the distribution of the bubble population. In the first few meters near the surface, bubbles are present due to waves breaking on the sea surface when the wind is strong. Wind-driven shear creates turbulence to inject large numbers of bubbles into the ocean. Larger bubbles (>200µm) being more buoyant, return to the surface and dissipate very quickly. Smaller bubbles, being much less buoyant, tend to persist for minutes to hours. In case of wind-generated bubbles, the number of bubbles/m^3 and their function of depth are greatly influenced by wind speed. **Figure. 18** shows the plots with horizontally averaged estimates of the mean bubble concentration as a function of depth for three different wind speeds. It is reported through video graphic observations, in 30m of water and a wind speed of 8-10m/s blowing for several hours, all bubbles at 0.7m and 1.8m were < 100µm and <128µm, respectively.

Based on a research results (by Office of the Naval Research/ONR and Ifremer, France) published in the Journal of the Acoustical Society of America (JASA), the presence of air bubbles account for an increase in the background noise level of 8-10 dB in Sea State 3, 10-13 dB in Sea State 4, and > 15 dB in Sea State 5. Seafloor acoustic backscatter measurements made with hull-mounted arrays are adversely affected during Sea States >4 due to bubble sweep down (BSD) phenomena **(Figure. 19).** The BSD is further increased by the pitching motion, thus limiting the mission capability of the hydrographic vessel.

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Hitherto, there is no complete remedy for the avoidance of the bubble formation in the flow stream. Part B of the article describes a hydrodynamic re-design approach for the hull geometry in the forward region and the creation of an effective bubble diverter bow. **A new modified bow form is investigated to help in deflecting the stream lines away from the location of the sonar transducer.** Numerical flow simulations for the developed hull form using computational fluid dynamics (CFD) tools are used to demonstrate that the streamlines can be effectively diverted without degradation of the performance of the sonar transducer.

Abbreviations

AC	Alternating Current
ANSI	American National Standards Institute
BSD	Bubble Sweep Down
CFD	Computational Fluid Dynamics
dB	Decibel
DC	Direct Current
DWT	Dead weight tonnage
EEDI	Energy Efficiency Design Index
EU	European Union
IACS	International Association of Classification Societies
IGBT	Insulated Gate Bipolar Transistor
IMO	International Maritime Organization
ITTC	International Towing Tank Conference
JASA	Journal of the Acoustical Society of America
MBS	Multibeam Sonar
MLI	Multi-level Inverters
MW	Megawatt
NMFS	National Marine Fisheries Service
ONR	Office of the Naval Research
PM	Permanent Magnet
PTS	Permanent threshold shift
SDG	Sustainable development goal
SEEMP	Ship Energy Efficiency Management Plan
SOFAR	Sound Fixing and Ranging Channel
SOLAS	Safety of Life at Sea
TL	Transmission Loss
TRL	Technology Readiness Level
TTS	Temporary threshold shift
UN	United Nations
URN	Underwater Radiated Noise

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Predictive Maintenance Applications in the Maritime Sector

Prabu Duplex

Summary

The maintenance concepts applied in the maritime sector are generally still rather traditional, meaning that maintenance intervals are often constant in time, independent of the specific usage of the systems and the operating conditions. As a result, many systems and components are repaired or replaced before needed, while other components unexpectedly fail before the end of the interval. The early replacements are inefficient in terms of spare part and labour costs, hence lead to ineffective supply chains, while the unexpected failures affect the availability of the systems and may cause significant additional damage. Failures frequently lead to safety (failing naval systems) or environmental issues (offshore incidents), which means that there is a strong drive to prevent failures. However, at the same time both shrinking budgets and competitive business environments call for reducing sustainment costs. This work addresses these issues and offers an implementable solution.

Introduction

Ship propulsion systems are operated in a dynamic way. These systems are maintained by preventive or corrective maintenance concepts. However, company 2 reports a technical availability of their assets to be high (app 97.1%), but the operational availability is of 87.1%, considerably below their target [1]. Company 1 presently maintain their assets based on equipment manufacturer instruction, however if the ships are used in a conservative manner, they prolong the maintenance interval based on their manager's experience [2]. Therefore, the company needs a scientific approach to plan their maintenance activities. Shipping companies want to improve their operational availability and optimise improve their present maintenance practices. The challenge is to identify a suitable maintenance concept capable of optimising maintenance practices. In line with this discussion the present work analyses present maintenance practices in two companies, introduces a component selection procedure and proposes new maintenance practices. The discussed framework will also be helpful for the maritime sector in general.

Specific challenges

On board ships, preventive or condition-based maintenance are generally in use, which are generally based on predefined alarm thresholds or manufacturer instructions based on operating hours. In addition to that present maintenance programmes, mostly rely on previous experiences and expert knowledge, and do not consider the actual condition of the asset. Sometimes unexpected failures occur, which incurs operational risk, disruptions in supply chains and higher operational costs. To increase the reliability and dependability of assets, maintenance actions are being conducted in a more conservative way. These actions affect the flexibility of operations and associated logistics bottle necks. Competitive pressure

On board ships, preventive or condition-based maintenance are generally in use, which are generally based on predefined alarm thresholds or manufacturer instructions based on operating hours

now forces companies to increase the availability of their equipment. It is therefore important to plan maintenance actions just in time.

In practice it is not always feasible, to conduct maintenance only based on the actual condition of the asset. In order to do so, it requires collection of real time data, of the condition of the asset using acquisition systems. Predictive maintenance (PM) thus informs the current and future state of the assets. Although predictive maintenance offers various benefits, the adoption in practice lags the theoretical understanding of it. The challenge lies in selecting the most suitable components for physics modelling, having the highest asset benefits and best potential for implementation. Having identified it, the dominant material degradation parameters can be determined in relation to the component's operation and load conditions.

To address these issues, a component selection procedure is proposed in this work, and based on its outcome physical models can be developed to predict the lifetime of components. Once a physical model is identified, the benefits can be demonstrated, by means of its application in various operational scenarios.

Propulsion system across the fleet

While the pressure to reduce fuel consumption and emissions has increased, the operating profile of ships has become increasingly diverse. For example, offshore vessels perform numerous tasks, such as transit and critical dynamic positioning (DP) operations etc. Due to these diverse operating profiles, the power plant and propulsion plant must perform well on many performance criteria, such as, fuel consumption, emissions, radiated noise, propulsion availability, manoeuvrability, comfort due to minimal noise, and vibrations; maintenance cost due to engine thermal and mechanical loading; and purchase costs.

Furthermore, the diverse operational profile makes it hard to optimise the power and propulsion plant for a specific operating point at a vessel's design stages, as was conventionally done. Thus, the power and propulsion configuration has been adapted to a varied operating profile with electric propulsion. However, although electrical propulsion is more efficient at low speeds, it introduces additional conversion losses due to various electrical components such as generators, power converters, involved.

This trade-off between efficiency and adaptability to diverse operating profiles has led to a growing variety of power and propulsion architectures, which can be categorised into mechanical propulsion, electrical propulsion or a hybrid combination of both. This shown in **Figure 1**.

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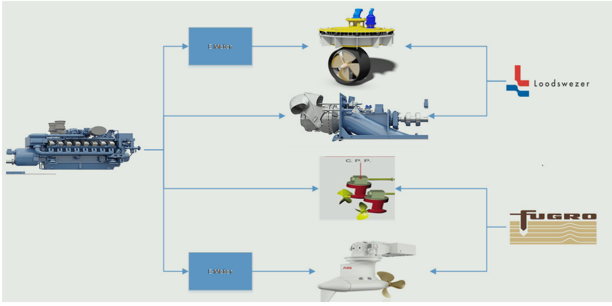

Figure 1. Propulsion system overview

Overview of ship operations and operational profile

Company 1

Company 1 is one of the world's leading geological specialists [2]. They provide advice to businesses and governments on acquiring natural resources and infrastructural challenges, by acquiring, processing, and interpreting geological data. To meet the client's needs all over the world, the organisation is decentralised in many countries. The services are organised into four divisions: Geotechnical, Survey, Subsea services, and Geoscience.

A major part of their turnover is related to research of the bottom of the sea, which makes the functioning of the supporting fleet an important factor in completing the projects. As the projects are conducted in challenging circumstances, the market requests reliable vessels. To offer their clients high quality standard and to limit opportunistic behaviour of external vessel managers, they started the in-house vessel managing company (VMC). VMC manages the fleet for the operating companies of Company 1. Since then, the fleet of VMC has grown. The projects are not carried out in the middle of the ocean, as the workable depth of the VMC vessels is limited, i.e. the sonar projects could be conducted at a depth from 5 to 2000 meter and AUV projects can be conducted down to a depth of 3000 meter. In principle there are no projects conducted at the ocean, so the work is restricted to projects nearer to the shores.

Company 1 owns, operates or co-operates survey ships, ships for subsea work, and geotechnical vessels. Survey operations incorporate precision equipment, which needs to be operated in less noise and vibration surroundings. In addition to that, the operations needs to be carried out precisely (good manoeuvrability) with less disturbances due to sea conditions, without external assistance from tugs.

Introduction to operation modes of the vessel

The Standard Survey Vessel (FSSV) is a type of survey vessel of which four are sailing. FSSVs are used for conducting survey projects. The durations of projects vary for a couple of weeks to months. Weather conditions play a vital role in the duration of the project. The vessel can be operational, lying for anchor (in or out of a port) or in a transition towards a new project location. **When the vessel lies for anchor in a port, the crew can be changed and delivered supplies and service men can easily board the ship.** The survey projects require reasonably good weather conditions, and the weather forecast is well up to 7 days ahead. Typical operation modes are summarised in **Table 1**.

Based on **Table 1**, it can be observed that each vessel lies approximately 109 to 153 days per year in anchorage, in a port or somewhere else. The yearly 13 crew changes need approximately 130 hours, and the projects need another 100 hours of mobilisation. It turned out that most of the anchor time is due to bad weather. The utilisation will vary due to different weather conditions over the years. A different usage of the vessel probably affects the deterioration of the equipment, so they avoid heavy weather conditions.

If operational profile **(Figure 2)** is studied, the ships are engaged in survey operations most of the time, and the transit operations are less compared it. During survey operations diesel engines which supply propulsion power are partially (less than 50%) loaded, in-order to have high redundancy to avoid sudden power loss (black outs). In order to satisfy these criteria, most of the vessels operated by company 1 have diesel electric propulsion combined with controllable pitch propeller. Diesel electric propulsion system is typically applied to vessels, whose applications all feature an operating profile with a significant period of time at low speed and propulsion power.

Table 1. Typical operation modes

Action	Range percentages yearly actions of FSSV	Average
Port/ Anchor	Varying from 30% to 42% per year	34%
Transit	Varying from 12% to 26% per year	17%
Operation	Varying from 43% to 56% per year	49%

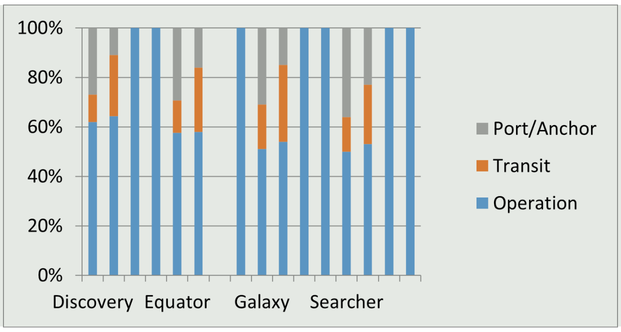

Figure 2. Vessel operation profile (selected fleet) [2]

Company 2

Company 2 offers support services to marine pilots [1]. The vessels it facilitates will bring the pilots to a ship at sea where they will guide the ship inside or the other way around. Depending on the size (depth) of the ship, the ship needs expertise from the pilot. Some ships are very large and need to be guided from deep sea of the port or back. The company is active in different areas of the Europe. Three types of vessels are currently employed by the company as follows (elaborated in **Table 2**).

Tender

A relatively small boat (~22 meter) that is used to transport pilots. The company has different types of tenders. Company 2 also uses SWATH's, a catamaran used as a tender.

Pilot Station Vessel (PSV)

These ships are large (~81 meter) and serve as waiting station for pilots. Pilots are transported to and from this ship by either a tender or an FLC.

Introduction to operation modes of the vessel

Pilot station vessels

Pilot Station Vessels (PSV) are waiting station at sea for pilots. There are permanently people on board, operating the ship to receive, send and provide service to pilots. The crew changes every week, ship returns to port every 3 weeks for supplies. On operation, the PSVs are located at central location at sea that doesn't change significantly during the period. Therefore, these vessels have light task (don't sail enormous distances, not always sailing, etc). In the design of the vessels, this has been considered (hence 2 different engines). PSVs has Diesel-Electric propulsion system. The usage of the Pilot Station Vessels is equal,

Table 2. Overview of Company 2's fleet

Vessel category	Propulsion type		Engine type
Type 1 tender		Waterjet	2 x Caterpillar C32 Acert, 12 cyl
Type 2 tender		Waterjet	
Type 3 tender		Waterjet	Caterpillar C32 Acert, 12 cylinder
Type 4 tender		Fixed propeller	Caterpillar C32 Acert, 12 cylinder
Type 5 tender		Fixed propeller	Detroit 12V71, 12 cyl (2S)
Pilot vessel	Diesel electric	Fixed propellers	Caterpillar C32 Acert
Swath	Diesel electric	Fixed propellers	2 x MTU 12V 2000M70

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measured in operating time. There are three PSVs. Since the vessels need to be used equally, they change positions twice a year.

Tenders

Tenders are smaller vessels, used to transport pilots. The way they are used is different from the PSVs. Instead of lying still at sea, these boats sail large distances most of the time. They operate at high speed (PSVs do not) and in high swell and wear faster than the PSVs. Tenders have Diesel-Direct propulsion system with water jet engine. Jet engines are safer to operate, especially for a company like this, because people cannot be injured by a propeller when falling in the water. These tenders are very different from the PSVs, both in the way they are used and the way they are driven.

"The plan includes the prescription of how equipment should be maintained in between dry docking periods and which and how much spare parts should be taken on stock for breakdown maintenance"

The usage of the tenders differs heavily in both time and intensity. The different locations also make the intensity of the trips different. The swell for instance is different and the swell can change at a certain location too. Therefore, not every vessel at one location necessarily must be used an equal amount of time. Company 2 also has also vessels designed for icy conditions, they have a steel hull and are propeller driven. Both the ice conditions and vessel specifications make the ships to be operated differently.

A typical pilot transfer operation consists of 15 mins low RPM sailing, 1hour full speed, 10 mins lower RPM pilot transfer, 1-hour full speed, and 15 mins low rpm. The operation profile of propulsion system of vessels considering 3500 hours annual operating time, has the following load profile:

- 10% of operating time   100% load
- 50% of operating time   80% load
- 10% of operating time   15% load
- 30% of operating time   10% load

Present Maintenance Practices

Details of Maintenance practice at Company 1

In Company 1 external maintenance services are planned by the vessel superintendent, and internal maintenance jobs are prescribed by the Maintenance Engineering (ME) department and conducted under the supervision of Chief Engineer in ships. Spare parts are stored aboard, and new spare parts are arranged via purchasing division. The maintenance plan is made and implemented in computerised maintenance management system (CMMS) under control of the ME department. The plan includes the prescription of how equipment should be maintained in between dry docking periods and which and how much spare parts should be taken on stock for breakdown maintenance.

Maintenance practice

The maintenance task falls under, preventive or corrective depends on the equipment and the involved suppliers. The maintenance is based on the criticality of the components of the system; assessed by FMECA analysis (Failure Mode, Effect and Criticality Analysis). Based on the outcome of FMECA, and the recommended maintenance by the supplier, the maintenance task and required spare parts is identified. When the recommended maintenance is not suitable, the maintenance is adjusted on experience, and on another expert's advice. For each vessel there is an overview of the different components, criticality, and recommended maintenance. When it is not feasible to take the recommended spare parts aboard, options are to store the spares at a warehouse or at the supplier.

In general, there are sufficient maintenance opportunities, therefore preventive maintenance jobs that are conducted in such opportunities do not lead to downtime. Besides, not all jobs require the vessel to anchor (each vessel lies ~4-5 months/ year in anchorage). This creates many opportunities to conduct maintenance. A different usage of the vessel probably affects the deterioration of the equipment. The varying effect on required maintenance caused by differing vessel usage will be considered when the maintenance plan needs to be adjusted.

Maintenance tasks

Some equipment runs to failure, like the electronic equipment at the bridge. In each vessel on an average ~ 1500 maintenance jobs conducted at the FSSVs. However, only 8% of the jobs require spare parts. Most jobs are extensive inspections, and few spare parts are required at this time.

Corrective maintenance

Approximately 6% of the jobs on the Standard Survey Vessels are corrective. The corrective maintenance varies from the replacement of the coffee machine to the overhaul of a failed engine at dry dock.

Preventive maintenance

Time based maintenance

Approximately 93% of all jobs are time-based (week, month or year based) as shown in the **Table 3**. A lot of tasks are executed to check, the condition of certain

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part of equipment. Usually, the steps described in the maintenance manual are followed. When an error occurs during such an inspection, steps will be undertaken to solve the error.

Usage based maintenance

For few equipment usage-based maintenance is carried out. This is done based on, the logged in running hours. Equipment like hydraulic and oil pumps, the generator and propulsion engines and several compressors are maintained in this approach. The most expensive jobs are based on their usage: the overhauls of engines are prescribed based on the hours the engine has run.

Load based maintenance

Although FMS has data available on loads of the engine, this is not used in the planning of maintenance.

Condition based maintenance

Condition based maintenance is conducted just in time, to prevent that the performance drops below a certain arbitrary chosen limit. In the most expensive equipment like engines, the condition is monitored by lube-oil and fuel analyses, endoscopic inspections, performance tests and vibration monitoring. While condition of the engine is monitored, it is not yet possible to adapt the overhauls upon the values measured. High-speed engines need more maintenance than low-speed engines. Personnel are usually more experienced with the marine common low-speed engines. It is expected that future technological developments require more external maintenance services, which probably includes practises of condition-based maintenance. The largest part of the work is conducted at the engine room and on deck as shown in the **Figure 3**.

Challenges in optimising schedules for engines

The utilisation of the vessels differs. A varying time working at operations will have a varying effect on the required maintenance. For example, the engines are lightly loaded during a project, as the FSSV sails on a relatively low speed. During low-speed operations, incomplete combustion occurs and contaminates the oil, which in turn affects the condition of the engine. Although the supplier insists to operate engines at full load, this is not done. Some low-speed runs can last a couple of straight days or last over a week. In short, the engines for electricity are badly used during anchorage and projects.

Table 3. Corrective and preventive maintenance

Description	Average	Range, part of 1500 conducted jobs per year
Corrective maintenance	5.5%	Varies between 2.9% and 8.0%
Preventive maintenance	94.5%	Varies between 92.0% and 97.1%

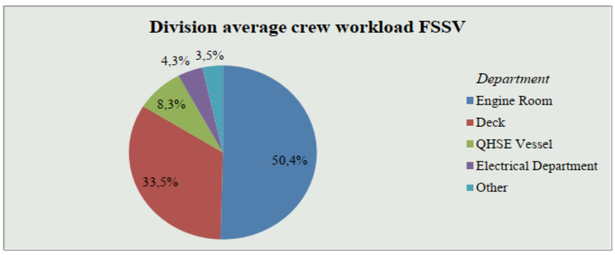

Figure 3. Average of jobs over department [2]

The OEM standard maintenance manual is not applied to marine activities, and the supplier is unwilling to do a reasonable estimation of high-speed engines. The difference in recommendation of the OEM and the current service provider is large. The OEM recommends executing the expensive large overhaul, after 8,000 hours, while Company 1 does the same after 30,000 hours. Regardless of the costs, the operating time lost in case of the schedule of the OEM would be unacceptable. Unfortunately, the OEM is not willing to take a closer look due to the limited size of the market. To prevent failures due to deferred maintenance of the diesel engines, Company 1 would like to consider the condition of the engines in determining the optimum maintenance interval.

It is to be noted that, most jobs are conducted individually as the jobs are involved with one piece of equipment. Therefore, opportunities to cluster maintenance activities are limited.

Maintenance cost analysis

An overview of the most expensive components of a Standard Survey Vessel is shown in the **Figure 4**. **Figure 4** identifies the diesel engines for main electrical power production as the most expensive equipment in maintenance. There is a distinction between diesel engines and propulsion equipment (three diesel engines for the electrical power production, while two for propulsion equipment). The propulsion equipment including the electric engine, hydraulic installation and the thrusters are maintained during the large dry dock every five years. On the third and fourth largest types of equipment, the communication and navigation, searching equipment, the maintenance is about run to failure or time-based replacements. For example, the radar needs to be replaced every 7 years. However, the possibilities of condition-based maintenance are limited (available but not implemented). Fuel costs are 25% of the total yearly costs, and a noteworthy for the maintenance and service logistics, are less than 1 percent of the total costs.

Company 1's expectation

Improve maintenance decision making

Despite few unexpected failures, the availability has already been at the managerial target level. Moreover, with the current maintenance plan applied in the following years, the availability is expected to be high. In this FMS maintenance policy, an extensive amount of maintenance is prescribed according to the recommendations of suppliers. Suppliers, of course, recommend a lot of

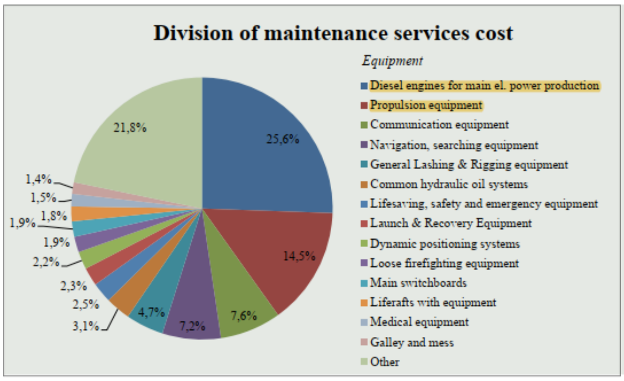

Figure 4. Overview of maintenance costs [2]

maintenance, but this is usually at the safe side of the reliability and at the more profitable side of the supplier. Questions as "what is the best maintenance schedule?" and "what will be required maintenance in case of a change in usage of the vessel?" remain. As there is a lack of similar assets and if there are it remains questionable whether they have the appropriate failure data, data cannot be easily gathered in the market. Besides, technical knowhow is insufficient to manually adjust the type and interval of maintenance. Concluding, the effect on the long term of regular, increased, deferred or skipped maintenance on the availability and costs is simply not known. As performance is expected to be relatively well, there is an opportunity to gather extra data at four vessels sailing during the coming years. What the measurements should be and how these are related, must be constructed upfront.

Identify maintenance driving component

A large amount of the total maintenance and storage costs is caused by a limited number of systems like diesel engines. Selection of critical sub systems determines the required maintenance and expected reliability. The maintenance of the cost driving components in diesel engines, must be taken into the account for cost optimisation of maintenance.

Clustering maintenance activities

Most jobs are conducted individually as the jobs are involved with one piece of equipment. Therefore, opportunities to share work (cluster maintenance activities) maintenance tasks are limited.

Details of Maintenance practice at Company 2

Maintenance strategy at Company 2

A small fraction of the company's income is used for maintenance. The maintenance of the vessels does have a lot of implications for the company. As the company's main task is to provide the pilots with services for which they need their vessels, maintenance is very important. Very less historical data is available to be able to plan the preventive maintenance. This is an issue because, the company currently spends about half of the work orders and significant money on preventive maintenance and does this by generally following the guidelines from suppliers. The two vessel types under investigation are the tender and PSV. The two vessels have Diesel-direct and Diesel-electric propulsion respectively. Both are unique in the maritime sector and Company 2 has three of each. The tenders are used to transport pilots from the port to the PSVs and vice versa (PSVs permanently located at sea). FMECAs are available on all vessel types and are updated when new equipment is installed on board. Failure modes are known in detail (component level). However, information on failure mechanisms is not available. Root cause analysis is not performed.

Maintenance overview

There are three different ways maintenance is performed. The extent to which each type is performed differs between PSVs and tenders as shown in the **Table 4**.

1. First, maintenance can be done by the ship personnel.
2. If the ship personnel cannot solve the problem, a mobile technician from shore travels to ship and perform the maintenance task. Certain parts are covered by service contracts (e.g. radar systems) and in these cases the service provider is sent.
3. When the problems still are not solved, the vessel is transported to a place where it can be repaired. Below, an estimation of the number of work orders being performed within each of the three types of doing maintenance.

Contracts

Company 2 does not have full-service contracts. Although the company wants such in the future, the market is not ready to supply. The reason is the lack of knowledge of both suppliers and Company 2, about the failure behaviour of components and the effect of different usage on the very specific maritime fleets. Usually, the customer pays the provider of full-service contracts to cover a certain risk, but as this risk is unknown, no agreement on this can be reached. Fortunately, Company 2 has a lot of expertise to do maintenance themselves so full-service contracts are not necessary (but it could take away risks). There are, however, large framework contracts with important suppliers for safety equipment), radar and engines. In these contracts, pricing agreements are made, and the maintenance intervals are agreed on. In addition to these contracts, Company 2 has smaller contracts as well.

Table 4. Work share

Type	PSV	Tenders
By crew	80%	10%
By mobile technician	10%	80%
By external party	10%	10%

Maintenance tasks

Generally, two types of maintenance are followed across the fleet namely, corrective, and preventive maintenance. Corrective maintenance is not subject to choices, if a vessel breaks down, it will be repaired. Preventive maintenance on the contrary, introduce choices. The choice here is when to do maintenance and on which components. Depending on these two factors, there are different maintenance rules. These maintenance rules are time based, usage based, usage severity based, load based and condition based maintenance. In the **Table 5**, it can be seen that 42% of the work-orders are due to preventive maintenance activities. Time based, usage based, and condition-based maintenance are also performed alongside. CBM roughly consists of taking oil samples and some visual checks, the share of CBM in the total preventive maintenance is small.

These maintenance rules are time based, usage based, usage severity based, load based and condition based maintenance

Maintenance cost drivers (pilot station vessels)

The usage of the Pilot Station Vessels is equal, measured in operating time. **Table 6** shows the costs as a percentage of the total costs. As seen in the table the propulsion system together with the generators are the main cost drivers.

Maintenance cost drivers (Type 1 tenders)

The different locations also make the intensity of the trips different. One can imagine that the swell for instance is different everywhere. Company 2 also has vessels that are designed especially for icy conditions. Both the ice in the water and the different vessel specifications make the wear for the ships in this region different. The usage of the ships is optimised to make them as equal as possible, so that the future usage and maintenance can be adjusted.

The numbers for the tenders are not different from the PSVs. Table 7 Shows the costs as a percentage of the total costs. As seen in the table the propulsion systems together with the generators are the main cost drivers. 40% of money is spent on the propulsion system and 33% of the work orders are propulsion related. This makes it by far the most important part of the vessel.

Table 5. Distribution of various maintenance tasks

Total fleet	Category 1	Category 2	Category 3
PM order	42%	35%	50%
CM orders	58%	65%	50%
PM costs	10%	9%	22%
CM costs	90%	91%	78%

Table 6. Share of cost among various systems

System	Share of Costs	Share of Work orders
Propulsion	1%	6%
Generators	30%	20%
Bow thruster	1%	3%
Axis	1%	1%
Main Electric Motor	0%	4%
Propeller	0%	4%
Steering	1%	8%
Gears	1%	1%

Challenges in maintenance activities

The vessels are designed specifically for Company 2, which means there are no vessels in the world are the same. This has implications for the optimisation of maintenance, as not much data is available regarding the failure history. The company does most maintenance by its own, and it applies its own judgement to predict preventive maintenance intervals. The result is a fleet-wide technical availability of 97.1% (which is considered high and is higher than the target of 97%). The fleet-wide operational availability is reported to be 87.1%, considerably *below* their target (92%). The management of Company 2 wants to balance the situation to improve operational availability.

Each year Company 2 sets goals to justify their budget for next year. To do this, the company sets goals for their technical and operational availability and cost control. In the past, when primarily breakdown maintenance (replace when broken) was executed, the technical availability was around 90%. Some years ago, Company 2 started to decrease the unexpected downtime of their vessels. The reason for this was that the low technical availability led to reduced safety (technical problems at sea) and reduced operational flexibility. As exactly these two factors are the very important in piloting, Company 2 decided to change their maintenance method. The company had a transition towards a preventive maintenance strategy (maintenance

Table 7. Share of cost among various systems

System	Share of Costs	Share of Work orders
General	10%	2%
Propulsion	40%	33%
Generators	2%	8%
Gears	0%	11%
Axis	0%	2%

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according to maker's manual). This maintenance method turned out to be very conservative: maintenance is done too soon. The new method increased the technical availability, but because of the increased maintenance efforts, the operational availability decreased. Company 2 needs a less conservative preventive maintenance plan without additional safety risks (unexpected downtime). The goal is to decrease the total expected and unexpected downtime.

Expectations

As the preventive maintenance is the cause of the low operational availability, the company wants to determine whether this can be done differently. An important restriction to this problem is the absence of historical failure data which is typically needed to calculate optimal maintenance intervals. This problem seems persistent in the entire maritime sector. There are a couple of reasons for this. Due to the fact that the number of comparable assets is usually small or even just one less comparable failures will occur than with an installed base of hundreds (like airlines). In addition, most maritime companies will not run (critical) components to failure, as this will have a huge effect on safety and ability to operate. The objective therefore is to design a maintenance policy that can reduce the total maintenance time. To get to this point, the policy needs to be able to reach feasible balance between technical and operational availability while meeting the targets set by the company. It also needs to guarantee safety, continuity, and future orientation.

Critical component selection procedure

Introduction

This section addresses the critical component selection procedure (as required by Company 1) and based on the outcome new maintenance techniques can be suggested for both the companies as discussed in the earlier sections. Ships are typically complex systems containing large numbers of subsystems and components. The ship is subdivided into main functions (e.g. sailing, anchorage etc), Finally, each of the sub functions is realised with few installations, like diesel engine, steering gear system or cooling water pumps. However, it should be realised that this is not the lowest level, as each of the installations consists of numerous components. For the diesel engine, these are e.g. bearings, liners, pistons, etc. Prognostic methods, especially physics of failure-based methods, are typically developed at this lowest component level. But asset owners and operators are interested in the functioning and maintenance optimisation on the highest (system/ship) level [4]. This immediately demonstrates one of the largest challenges in predictive maintenance: how can the system level maintenance optimisation be connected to the component level prognostic methods?

An important restriction to this problem is the absence of historical failure data which is typically needed to calculate optimal maintenance intervals

Key challenge

Prognostic models are available for all individual components. However, due to the large numbers of components and the effort required to develop prognostic methods, this full coverage is not feasible [4]. Therefore, a suitable selection method is required to select those components for which developing prognostic methods is useful.

For a few numbers of components accurate models or relations for the failure rate at different operating conditions can be derived. This can be physics-of-failure based models or data analytics relations derived from large data sets. For the remaining components (typically the majority), two options remain. The first option is to assume a failure rate (constant failure rate MTBF) based on information from the OEM of the system, and in exceptional cases the OEM provides a differentiation in failure rates at different conditions. A second option would be to base these failure rates on expert opinion. Operators of specific systems typically know quite well, based on experience, how the system behaves under certain circumstances. By quantifying this experience, and consulting different experts a failure rate function can be established, and the optimisation method can be fed. Both options, however, provide estimates of the failure rates, which are less accurate than the values obtained from prognostic methods. Therefore, it is essential to differentiate between critical and non-critical components, because an inaccurate estimate for a critical component could lead to poor results. This clearly illustrates the need for a critical part selection method.

Failure Mode, Effect and Criticality Analyses (FMECA)

Traditionally, Failure Mode, Effect and Criticality Analyses (FMECA) are executed to assess the criticality of components, expressed in terms of Risk Priority Numbers (RPN). That approach was also initially applied to the maritime systems, like vessel propulsion systems and a radar system, in the companies under consideration. However, prioritising subsystems or components for developing prognostic models just on the basis of RPN appeared to give some complications.

Complications

Firstly, risk is a combination of frequency and impact. A failure with moderate effect that occurs regularly can therefore represent a similar risk as a (potential) failure with large impact, but a low probability of occurrence. For the first type of failure a predictive method would be very useful, while for the second type of failure the low probability of occurrence would probably not justify the development effort of such a method.

Secondly, for a complex system a FMECA analysis is very extensive and time consuming. Higher level approaches, like quick RCM or streamlined RCM may solve the time issue, by only focusing on subsystem or assembly level. But at the same time they do not guarantee that all critical components have been identified.

Thirdly, in a FMECA the quantification of the RPNs is based on a predefined scaling of occurrence and severity. However, the severity or impact can be quantified in many different ways, e.g. in terms of down-time, costs, environmental effects or safety. Depending on the application, one of these factors might be dominant, but in many cases a weighted combination of these factors will quantify the impact. In the maritime applications studied in this project, different situations have been encountered.

Finally, it was discovered in the present project that only being a critical component does not make a component a suitable candidate for predictive maintenance. A prognostic method is only useful when the prediction of failures actually enables to extend or reduce the standard maintenance intervals and an increase in system availability.

Solutions to the complications

To tackle this issue, 4-quadrant method is suggested, in which failures can be plotted along two axes: the failure frequency and the failure consequence (which is expressed in terms of e.g. costs or down-time). A modification of this method using different boundaries between the four regions is available in [3]. Such a graph is shown for a series of failures of a vessel propulsion system in **Figure 5**. The failures with low impact can be addressed by either applying regular OEM prescribed maintenance (for low frequency failures) or arranging a sufficient amount of spare parts (for high frequency failures). Unacceptable failures are those failures that either combine high failure frequencies with high impact,

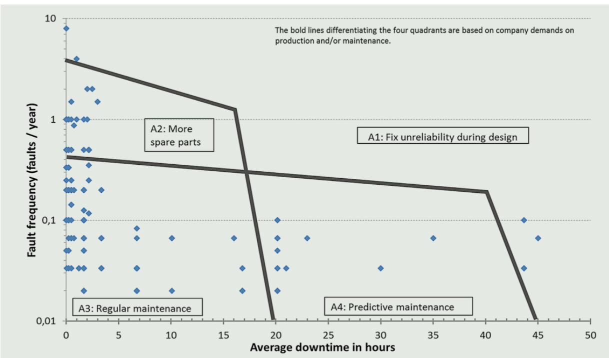

Figure 5. Four quadrant analysis [3]

or only have very high impact or very high frequencies. Failures in that region of the graph should be prevented by all means, so a redesign or modification of the system is the best option. Finally, the failures that remain in the fourth quadrant, representing moderate to high impact at moderate to high frequencies, are (in principle) suitable candidates for predictive maintenance. However, in the FMECA analyses performed on the propulsion system, many potential failures with high impact were mentioned, but these did not occur yet in the vessels in operation for the past 5–10 years. Examples are gear box failures and propeller shaft fracture. Developing prognostic methods for these type of failures will therefore probably never pay back. It is therefore proposed to exclude the low frequency failures from the 4th quadrant, and define the region with potential for predictive maintenance.

Monitoring and data gathering

Once a component is selected, application in practice requires the monitoring of appropriate parameters on usage and loading of the systems. The type of data steers the selection of suitable maintenance technique as shown in the **Figure 6**. For example, to assess the condition of cylinder liner and valves, engine operational parameters such as engine speed, load, temperature and pressure has to be observed as a function of time. Although both requirements in principle can be met by deploying rather simple sensors or data acquisition systems, in maritime systems this appears not to be common practice. Typically, three types of challenges are encountered.

Firstly, many systems nowadays contain built-in monitoring systems, but the data is often not stored over time. This means that a history of some days up to two months is available, typically for diagnostic purposes in case of failures, but the data is overwritten when it has reached the expiry date. This means that the complete time history of the usage is often not available.

Secondly, the sampling frequency is often inappropriate. For a quickly varying diesel engine parameter like speed or load, one measurement every hour is useless.

Thirdly, the quality of the data is often inadequate, especially when data has to be entered manually by an operator of the system. For example, registrations of failures are often not entered directly into the maintenance management system, which often leads to wrong dates/ time in the registrations. Also the cause and details of the failure are often incompletely registered, which makes additional analyses quite challenging.

For engine propulsion systems, detailed data on usage and loads is not readily available. The concept of defining several functional usage profiles and register the relative occurrence of those partly solves the lack of continuous monitoring data. In general maintenance engineers have good overview of these variables, in a given operational condition. With this information in hand, a suitable maintenance technique can be selected (as shown in the **Figure 6**).

Maintenance techniques

This step aims at selecting the applicable maintenance technique (MT), for conducting the maintenance analysis. The available data and the required outcome determine what MT to select (as shown in the **Figures 6** and **7**). This requires prior consideration of the amount and quality of the available data and the possibilities for data collection (Step: Monitoring and data gathering). The framework generally comprises of five types of MTs [3]:

I. **Experience-based predictions** of failure times are based on knowledge and previous experience outside (e.g. OEM) or within the company. Sometimes they are supported by little or scattered data. Predictions are based on expert judgement (e.g. facilitated by FMECA techniques). These methods estimate the life of an average component operating under historically average conditions.

II. **Reliability Statistics prediction** techniques are based on historical (failure) records of comparable equipment without considering component specific (usage) differences. This approach accurately describes population-wide failure probabilities. These methods also estimate the life of an average component operating under historically average conditions and are based on e.g. Weibull distributions.

III. **Stressor-based predictions** are based on historical records supplemented with stressor data, e.g. temperature, humidity or speed, to include environmental an operational variances and give results in terms of expected lifetime of an average system in a specific environment. Predictions are based on the extrapolation of a general path derived from a physical model, build-in-test results, or operating history.

IV. **Degradation-based predictions** are based on the extrapolation of a general path of a prognostic parameter, a degradation measure, to a failure threshold. By measuring symptoms of incipient failure, e.g. rises in temperature or vibration, the system can be diagnosed. The prognostic parameter is also inferred from sensor readings, i.e. is always based on a measurement. The prediction starts from the current state of degradation and results in an expected remaining lifetime of a specific system in a specific environment.

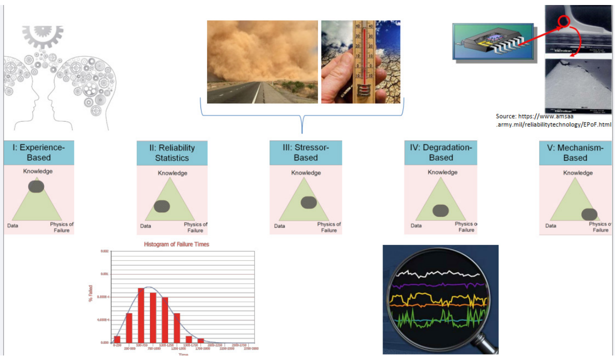

Figure 6. Maintenance techniques based on available knowledge [3]

V. **Model-based predictions** give the expected remaining lifetime of a specific system under specified conditions. Two types of model-based approaches can be followed:

A. Physical model-based: The prognostic parameter is calculated using a physical model of the degradation mechanism based on direct sensing of the loads or usage that govern the critical failure mechanisms of individual components.

B. Data model-based: The prognostic parameter is calculated or inferred using data analytics that uses sensed variations of loads, usage data, process data, or condition/health monitoring data as input. The algorithms aim to derive patterns or relations in the data or try to predict anomalies by comparing with historical data.

Out of all these approaches, Mechanism-based (physical model based) predictions are based on direct sensing of the critical failure mechanisms of individual components. Therefore, this approach is suitable for predicting the expected lifetime of cylinder liners and valves, under specified conditions (not previously encountered loading conditions or new system configurations). The prognostic parameter is calculated using a physical model of the degradation mechanism and this model uses the sensed variation of loads or usage as input. However, this requires detailed knowledge about the failure mechanisms, an accurate mathematical model, and the behaviour of a failure mode in quantitatively characterised physical laws.

Conclusion

Although this work has analysed two types of companies, the discussion could also be viewed as generic. This framework can be used to promote the use of predictive maintenance models in the maritime industry and aid in the development and application of these. The approach therefore introduces Industry 4.0

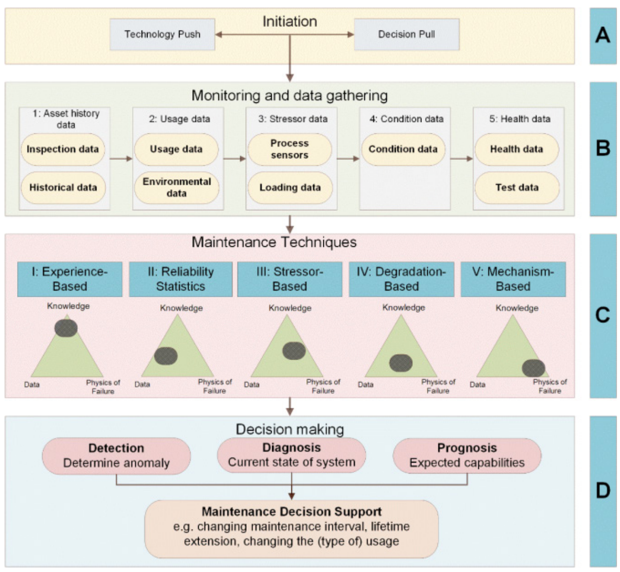

Figure 7. Monitoring and data gathering, maintenance techniques and decision making flow chart [3]

to maritime sector, by integrating prognostics-based methods with production, logistics and services. The presented concept thus enables the shipping companies to improve the reliability and availability of the ships.

Acknowledgement

This is an academic work for Professional Doctorate in Engineering (PDEng) program performed at the University of Twente. As this PDEng is also an industrial project I also express my gratitude to Prof. Tiedo Tinga who headed Dynamics based maintenance (DBM), for his guidance to perform this work and to sustain funding from industrial partners to support this work. The idea to introduce this framework in to maritime sector was first proposed by researcher Filippos Amoiralis [4] (based on extensive interviews with stake holders), who worked in DBM group in the year 2015. These predictive models are under further development now.

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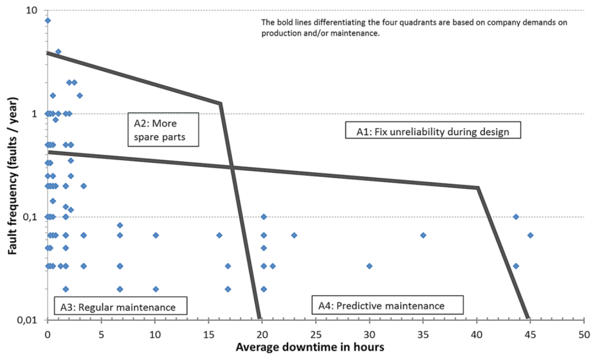

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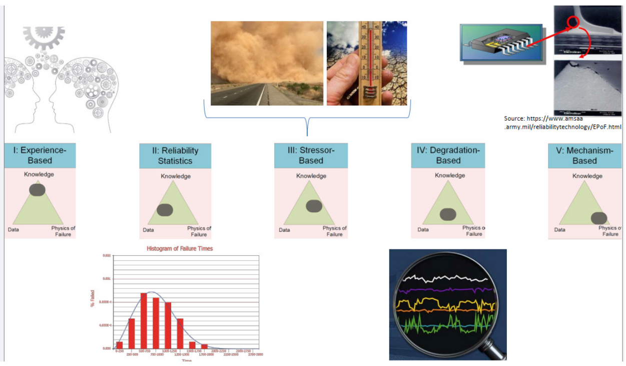

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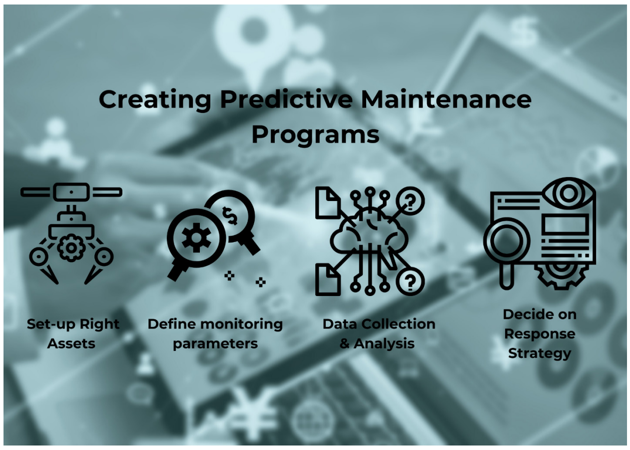

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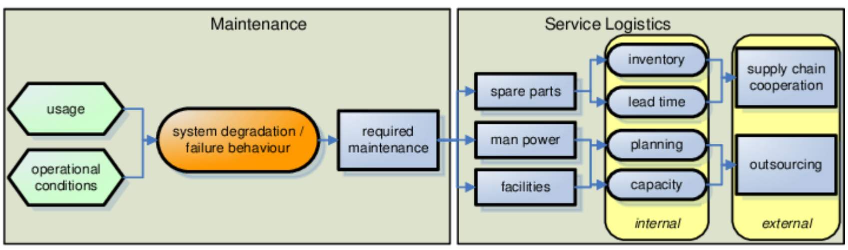

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About the author

Prabu Duplex had sailed as a marine engineer between 2005 - 2013. He graduated from a Professional Doctorate in Engineering (PDEng) program at the University of Twente, in the Netherlands. He also worked in a research group called "Dynamics Based Maintenance (DBM)" which actively focuses on developing innovative predictive maintenance methods for a wide range of industries. His work involved in developing physics based mathematical models to predict the life time of diesel engines components in maritime propulsion systems. He has also a Master's degree in Naval Architecture. Presently, he is looking for a career in design or research activities in naval, wind, offshore or predictive maintenance domains. He contributes regularly to MER.

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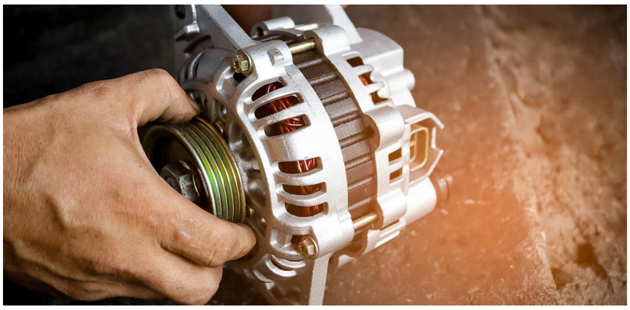
Troubleshooting of Alternators Part 3B

Elstan A. Fernandez



1.14.2 Fault Symptoms and Remedies whilst On Load

Symptoms	Probable Causes	Remedy
Unbalanced Voltage (On Load)	Single-phase load current is unevenly distributed over the three phases.	Check the current in each phase with a clip-on ammeter. The full load rated current must not be exceeded on any one (single) phase. Re-distribute the load if necessary.
	Single-phase load current is unevenly distributed over the three phases.	Check the current in each phase with a clip-on ammeter. The full load rated current must not be exceeded on any one (single) phase. Re-distribute the load if necessary.
	The engine governor is unstable (hunting)	Check the frequency meter or the tachometer for the engine governor 'hunting', or cyclic irregularities in the engine.
	Leading power factor load created by power factor correction capacitors.	Isolate the power factor correction capacitors until sufficient motor load has been applied to counteract the leading power factor.
	Permanent magnet stator is positioned incorrectly (Pre 1989 AVR's only).	The radial position of the stator housing is important for the stability and response of the AVR. Modern AVR models do not require this adjustment.
	Non-linear loads, causing interaction between dynamic closed loop control systems.	Instability caused by over sensitive control settings. Adjust the AVR to high gain, (stability), and load drives to low gain. Increase the engine speed 'droop' to reduce sensitivity. Contact the manufacturer for further advice regarding non-linear loads.

Symptoms	Probable Causes	Remedy
Unbalanced Voltage (On Load)	Fluctuations in the load current, (motor starting, or reciprocating loads).	Check the load current on a stable supply, i.e., the mains, or separately excite the machine. A variable D.C. supply is required for on load separate excitation tests.
	AVR stability control incorrectly adjusted.	Adjust the AVR control, until the voltage is stable
Poor Voltage Regulation (On Load)	Large speed droop on the engine. AVR UFRO protection has activated.	Check that the speed droop from no load to full load is no greater than 4%. Check the AVR LED. If it is lit, increase the engine speed.
	Parallel droop circuit is incorrectly adjusted, or requires a shorting switch for single running.	The droop circuit will give an additional voltage droop of -2½ % at full load 0.8 pf. For single running machines, this can be improved by fitting a shorting switch across the droop CT input, (S1 – S2), on the AVR. Pre 1989 machines. Short across the burden resistor in the terminal box.
Poor Voltage Regulation (On Load)	Unbalance load.	Check the voltage and load current on all phases. If it is unbalanced, redistribute the load more evenly across the phases.
	AVR stability adjustment is incorrectly set.	Adjust the 'stability' potentiometer anticlockwise until the voltage becomes unstable. Adjust it slightly clockwise until the voltage stabilises.
	Voltage drop between Generator and load, caused by losses in supply cable, (I2R losses).	Check the voltage at both ends of the cable run at full load. Large differences in voltages indicate a large voltage drop along the cable. A larger diameter cable is required in severe cases.
	Fault on the main rectifier or excitation winding.	Check the no load excitation voltage across the AVR X+ (F1) and XX- (F2). If it is higher than 12 volts D.C., the machine must be tested as per article 1.5.5.
	Under frequency protection (UFRO) has activated.	Check the LED on the AVR. If it is lit, the UFRO has activated. (the engine speed is too low). Check the speed and adjust it to nominal.
	Permanent Magnet stator position is incorrect. (Pre 1989 AVR' s only).	The radial position of the stator housing is important for the regulation, and response of the AVR.

Symptoms	Probable Causes	Remedy
Poor Response to Load Surges or Motor Starting	Engine governor is sticking or slow to respond. The AVR 'UFRO' protection circuit has been activated.	Check the performance of the engine while loading. Check if the AVR LED is lit during motor starting. Check if the AVR 'DIP' or 'DWELL' circuits are activated. Adjust or de-activate them.
	Parallel droop circuit is incorrectly set.	Too much droop will increase voltage dips when a motor is starting. Fit a shorting switch for single running Generators. Adjust the droop.
	Load current surges exceed 2.5 times full load of the machine.	Check surges with a clip-on ammeter. Check with the manufacturer for advice on voltage dips while starting motors.
	UFRO protection circuit has been activated.	Check the engine speed DIP on load. Check the LED on the AVR. Low engine speed will activate the UFRO protection circuit. (LED is ON).
Poor Response to Load Surges or Motor Starting	The voltage drop between the generator and the load is caused by I^2R losses in supply cable. This will be worse during current surges, (motor starting, etc).	Check the voltage at both ends of the cable run while it is at full load. Differences in voltages indicate a Voltage drop along the cable. A larger diameter cable may be required in severe cases.

Continued...

Symptoms	Probable Causes	Remedy
	Incorrect position of permanent magnet stator (Pre 1989 type A.V.R.'s only).	The position of the PM Stator affects the response performance of the AVR
	Motor contactors dropping out due to voltage dip on starting.	All symptoms and Remedies in this section may apply to this problem. Refer to the manufacturer's manual for voltage dip calculations.
	AVR 'Stability' controls are incorrectly set.	For best performance, adjust the 'Stability' control potentiometer anticlockwise until the voltage is unstable, then turn it slightly clockwise, until it is stable.
	Fault on windings or rotating rectifier.	Check the no load excitation voltage across the AVR X+ (F1) and XX- (F2). If it is much higher than 12 volts D.C. the machine must be tested as per article 1.5.5

Symptoms	Probable Causes	Remedy
Poor Response to Load Surges or Motor Starting	Engine relief circuits in AVR activated.	Check if the AVR has "DIP" or "DWELL" circuits. Adjust them or zeroise if they are affecting load response.
	Fault in the AVR.	Replace and test it on load.
Voltage Collapses (On Load)	Protection circuit in the AVR has activated due to the high excitation across the AVR's output, (X+ (F1) and XX- (F2).	Excitation voltage is higher than 70V D.C. Check it across X+ (F1) and XX- (F2) on load. Ensure that the engine speed is correct at full load. Check output voltage, ensure it does not exceed the rated voltage. Check load current for overload.
	Protection circuit in the AVR has operated, due to fault in the generator's windings or diodes.	Check the AVR LED, if it is lit, the protection circuit has activated. Shut down the engine, and restart it. If the voltage returns to normal, but collapses again on load, the protection circuit has activated due to high excitation. Carry out tests as to identify the cause of high excitation voltage as mentioned in this chapter.
Voltage Collapses (On Load)	Malfunction of protection circuit in the AVR.	Replace the AVR and test it on load.
	Severe overload or short circuit across phases.	Check the load current with a clip-on ammeter.
High Voltage (On Load)	Unbalanced load.	Check if the voltage on all three phases. for imbalance, re-distribute loading over the three phases
	Leading Power Factor Load.	Check for capacitive (leading) PF load, i.e. kVAr correction, fluorescent lights. Apply motor (lagging) PF load, or switch off capacitors. A leading power factor load will give abnormally low D.C. excitation voltage across X+ (F1) and XX- (F2).
	Parallel droop transformer is reversed, (when fitted).	Check for reversal of droop CT, P1 - P2 or S1 - S2, reverse either to correct.

Symptoms	Probable Causes	Remedy
Low Voltage (On Load)	Engine speed droop is greater than 4%.	Check if the AVR LED is lit, the UFRO is activated, (low speed indication). Check the engine speed on no load and full load. Engine governing should be within + 4%. and –1% of the nominal speed. Reset it as necessary.
	Under frequency protection circuit has operated (UFRO).	Check the AVR LED. If it is lit, the UFRO is activated, increase the engine speed to correct levels.
	Faulty permanent magnet generator (PMG) stator or rotor.	Disconnect the PMG leads from the AVR terminals P2, P3, P4. Check the voltage across leads with a Multimeter, with the set running at correct speed. For 50 Hz, the voltage across P2, P3 and P4 should be approx. 170VAC. For 60Hz, Voltage is approx. 200 V AC.
	AVR is faulty.	Replace the AVR and re-test it.
	Fault on the winding or rotating diodes	Any fault in this area will appear as high excitation voltage across X+ (F1) and XX- (F2).
	Voltage drop between the generator and load, due to I^2R losses in the cable. This will be worse during current surges (motor starting, etc).	Check the voltage at both ends of the cable run at full load. Differences in voltage indicate a voltage drop along the cable. In severe cases, a larger diameter cable is required.

About the author

Elstan Fernandez has an experience of 44 years in the Maritime and Energy Industries. He has been an Author / Co-author of 80 Books. He holds the statuses of Chartered Engr, FIE, MIET (UK), MLE℠ Harvard Square (USA). He is the Joint Inventor with a Patent for Supervised BNWAS and won the Promising Indian of the Year in 2017.

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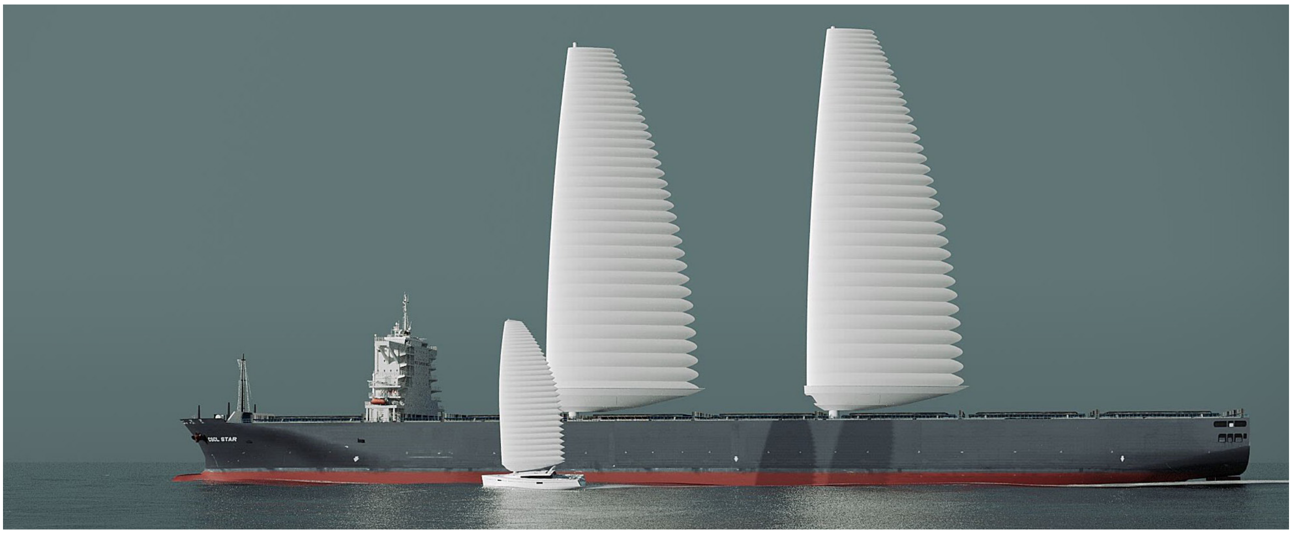
TECHNICAL NOTES

Harnessing the Wind: The Science Behind Kites Dragging Huge Ships



**Punit Kumar,
Sanjeev Kumar Varshney**

Summary: Kite propulsion leverages wind power to propel ships, blending ancient wisdom with modern engineering. By flying kites at higher altitudes, vessels access stronger winds, enhancing efficiency and reducing reliance on fossil fuels. Sophisticated control systems regulate kite position and tensioned lines, ensuring safe operation. Safety measures and crew training mitigate risks, while zero emissions make kite propulsion environmentally friendly. This innovation reflects human adaptability and collaboration, offering a sustainable path forward for maritime transportation.Top of Form

Main body text:

In the realm of maritime transportation, where the vast expanse of the ocean stretches endlessly, the age old practice of sailing has evolved into a modern marvel of engineering and innovation. Among the latest advancements in this field is the utilisation of kites to propel large ships across the seas. This concept, known as kite propulsion, represents a fusion of ancient wisdom and cutting edge technology, harnessing the power of the wind to provide sustainable and efficient propulsion for vessels of all sizes.

Kite propulsion is not a new concept but rather one that has been rediscovered and refined over centuries. The origin of kite propulsion can be traced back to ancient civilisations, where kites were used for various purposes, including transportation and communication. However, it was not until the modern era that kite propulsion began to be seriously considered as a viable alternative to traditional means of ship propulsion.

The origins of kite flying in India can be traced back thousands of years, with references to kite-like objects found in ancient scriptures and texts. It is believed that kites were first introduced to India by Chinese traders who brought them along the Silk Road. Over time, kite flying evolved from a simple pastime into a cherished tradition embraced by people across the country.

Historically, kite flying held religious and symbolic significance in India, with kites often used in ceremonies, rituals, and festivals. The concept of flying kites as a form of celebration dates back to the era of Mughal rule, where kite flying was a popular pastime among the nobility and commoners alike. In contemporary India, kite flying continues to hold immense cultural significance, particularly during the festival of Makar Sankranti, also known as Uttarayan. During Makar Sankranti, millions of people across India take to the rooftops and open fields to fly kites of all shapes, sizes, and colours. Beyond Makar Sankranti, kite flying remains a beloved pastime throughout the year, with enthusiasts gathering in parks, playgrounds, and open spaces to engage in friendly battles known as 'kite duels'.

The origins of kite flying in India can be traced back thousands of years, with references to kite-like objects found in ancient scriptures and texts

At its core, kite propulsion harnesses the power of the wind to provide additional thrust to propel vessels forward. Much like the sails of old, kites operate on the principles of aerodynamics, utilising the dynamic forces generated by airflow to generate lift and traction. By flying specialised kites tethered to ships, operators can tap into the immense energy of the wind, leveraging it to enhance propulsion efficiency and reduce fuel consumption.

Kites, operate on the principles of aerodynamics. The shape and design of the kite allow it to harness the force of the wind and convert it into forward thrust. As the wind flows over the kite, it creates lift, which propels the kite and, in turn, the attached vessel forward. Bernoulli's principle states that as the speed of a fluid (such as air) increases, its pressure decreases. In the context of kite propulsion, the airflow over the curved surface of the kite generates lower pressure above the kite compared to below it. This pressure difference creates lift, pulling the kite and the vessel attached to it in the direction of the lower pressure area. The force generated by the kite pulling against the tensioned line attached to the ship provides traction, causing the vessel to move forward as depicted in **Figure. 1.** The larger the kite and the stronger the wind, the greater the traction force exerted on the ship.

Kite propulsion systems harness the power of the wind, which can be significantly stronger and more consistent at higher altitudes compared to the surface level. By flying kites at higher altitudes, ships can access stronger winds and generate more thrust, increasing their speed and efficiency. Control systems are used to regulate the angle and position of the kite relative to the wind direction and the ship's trajectory. By adjusting the kite's angle of attack and orientation, operators can optimise the amount of lift and traction generated, maximising the propulsion efficiency.

The primary mechanism by which kites propel ships forward is through traction, the force exerted by the kite pulling against the tensioned line attached to the vessel. As the wind catches the kite and generates lift, the tensioned line transmits this force to the ship's hull, causing it to move in the direction of the kite as shown in **Figure. 2.** The larger the kite and the stronger the wind, the greater the traction force exerted on the ship, enabling it to achieve higher speeds with less reliance on conventional propulsion methods.

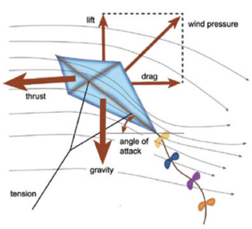


Figure. 1: Forces acting on a kite
(Source: https://airandspace.si.edustorieseditorialhow-kites-fly*)*

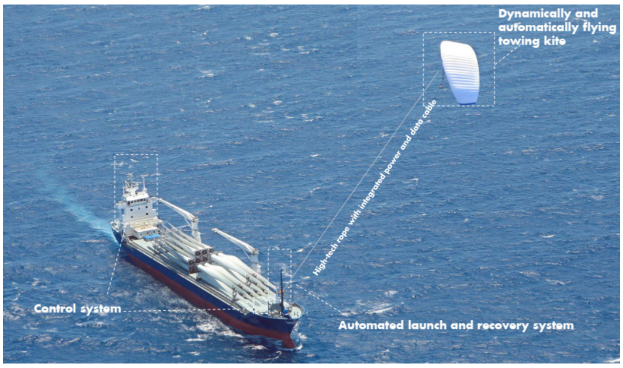


Figure. 2: Kite guiding the ship
(Source: https://gmn.imo.org/wp-content/uploads/2018/08/2-SkySails-181017-SB-en-SkySails-IMO-1.pdf*)*

The primary mechanism by which kites propel ships forward is through traction, the force exerted by the kite pulling against the tensioned line attached to the vessel

One of the significant advantages of kite propulsion is its reliance on wind power, a clean, renewable energy source that is abundant and freely available across vast expanses of the ocean. By flying kites at higher altitudes, ships can access stronger and more consistent winds, significantly enhancing their propulsion capabilities. Additionally, kite propulsion systems can be deployed in regions known for favourable wind conditions, further optimising their efficiency and effectiveness.

While the concept of kite propulsion may seem straightforward in theory, its practical implementation requires sophisticated control systems to regulate the kite's position, angle of attack, and tensioned line tension. Advanced algorithms and sensors are employed to monitor environmental conditions such as wind speed and direction, allowing operators to adjust the kite's parameters in real-time to optimise performance and ensure safe operation. Additionally, automated winches

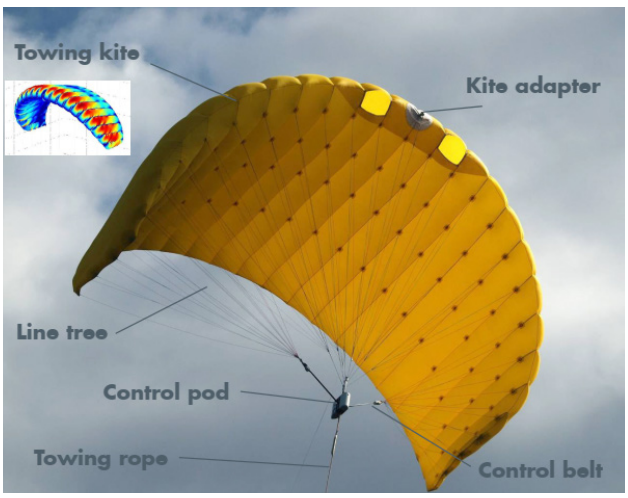


Figure. 3: Kite designed for ship propulsion
(Source : https://gmn.imo.org/wp-content/uploads/2018/08/2-SkySails-181017-SB-en-SkySails-IMO-1.pdf **)**

and rigging systems are used to deploy and retract the kite quickly and efficiently, enabling seamless integration with existing shipboard infrastructure. A schematic diagram is shown in **Figure. 3.**

> *By flying kites at higher altitudes, ships can access stronger and more consistent winds, significantly enhancing their propulsion capabilities*

Safety is paramount in kite propulsion systems, particularly when dealing with large vessels and unpredictable weather conditions. Rigorous testing and certification processes are employed to ensure that kite propulsion systems meet stringent safety standards and can withstand the rigors of marine environments. Redundant safety measures, such as emergency release mechanisms and onboard monitoring systems, are incorporated to mitigate the risk of accidents or malfunctions. Additionally, comprehensive training programs are provided to ship crews to familiarise them with the operation and maintenance of kite propulsion systems, enhancing their ability to safely navigate and control the vessel.

Beyond the technical and practical considerations, kite propulsion offers significant environmental benefits compared to traditional fossil fuel-powered engines. By harnessing the power of the wind, kite-propelled ships produce zero emissions, reducing their carbon footprint and minimising their impact on the marine environment. Additionally, the use of renewable wind energy reduces dependence on finite fossil fuel resources, making kite propulsion a more sustainable and environmentally friendly option for maritime transportation.

In the grand tapestry of human history, the story of kite propulsion for large ships represents a testament to our ability to adapt, innovate, and harness the forces of nature to propel us towards a brighter tomorrow. As we navigate the winds of change, let us continue to embrace the spirit of exploration, discovery, and collaboration, ensuring that the science behind kite propulsion remains a beacon of hope and progress for generations to come.

About the author

Dr. Punit Kumar is an Associate Professor in the Department of Physics at the University of Lucknow, where he specialises in Plasma Physics. Dr. Kumar's research focuses on understanding the behaviour and properties of plasma, a state of matter fundamental to various natural and technological phenomena. Beyond academia, he shares his knowledge and enthusiasm for science by writing articles on popular science topics, aiming to engage and educate a broader audience.

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Dr. Sanjeev Kumar Varshney superannuated from Department of Science & Technology where he worked as Advisor & Head, International Cooperation Division. Geologist by training, he has worked in Siwalik sedimentology initially and later focused on Science Policies. He writes on Science Policies towards International Cooperation and on popular science of contemporary interests.


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"You Get to Make Your Own Choices, but You Do Not Get to Choose Your Consequences"

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, we had everything before us, we had nothing before us, ..."

Charles Dickens comes to our minds as we reflect upon the state of shipping today. Juxtaposed between Trade Wars, Galloping Technology, Regulatory Challenges and Climate Change issues, we could be looking like a deer caught in the headlights, unable to comprehend where our future lies.

The Lehman Brothers crisis of September 15, 2008, now close to 15 years ago; yet we have not been able to overcome its impact, just as we have never been able to avoid the odd bout of flu every winter, and of course the Covid-19. There has been a continuous stream of regulations, in the wake of galloping technology, escalating political gamesmanship across nations, and also with safety management continuing to be an issue, duty of care towards crew remains questionable.

Is it the first choice industry for an entrepreneur? For the hopeless romantics, it is!

We would like stakeholders in the industry to come forward to make a case for Shipping, We invite you to Chennai and fearlessly present views to make the industry safe, environment friendly and investor supportive. In Chennai, one of India's largest cities and its cultural capital, you would find the rhythm and the beat to speak your mind, with an unwavering conviction and unfounded joy.

On behalf of the Organising Committee and The Institute of Marine Engineers (India), Chennai Branch, we extend a warm invitation to you and your organisation to actively participate and support the three day event, between December 4-6, 2024 in Chennai. We provide you in attachment, a copy of the canvas, and we hope to engage you in cool pre-winter periods in India.

World Maritime Technology Conference (WMTC - 2024)

"GLOBAL SHIPPING – A BATTLE FOR SURVIVAL OR A TORCHBEARER OF HOPE"?
{AMIDST TECHNOLOGY, REGULATIONS, GEO-POLITICS & CLIMATE CHANGE}

Is Shipping a good story? Let us debate.

Looking forward to meeting you in Chennai
On behalf of the Organising Committee, WMTC 2024

Hrishikesh Narasimhan
Convenor

C V Subba Rao
Chairman

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PAPERS

Papers are invited from Financial Institutions, Business Managers, Ship Owners and Managers, Shipping Associations, Regulatory Institutions, Classification Societies, Analysts, Brokerage Houses, Academic Institutions, Shipbuilding & Repair Yards, Professional Bodies, Engineers, Designers, Manufacturers, Students, Researchers, Recyclers, Salvors, Adjudicators etc.

Navigating the Future - Blockchain, AI, Data Analytics and Digital Transformation

Managing and Hedging Risk - Asset, Cargo and Currency

Ship Building and Repairs - Can India grab a share of the market?

Shipping Markets - Can we predict the future?

Marine Money - Do Banks believe in Shipping? - The Basel and The Poseidon Narrative

Duty of Care - Safety Management and Crew Welfare

Reforming (or Romancing) the Future - Is Education the same as Schooling?

Classification Society - A voice of Influence or just an IMO ally?

The Bugle of Geo Politics - Sounds of the 21st Century for Shipping

Sustainable development - Is it only about climate change?

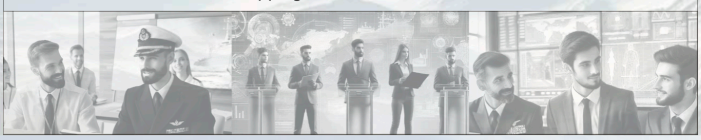
Powering Academic Research - Hulls, Propulsion Equipment, Vibration & Underwater Noise

The Connectivity Conundrum - Linking Rivers, Ports and Railways

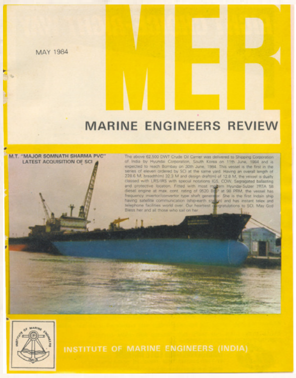
Advancements in Product Technologies - Fuel Lubricants, Paints, Chemicals & others

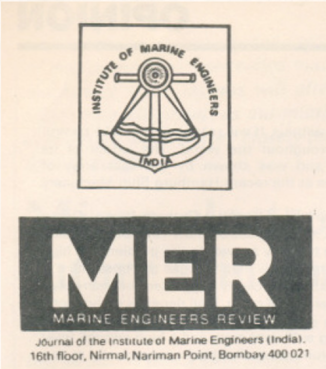
Cost Leadership in Maintenance

Managing Learning - What can Shipping learn from other Industries?



Going Astern into MER Archives...





This issue's Editorial bemoans the weak state of Indian shipping companies (about 60, it says) and highlights the default in payments to SDFC loans (SDFC: Shipping Development Finance Corporation?; the write-up does not specify. The Editorial says that the Government is contemplating on mergers and suggests that 'compatibility' also need to be checked for such solutions and financial parameters must not be the only factor. Further funding for new acquisitions will not be forthcoming, the Editorial says. The later half of 80s were waning times for shipping in the cyclic wave the service industry dwells on. We can initiate a dialogue with experiences shared by those who were in the midst of those times.

The next Editorial speaks of the sub standard operations of Classification Societies.

The next Ed piece bring the low quality fuel burning capability of 2S engine and 4S engines. The issue has a few articles on this.

The tail piece is interesting... it talks of a poor response to a survey seeking energy and cost saving measures. The reason projected: Shipowners do not want their employees divulging measures which eventually might give a competitive edge to others!

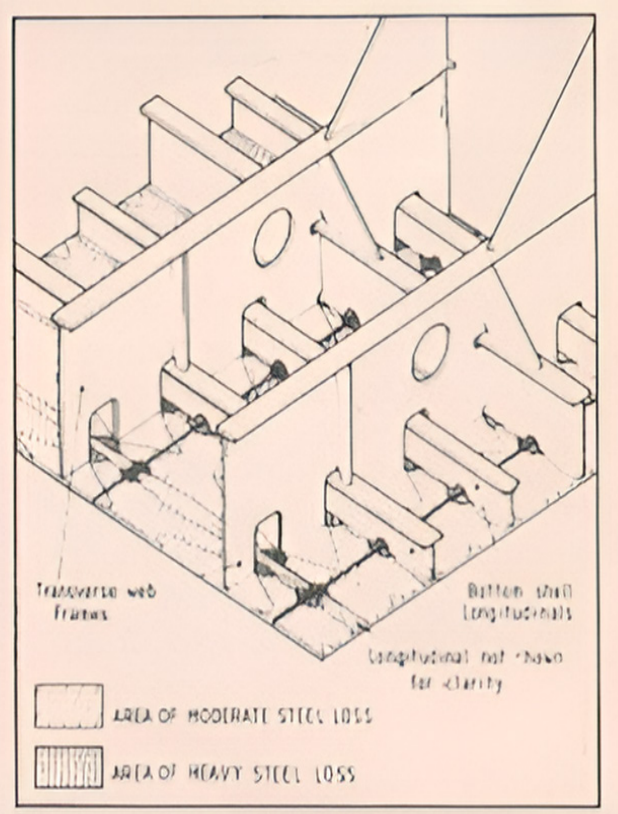
We move on to the articles...

The first lot has a series of information: medium speed engines are a cheaper option, charge air temperature control, Sulzer's efforts on fuels, HFO experience, MAN 4S and a few more.

The next interesting one is on oil tanker surveys. The article discusses development of guidelines and how to look at the structural components. This is a good read for all engineers. Few extracts to draw your interest.

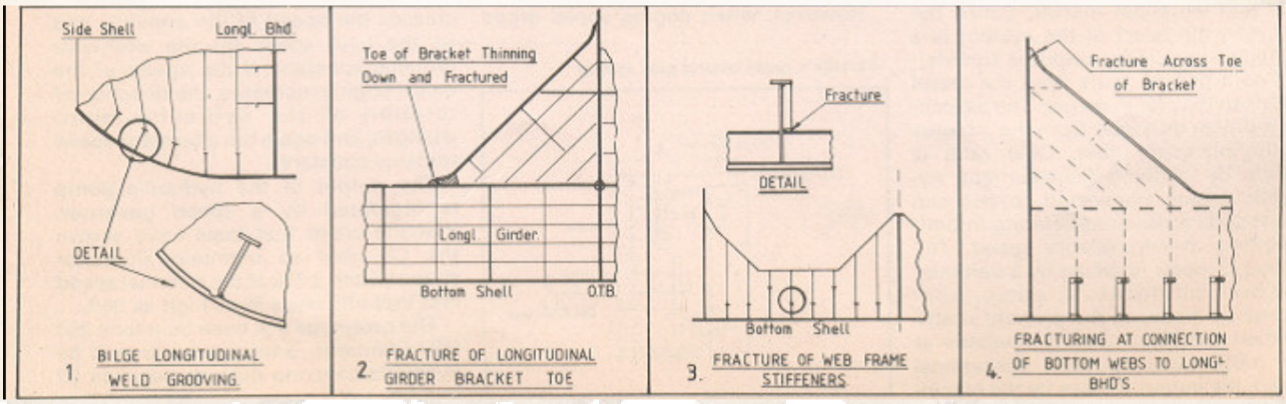
This is followed by a discussion on developments in Soviet shipping, a ro/ro vessel descriptive article and a historical recall of paddle wheel steam vessels maturing to screw-driven design for towing etc. This is an easy read.

The POSTBAG has a good mix, especially one on cost cutting. There is one contentious letter on the low state of training in India from a Radio Officer's point of view.



▲ Fig 1: Typical bottom shell loss patterns.

▼ Fig 2: Typical bottom structure defects.



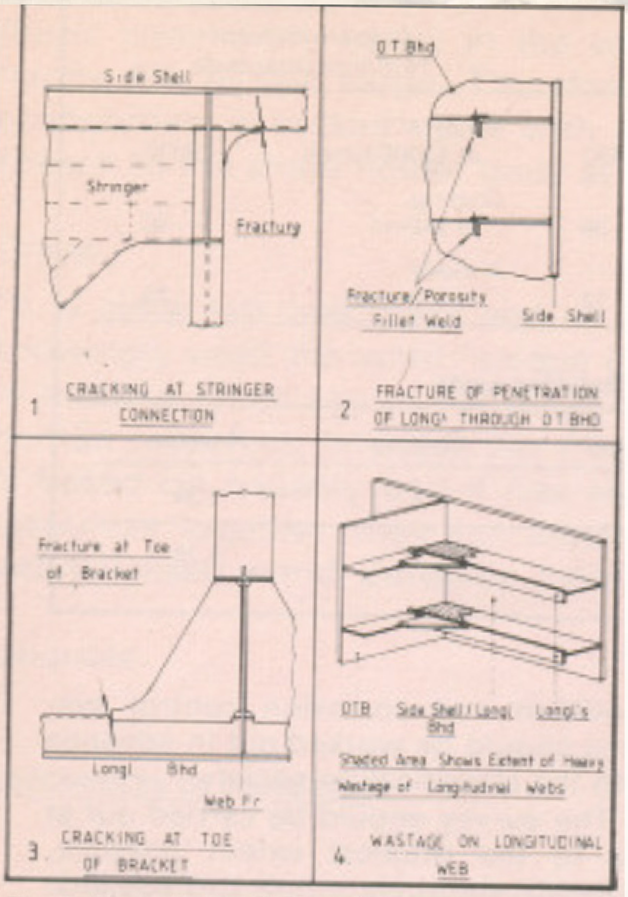
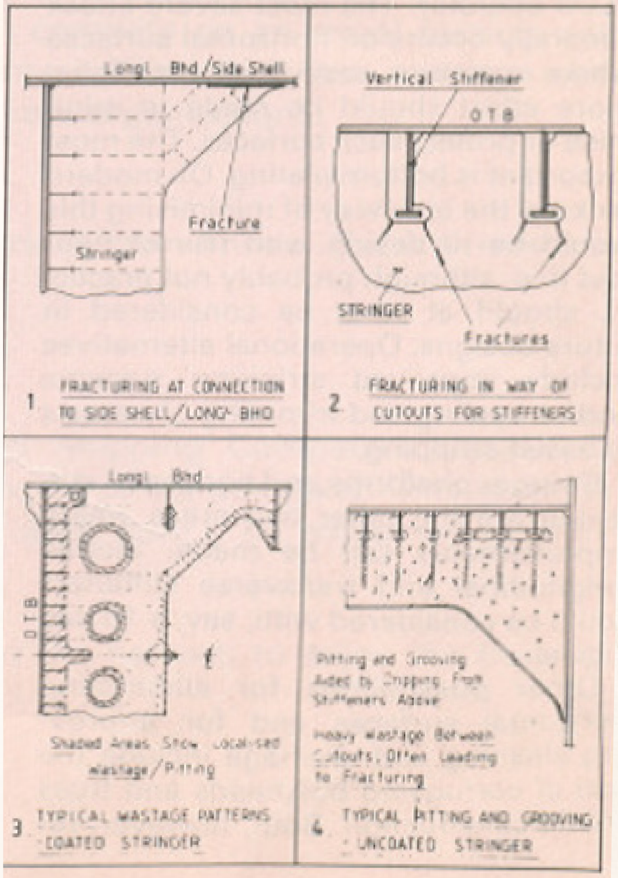


Fig 3: Typical side shell and bulkhead defects.

Fig 4: Stringer platform defects.



Structure	Classification society 'A'	Classification society 'B'
Section modulus	15% below current rule minimum	18% below current required rule area
Individual deck, bottom, side shell, and longitudinal bulkhead plates:		
– deck or bottom plate	0.85R	0.75D
– within 10% of deck or bottom	0.85R	0.80R
– elsewhere	0.75D	0.80R
Longitudinals	0.75D	0.75D
Transverse bulkhead:		
– Plates	0.70D	0.80R
– Stiffeners	0.70D	0.75D
Stringers, web frames, vertical girders, cross ties	0.85D	0.80D

R = current rule minimum thickness; D = design thickness

Table 1: General wastage limits.

1 square metre of 25 mm bottom plate		1 square metre of 14 mm internal plate	
Renewal: at $2500/tonne	$490	Renewal: at $3000/tonne	$330
Coating: at $35/m²	35	Coating: at $40/m²	80
Anodes: at $75 each	12	Anodes: at $75 each	23

Relative costs

Structure	Renewal	Coating	Anodes
Bottom plate	14	1	0.34
Internal plate	4	1	0.29

Table 2: Costs of protection.

POSTBAG

Dear Sir,

Apropos your editorial in April'84 issue of M.E.R., the training aspect of our sea going personnel has been neglected to an alarming degree and your leader is an overdue reminder to all concerned.

It is common knowledge that Indian Certificates do not comply with requirements of latest conventions. Even in a port like Bombay one can neither get a training nor certificate for so elementary a subject as first aid or fire fighting or life boat, without wasteful waiting for months.

M.O.T examinations are conducted only in Bombay and Calcutta and there too not adequate seats are available. There are not enough teachers in training institutions, not enough examiners in examination centres.

There is hardly any Post Sea Training anywhere in India and where it is, the available instruments are ridiculously insufficient.

There is no proper training for Merchant Navy Radio Officers.

Whereas shipping is becoming more and more technical our existing training facilities seem to shrink.

In the name of reducing unemployment existing training facilities are being curtailed at a time when these facilities should be working double overtime to RETRAIN existing ratings and Officers to cope with modern shipping.

That the actual situation is not far worse is perhaps due to natural innovativeness and self training of many officers and ratings. But it is high time that this vital aspect is given due consideration.

An example may be given in the offshore industry whereas the nation has committed several thousand crores in offshore ventures, support vessels etc. we still do not have a single training institute in this regard.

Govt. and Corporate support and enlightened policies are required so that the initiatives of so many skilled and motivated officers and ratings do not go waste.

I strongly support your call for a high level committee to look into this. I also request all concerned individuals to give this matter much thought and initiate discussions and debates at various forums to generate enlightened opinions.

Date 12-6-84.

Dipak Raut
Glamour Glenn
Flat No. 20, 5th Floor
100, Dr. Ambedkar Road
Pali Hill, Bandra
Bombay - 400 050

70 MER MAY 1984

Cost-cutting ignored

Sir,
I read, with some amusement, your remarks in the October 1983 issue concerning cost-cutting and economy consciousness of seagoing engineers and your pleas for correspondence about problems encountered at sea.

I am one of those that has submitted suggestions to my employers, time and time again, about improvements to machinery performance and plant efficiency. Tests, modifications and trials had been completed onboard with the full co-operation and involvement of the engine room staff, prior to those submissions. Definite improvements and savings have been demonstrated and verified at sea.

In my experience nothing whatsoever is normally done with any findings unless a solution to a problem is desperately sought. Any changes made usually revert back to the original when those engineers concerned with the saving or modification leave the vessel for pastures new.

On the rare occasion a bright idea emanates from head office, a certain modification or change of practice is carried through, even if considered to be detrimental or too costly by ships' engineers.

It does appear that no chief or second engineer will accept responsibility for any modification or change introduced by a previous engineer in case something goes wrong and they have to 'carry the can'. Few changes in running practices or alterations of procedures and plant requested by sea staff will be approved by head office for the same reason.

Few engineers will stick their necks out by reporting on economy measures if they risk the ire of those superiors who disregarded the reports in the first place.

Name and address supplied

Fluidised beds

Sir,
The paper 'Development of marine coal-fired boilers', presented to the IMarE recently, touched upon the problem of slagging. This can be a major problem when using coal with a high chlorine content. In one of the CEGB power stations I witnessed severe slagging on pulverised fuel boilers. Molten slag dripped from the superheater pendents bridging across the ash hopper. A number of remedies were tried, but the only way that a substantial amount of slag could be removed was by reducing the load by about one third and water lancing to chill and embrittle the slag.

This, though the most successful, required a lot of hard labour and even then the results were not always satisfactory. I have heard of other cases where slagging has been so severe, that the unit had to be taken out of service.

Clearly, slagging of such dimensions could be disastrous at sea, but in the papers on marine coal-fired boilers that I have read so far, this subject appears to have only been touched on.

I would have thought that, for powers lower than, say, 5000 kW, a poppet valved uniflow steam engine would be ideal, especially as such engines are still manufactured in the USA by Skinner in ranges up to 15 000 kW.

T Sheriff
Zimbabwe

Alarms

Sir,
Referring to MER February 1984, 'Keeping engines going with heavy fuel oils', there is a curious remark in the second column '75% of all alarms occurred between 8 and 10 am'.

Could this not be due to the fact that in the morning the Chief Engineer is usually in the engine room, so all alarms are recorded while he is there. After his morning appearance he would then usually go for coffee and most of the day would be heavily involved in paperwork.

When he is not there and, say, an alarm sounds because a purifier outlet has become blocked, then this can simply be dealt with by an oiler who would unblock the outlet and would allow the purifier to continue operating.

This type of alarm is relatively minor, if rapidly dealt with. The duty engineer might not feel it is worth recording on a relatively old ship, where alarms sound periodically.

If the same problem had occurred while the chief engineer was in the control room then it would have to be recorded in the engine log book.

A Protopapadakis
Clipper Maritime Agencies,
London SW7

Lube rates

Sir,
I refer to the February 1984 edition of the MER and the misprint on page 16 regarding my having stated Japanese licensee recommended lower lubrication rates than their licensors. The opposite is, of course, true.

What was stated in my paper was 'It is well-known that the Japanese licencees recommend higher feed rates than the licensors'.

Clive Brindle
Hong Kong

● *We regret this error and apologise to all concerned—Ed MER.*

A few transaction/papers in the issue are worth a mention:

1. BP's Performance Monitoring System for Marine Diesel Engines
2. The 'Risk Element' in Maritime Joint Ventures: A Third World View
3. On the operation of a Diesel Engine with wood-derived Gas in Bi-Fuel mode

The May 1984 issue is substance packed.

We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.

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