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Innovating Inland Vessel Navigation

Page 9 Concept of Vertical Lift Mechanism for Self-Propelled Inland Cargo Vessels

Page 20 Maintenance Feedback Analysis for Effective Asset Life Cycle Management: A Study on Offshore Wind Turbine

Page 30 Alternative Fuels for Maritime Decarbonisation – Technology Adoption & Ship Design Aspects

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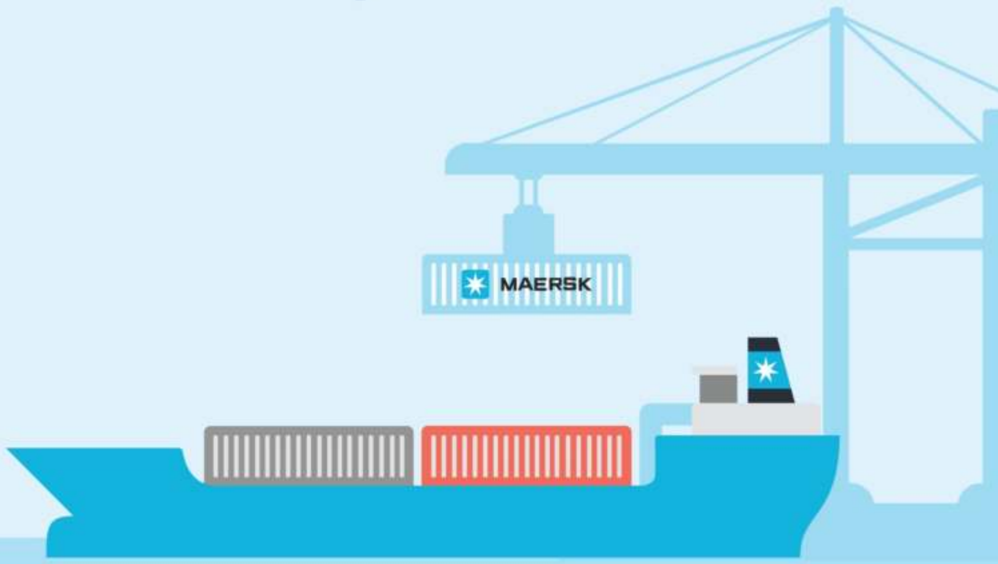

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EDITORIAL

Correction does much, but encouragement does more.
- Johann Wolfgang von Goethe

Chasing the COP27 was the MEPC 79 and there were expectations (like every MEPC) that IMO might align the targets and efforts with the UN's. The 79th also passed by. Four Annexures getting focus and yet the Exhaust Gas Cleaning System (EGCS) water discharge remained unresolved.

The Ballast Water story continued and two significant issues got due attention: Allowing temporary storage of treated sewage and grey water in ballast tanks (Guidelines awaited); and Convention adaptability to waters not conducive for treatment.

The sitting saw in-principle approval for designating particularly sensitive sea areas (PSSA). The cetaceans (whales, dolphins, porpoises) of NW Med Sea will get protection from risks of ship collisions, ship-sourced pollution etc. Marine Litter got attention too and studies are expected to provide direction.

The most eloquent motif was the GHG reduction strategies along with the pollution and the energy efficiency measures. Though options such as methanol, LNG, renewable sources for electrical energy etc., are nearer but yet to make the statement technologically strong for ships to adopt. The energy transition is inevitable and so are higher costs, as history would show. While transition from coal to the fossil fuels was quite rapid, the current carbon-free concept needs better arguments. Shipping, as an industry has not been as accommodative as automobile industry. Cutting the emissions to 50% (base 2008) by 2050 would require more corrections. Corrections would help but for a mind-set change towards climate change, some encouragement would help. It could be incentives or it could be an assurance of well proven technologies.

In this issue...

We start with an innovative proposition. A vertical lift mechanism is mooted for vessels navigating the inland waterways. Imagine the vessel encountering a shallow patch in the inland waterway and lifting itself, cross the shallows and settle back in the increased water depths again and continue its passage. The idea interestingly envisages the vessel lifting itself with up thrust created by propellers placed in the hull bottom. Anup Ghatak, who has been an Engineer with the IWAI, presents the solution and tries to answer many questions on stability, maximum possible vertical lift etc., considering waterways as cases-in-example. This concept gets its space for the creative approach, however much of the design still requires resolution and validation. I invite discussions on this.

This is followed by Prabu Duplex continuing the maintenance-based-on-analyses talks. Reliability Centred Maintenance has evolved into a rational approach to managing assets in a cost effective manner. The lacuna of obtaining continuous feedback for effective Failure Mode Effect & Analysis (FMEA) is explored. Prabu follows up with a case study on gas turbine blade, considering the phenomenon of creep. The point of maintenance feedback analysis being used as an extension of FMEA is presented well. There is merit in the case being applied to other marine components also.

Adding relevance to the MEPC comes an article on alternate fuels. Sajeendra Kumar Nambiar has culled as much information as possible and presents a somewhat comprehensive summary of the fuel options. An interesting angle discussed is that of the ship design for the emerging fuel options. This could be an interesting read for one catching up with alternate fuels.

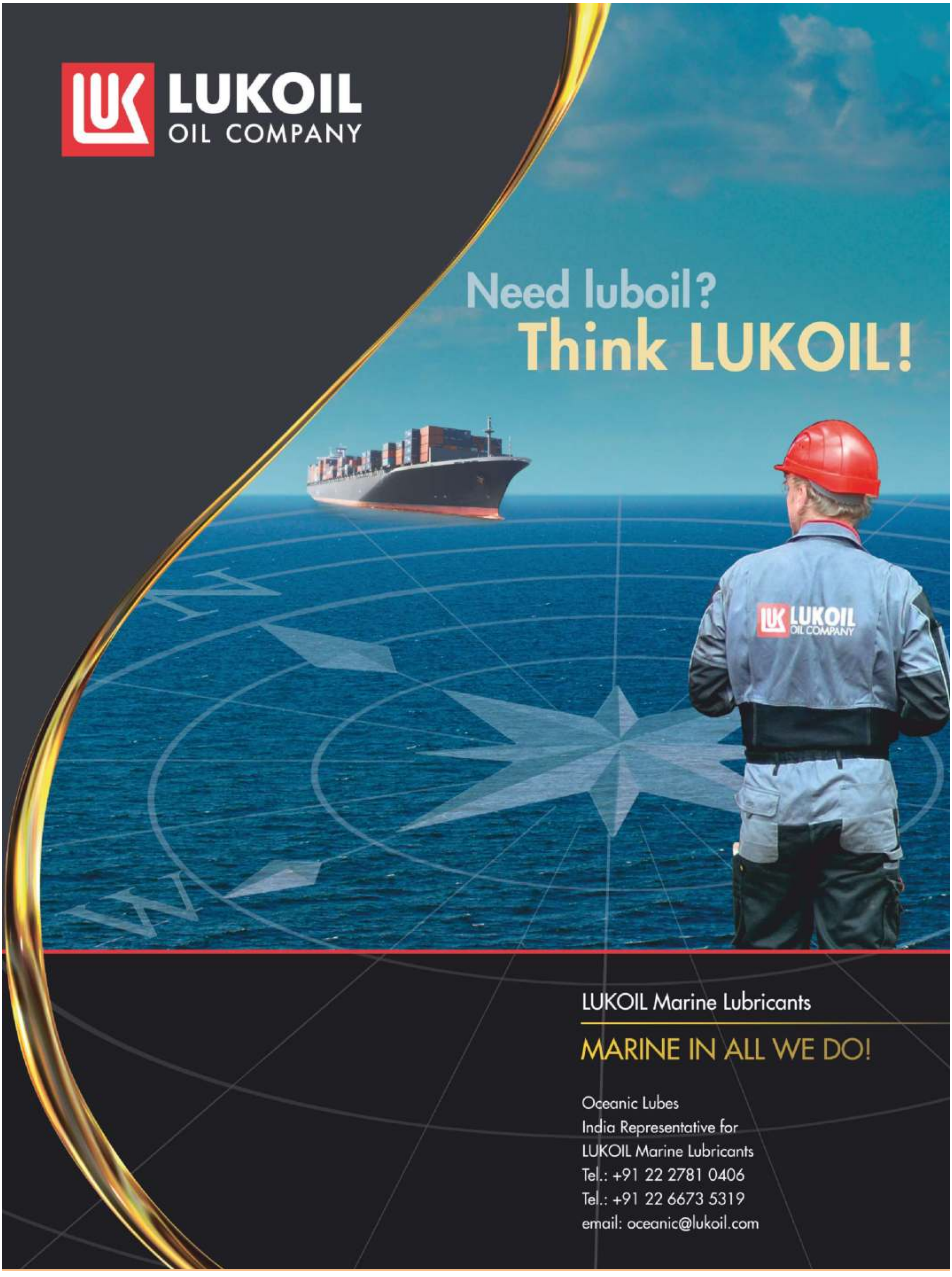
And under Technical Notes/Lube Matters, Sanjiv Wazir explains friction. From the archives, we post few interesting engineering thoughts from January 1983.

We ring in the bells for another new year.

May the mutations may not turn malignant and may the militaries retire to the barracks as 2023 rolls in.

Here is the January 2023 issue with the New Year wishes!

Dr Rajoo Balaji
Honorary Editor
editormer@imare.in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In This Issue

ARTICLES

09 Concept of Vertical Lift Mechanism for Self-Propelled Inland Cargo Vessels
– Anup Ray Ghatak

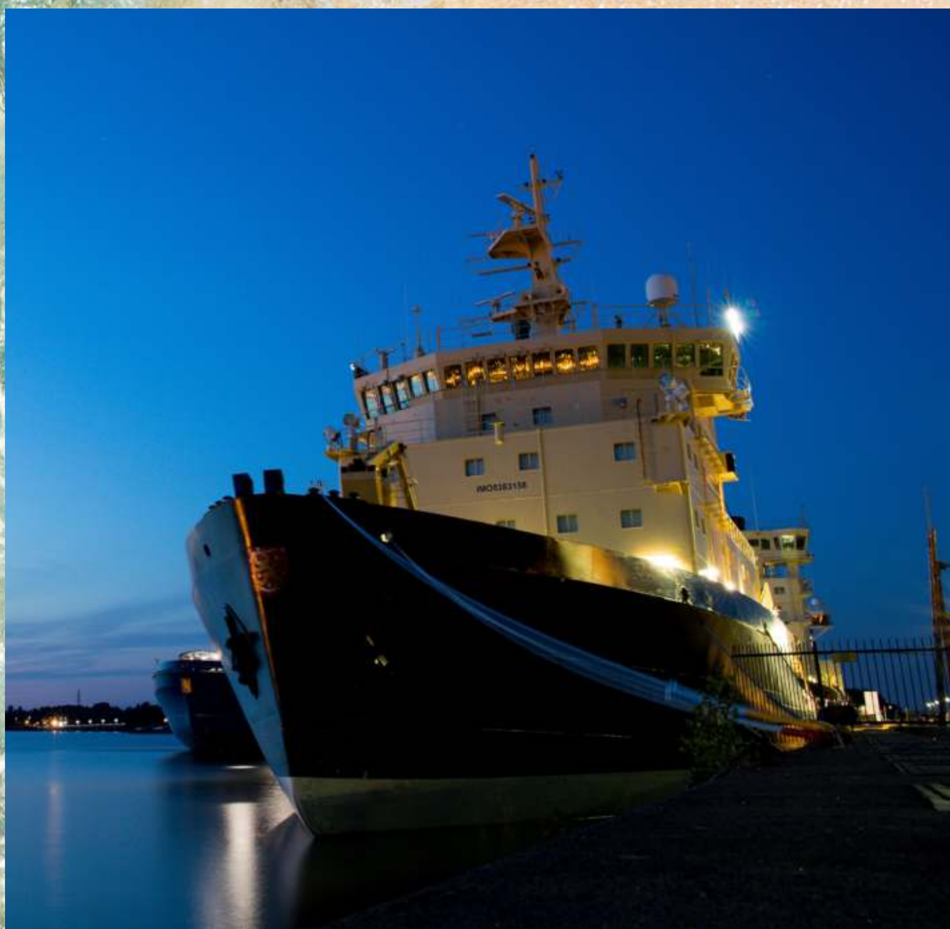
20 Maintenance Feedback Analysis for Effective Asset Life Cycle Management: A Study on Offshore Wind Turbine
– Prabu Duplex

30 Alternative Fuels for Maritime Decarbonisation – Technology Adoption & Ship Design Aspects
– Sajeendra Kumar Nambiar

COLUMNS

44 Technical Notes

49 MER Archives



Cover pictures: **Vessels in Indian inland waterways.**
Cover pictures courtesy: **Anup Ray Ghatak**

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CONCEPT OF VERTICAL LIFT MECHANISM FOR SELF-PROPELLED INLAND CARGO VESSELS

A. R. Ghatak

ABSTRACT

The objective is to present a new concept developed for the design of Self- Propelled Inland Cargo Vessels especially for the National Waterways. With the proposed method, a cargo vessel fully loaded to her maximum draught can cross shoals safely by reducing her draft instantly with stability. This will be by means of a **Vertical Lift Mechanism** to be built at vessel's hull bottom as discussed in detail.

The basic concept is to lift the vessel up as she finds less depth to sail ahead with her maximum draft. With the system proposed, the vessel will lift herself up with a vertical up thrust produced by a few horizontal propellers to be built at the hull bottom at bow & stern immersed in the minimum available water required to maintain her stability i.e. at her minimum draft level. It also enables the vessel to sail ahead with her normal propellers after being lifted up, of course, with much reduced speed for precaution over the shoal as elaborated in detail in subsequent paragraphs.

This will save a huge amount of expenditure by the Government towards bandalling and dredging activities as the **Least Available Depth (LAD)** committed will reduce to only 1.4 m instead of 2 m for 650 dwt vessels and likewise to a LAD of 2 m to 2.40 m only for bigger vessels of 1,500 – 2,500 dwt capacity to sail on almost the entire length of the National Waterways no. 1 & NW 2 and other National Waterways throughout the year instead of a LAD of 3.0 m being maintained presently.

This will, undoubtedly, enhance the credibility of Inland water transport operations on our National Waterways compared to other modes of Roads and Railways.

1. Introduction:

The objective is to present a new concept developed for the design of Self- Propelled Inland Cargo Vessels especially for the National Waterways by which a cargo vessel, fully loaded to her max. draught, can cross shoals safely by reducing her draught instantly with stability required. This can be achieved by means of a **Vertical Lift Mechanism** to be built at vessel's hull bottom as discussed in detail.

The concept has been developed by the Author's experience of working with Inland Waterways Authority of India (IWAI) for over 20 years and retiring as its Chief Engineer.

Despite being the cheapest mode compared to Road and Railways and having adequate existing infrastructure facilities like Terminals, mechanised cargo handling systems at places like Kolkata, Sahibganj and Patna in Bihar and Varanasi in UP on NW 1 (River Ganga) and Dhubri, Jogighopa, Pandu, Tezpur, Sadiya in Assam on NW 2 (River Brahmaputra) even 650 dwt cargo vessels could not sail from Kolkata to Prayagraj (Allahabad) even to Varanasi particularly in the lean season of the year from March/April to October/November despite regular expensive annual fairway maintenance work including Dredging & Bandalling.

(Bandalling is an old and cheap temporary river conservancy work which requires the erection of Bandals made of bamboo poles and bamboo mats erected across the secondary channel to divert its flow to go into the main fairway channel to increase its depth for navigation. But it may improve the depth of the main channel by not more than 0.40 m to 0.5 m).

As a result, the prospective shippers cannot venture to use the IWT mode mainly on our two National Waterways like NW 1 & NW2 which are the two most important national waterways.

Inland Waterways Authority of India (IWAI) was constituted by an Act of Parliament i.e., THE INLAND WATERWAYS AUTHORITY OF INDIA ACT, 1985 (No. 82 of 1985) under the Ministry of Shipping & Waterways. This Act provided for the constitution of an Authority for regulation and development of Inland Waterways for purposes of shipping and navigation and for matter connected therewith or incidental thereto.

Bandalling is an old and cheap temporary river conservancy work which requires the erection of Bandals made of bamboo poles and bamboo mats erected across the secondary channel to divert its flow to go into the main fairway channel to increase its depth for navigation

Amongst the various functions and powers delegated to the Authority, it has to carry out surveys and investigations for the development, maintenance and better utilisation of the national waterways, provide or permit setting up of infrastructural facilities on national waterways, carry out conservancy measures and training works and do all other acts necessary for the safety and convenience of inland navigation and improvement of the national waterways.

Besides these, other functions and powers are provided in the IWAI Act. For giving impetus to shipping and navigation, 111 waterways (106 new) were declared as National Waterways by THE NATIONAL WATERWAYS ACT, 2016 (No. 17 of 2016). For the overall development of IWT sector throughout the country, various works carried out are survey and investigations, river conservancy measures to provide certain **minimum Least Available Depth (LAD)** and also to provide the required dimensions for the fairway to facilitate navigation of inland vessels on National Waterways.

In order to undertake these works/ activities on the inland waters, the key requirement is of different kinds of inland vessels like survey launches for carrying out hydro graphic surveys like Thalweg survey, detail survey, bank to bank survey, Cutter Suction Dredgers, hydraulic surface dredgers and Amphibian Dredgers supported by Tugs / Workboats and Accommodation Boats to provide and maintain the fairway with requisite LAD.

Tugs / Workboats are also required for towing of vessels and also assist vessels which are grounded or in distress etc. Floating jetties (terminal pontoons) and fixed RCC jetties for providing terminal facilities, crane pontoons fitted with suitable crane for handling of cargo at the terminals are available with IWAI.

All the above works are carried out to facilitate cargo vessels for transportation of cargo; Ro-Ro vessels for transportation of vehicles from one shore to another; Ro-Pax vessels to facilitate transportation of vehicles and passengers. IWAI has procured vessels, dredgers, Tugs etc. over the years.

Among our National Waterways, NW 1 & NW 2 are the most important waterways, but most prone to silting after every flood season.

Presently, following Least Available Depths (LAD) are committed by IWAI:

NW 1: Haldia – Farakka: 3m, Farakka – Barh: 2.5 m, Barh – Ghazipur: 2.5 m, Ghazipur – Varanasi: 2.2 m & Varanasi - Prayagraj: 1.5 m.

NW 2: B'Desh Border - Neamati: 2.5 m, Neamati – Dibrugarh: 2.0 m, Dibrugarh – Oriam Ghat: 1.5 m.

Despite timely inception of dredging activities with erection & maintenance of adequate bandalling on the shoals on different critical locations along NW 1, NW 2 and other NWs, LAD as low as 0.6 m could be observed during Feb. & March in the Varanasi – Prayagraj stretch on NW 1 and LAD of 1.0 m could be observed in the upper stretches connecting Dibrgarh & Oriam Ghat on NW 2.

Image 1 and 2 - CSD YAMUNA of IWAI at work near Farakka navigation Lock upstream on NW 1

This is due to natural problems of siltation of alluvial rivers after every flood season beyond any control.

Based on fortnightly River Notices published by Inland Waterways Authority of India (IWAI) by hydrographic survey (Thakweg Survey along the entire navigable route of NW 1 & NW 2), the scenario for the last five years from April 2017 to March 2018, April 2018 to March 2019, April 2019 to March 2020, April 2020 to March 2021 and April 2021 to March 2022 is presented in **Table 1 and Table 2.**

Even with a negative metacentric height i.e. in a metastable condition, vessels with certain forms can still find a position of stable equilibrium at an angle of heel called 'angle of loll' which may be corrected only by lowering the gravity centre

With this concept in mind even under the above scenario every year during the lean season, a 650 tonne cargo vessel with an empty draught of 1.2 m having a max. loaded draught of 1.80 m, for example, can sail safely from Haldia to almost Prayagraj and B'Desh Border to almost Oriam Ghat with stability with a LAD not less than 1.4 m i.e. empty draught of 1.2 m+ 0.2 m keel clearance. Similarly, a 1500 dwt cargo requiring a draught of 2.5 m vessel can sail with her full load up to Varanasi on NW1 and up to almost Dibrugarh with a LAD of 2.1 m i.e. empty daft of 1.9 m + 0.2 m of keel clearance during lean season every year.

In principle, every cargo vessel can be lifted by the vessel's own propulsion system to be built additionally as proposed, hereunder, from her fully loaded max. draught up to the minimum draught to sail with stability across shoals safely with a LAD being not less than her empty draught plus a minimum keel clearance of 0.2m.

2. Basic Working Principle:

The basic concept is to lift the vessel up as she finds less depth to sail ahead with her maximum draught. The up thrust is produced in such a way just to replenish the buoyant force lost by the vessel at any instant of time due to the lifting of the upper part of the hull above water surface. The bottom hull propellers are to be built symmetrically fixed with hull bottom and positioned at bow & stern as close to the extreme Port & Starboard side corners as possible for stability.

As long as the vessel is lifted up vertically up to the designed minimum draught, its metacentric stability will not alter much except only by external forces like severe wind and waves.

Refer to **Figure 1** and **Figure 2.** With a small transverse healing of the vessel by say o^0 (Theta degrees), clockwise, looking forward toward the bow of the vessel (i.e. the S/B side going down and the Port side coming up), the centre of buoyancy rotates through the same angle o^0 anticlockwise towards the SB side.

The resultant R_{12} of the two Ps propellers and the resultant R_{34} of the two SB propellers develop each a

Table-1: National Waterway no. 1 i.e. River Ganga from Haldia to Prayagraj (1547 km).

Sl. no.	Stretch	River length(km)	Minimum LAD (m) observed in fortnightly River Notice by IWAI					LAD committed by IWAI (m)
			2017-'18	2018-'19	2019-'20	2020-'21	2021-'22	
1.	Haldia - Farakka	583	1.00	0.90	1.20	1.70	1.00	3.00
2.	Farakka - Patna	372	1.50	1.30	1.30	1.20	1.50	2.50
3.	Patna- Varanasi	363	0.80	0.60	0.70	1.10	0.80	2.50
4.	Varanasi- Prayagraj	229	0.80	0.60	0.80	0.80	0.80	1.50

Table-2: National Waterway no. 2 i.e. River Brahmaputra from B'Desh Border to Oriam Ghat (860 km)

Sl. no.	Stretch	River length(km)	Minimum LAD (m) observed in fortnightly River Notice by IWAI					LAD committed by IWAI (m)
			2017-'18	2018-'19	2019-'20	2020-'21	2021-'22	
1.	B'Desh border -Pandu	255	2.50	2.60	2.00	2.20	1.50	2.50
2.	Pandu-Neamati	374	2.10	2.20	2.10	2.10	2.10	2.50
3.	Neamati-Dibrugarh	139	2.00	1.90	2.10	1.80	1.70	2.00
4.	Dibrugarh-Oriam ghat	92	1.50	1.10	1.20	1.00	1.10	1.50

Sine component R_{12} Sin o and R_{34} Sin o both acting horizontally adding to the righting moment to restore stability.

R_{12} and R_{34} may be made equal or different in magnitude by the controlling Master of the vessel depending on the requirement of safety and stability of the vessel during both the vertical lifting and forward sailing over critical stretch only.

The resultant R_{12} of the two Ps propellers and the resultant R_{34} of the two SB propellers develop each also a Cosine component R_{12} Cos o and R_{34} Cos o both acting vertically.

> *In fact, with the system proposed, a vessel can lift herself up to any depth from her maximum draught to her minimum draught only as required depending on the LAD on the shoal*

As long as these two vertical components are same in magnitude each, they will develop an equal but opposite moment around the CG of the vessel cancelling each other.

In case, the angle of heeling tends to exceed the danger limit for any reason whatsoever, the S/B side two propellers at the stern & bow are to be controlled to generate more up thrust compared to the Port side bottom propellers to reduce the angle of heeling to bring the vessel to a stable position. As the vessel is lifted up, the resultant Up thrust is to be increased just to replenish the loss of buoyant force of water due to lifting and this righting-arm component too is strengthened more and more to increase the vessel's stability. The procedure will be reversed in case of an anticlockwise heeling of the vessel.

As proposed, out of four bottom propellers, a pair will be positioned at the stern bottom while the other pair will be positioned at bow bottom each yielding equal magnitude of up thrust for a normal uniform lifting as shown in **Figure 2**. The bottom propellers are therefore to be positioned at the four corners of the hull bottom as much as possible for stability all along.

In case the angle of heeling or trimming tends to exceed the danger limit due to any reason during lifting, the magnitude of up thrust generated by each pair of Bow or Stern may be adjusted accordingly by increasing/ decreasing the propeller RPM as required to increase/ decrease the righting moment to restore the stability of the vessel as and when required.

The Master of the vessel, above all, is, of course, the best judge to decide such actions as needed as he will control the bottom propellers individually by means of remote control in the Bridge.

In case of Inland Vessels, the Master of the vessel is the top most cadre of Ranking Personnel who has to bear the overall responsibility for the safe manoeuvring of a vessel.

The up thrust produced by each of the four hull bottom propellers can be increased or decreased by increasing or decreasing the rpm of the propeller concerned since the up thrust generated by a propeller is directly proportional to its rpm.

What is necessary is that each hull propeller has to be remote controlled from the deck of the wheel house by the Master who happens to be the best judge to decide which side hull propellers in the Port or in the starboard side are to be controlled by increasing or decreasing the respective rpm for adjusting the up thrust accordingly for the safe manoeuvring of the vessel with stability and safety.

If the bottom propellers are rudder propulsion type like **SCHOTTEL of Germany or Holland Rudder Propeller (HRP) of The Netherlands,** the required propellers **P or S/B** side may just be rotated clock or anticlockwise to generate the required thrust to strengthen the righting arm for stability.

But it is true only for calm weather conditions without any significant wind pressure and waves to apply lateral thrust to the superstructure of the vessel. In a rough weather with strong wind and waves, the wind pressure from an angle may weaken the righting moment

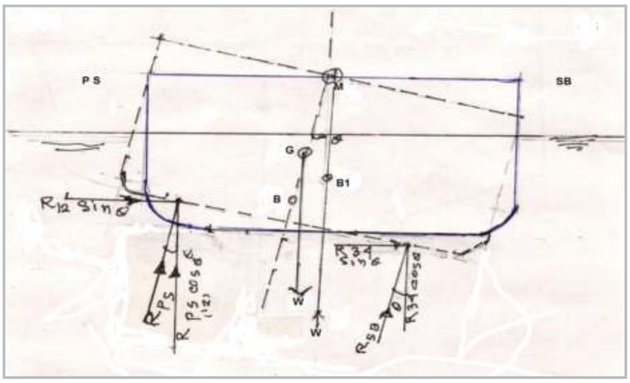

Figure 1

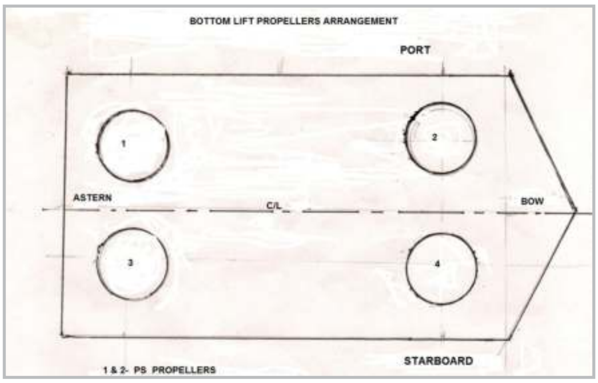

Figure 2

endangering thereby the stability of the vessel sailing with full load at its minimum draught, of course with much reduced speed over the shoals only. Duration of such a sailing at a stretch on a shoal will, of course, be for a few minutes only for our National waterways.

Even with a negative metacentric height i.e. in a metastable condition, vessels with certain forms can still find a position of stable equilibrium at an angle of heel called 'angle of loll' which may be corrected only by lowering the gravity centre.

3. Evaluation of up thrust & kw of the lifting bottom Propellers:

It is not necessary to go into the detailed intricacies of mathematical expressions related to force, power, rpm, torque or power losses by the propulsion mechanism of a normal inland vessel. Simply with the basic hydrodynamic relationship of various propulsion components, the subject may be discussed.

Following this, we understand the basic relationship between ship power, shaft torque and fuel consumption.

Power: Power is simply force (F) times velocity (v), where 1 HP (horsepower, English units) is equal to 0.7457 kW (kilowatt, metric) and 1 kW = 1000 Newtons meters/ second.

$$P = F * V \quad (1)$$

The above refers to the normal horizontal movement of a vessel along a fairway with her normal stern propellers.

Now let us imagine this phenomenon during the lifting process in a vertical direction too when the vessel is moving vertically upwards very slowly, of course, reducing her maximum draught slowly by means of a gradually increasing up thrust produced by her own system of a few horizontal propellers located at the hull bottom (keel level) symmetrically as proposed **(See Figure 2)**.

Number of pairs and thrust generated by these bottom hull propellers will depend on the size of the vessel. During this vertical lift, the forward propulsion is to be stopped.

4. Generation of vertical up thrust for lifting vessel:

The vertical up thrust produced by the horizontal bottom propellers will just compensate for the gradual loss of buoyant force (linear to the height of lift) at any instant of time during lifting process so as to keep the vessel always floating with stability.

In order to make the vessel sail with her own normal stern propellers being immersed in water to produce the required horizontal thrust, the vessel will have to

Image 3 - M V RAJAGOPALACHARI of 650 dwt capacity of IWAI operating on NW 1 and NW 2 (Through Indo-Bangladesh Protocol Route)

Table . 3: (Based on the SPV MV Rajagopalachari of IWAI fleet)

Sl.no.	Vessel Parameter	Value
1	LoA	62.80 m
2	Moulded breadth	10.60
3	Moulded breadth	2.10 m
4	Maximum loaded draught at even keel	1.80 m
5	Minimum navigational draught aft	1.20 m
6	Empty draught (mean)	0.69 m
7	Dead weight in river water (1.0 tonne per cubic meter)	650 tonnes
8	Pay load at maximum water of 1.80 m with 50% fuel, water and stores	625 tonnes
9	Pay load at minimum draught of 1.2 m with 50% fuel, water and stores tonnes	265 tonnes
10	Hold volume	1800 m^3
11	Propulsion power : Max/2	380 hp
12	Trails speed at draught of 1.2 m	17.5 km/h
13	Rudders	Rudder Propulsion type (HRP)

reach her minimum draught with the full load being carried i.e. Max. Lift possible = Difference between the Maximum and the minimum draught.

In fact, with the system proposed, a vessel can lift herself up to any depth from her maximum draught to her minimum draught only as required depending on the LAD on the shoal.

The answer is that a maximum loaded vessel can be lifted up till her Metacentre lies above the CG of the vessel for a stable equilibrium. But this is subject to necessary statutory provision of this Clause in the Inland Vessels Act by the Government of India and the States

4.1. Evaluation of vertical lift up thrust & kw of the bottom hull propellers:

(i) Smaller vessel:

Max. draught is 1.8 m and the minimum draught is 1.2 m for the vessel similar to M V Rajagopalachari. Max. lift possible with stability =1.8 m – 1.2 m= 0.6 m.

At the instant the vessel reaches a shoal with a LAD less than 2 m as recorded by the Echo sounder, forward velocity is made 0. Master instantly starts operating the hull bottom propellers located symmetrically at the bow and stern at the keel level in order to start lifting the vessel up vertically to attain a clear depth of 1.4 m (empty draught of 1.20 m + keel clearance of 0.2 m) above the shoal so as to sail safely further over the entire shoal length with stability, of course, with a slower speed. The maximum lift possible, therefore, to attain over a shoal of 1.4 m LAD = 0.6 m i.e. from a channel LAD of 2 m to a LAD of 1.4 m. The Master is to get all information of the shoals ahead from the Echo-Sounder.

Let us assume that the vessel takes just 1 minute to lift her up by 0.6 m at the point where she has to stop i.e. after getting a LAD of 1.4 m (!.2 m + 0.20 keel clearance minimum) at a lifting speed @ 0.01 meter per sec.

As the vessel lifts her up leaving the water surface, the upward buoyant thrust of water decreases inversely with lift height attained.

Now this reduction of buoyant pressure of water has to be exactly compensated for at every instant of time by the increasing vertical up thrust to be generated by the bottom propellers so as to keep the vessel floating with stability.

At the instant at t = 60 seconds when the vessel attains a clear lift of 0.6 m over the shoal existing ahead, the vessel attains an upward velocity v @ 0.6 m / 60 seconds i.e. 0.01 m/sec.

The vertical up thrust at that instant produced by the bottom propellers is equivalent to the weight of the volume of water reduced by the vessel while rising up leaving the water surface. This volume of water works out to 0.784 (Block Co-eff) X 62.80 m (LoA) x 10.6 m (breadth) x 0.6 m (Lift attained in m) = 313.14 m^3 = 313.14 tonne force.

The required up thrust to keep the vessel floating after lifting it by 0.6 m = Equivalent buoyancy lost due to the lift = 313.14 tf.

The Power in kilowatt (kw) is calculated by the following equation:

kw = tonne force x velocity (m/sec) x 9.80665 (g in m/sec^2) (2)

Therefore, total installed kw of propellers will be Up thrust in tonnes force x velocity of lift in m/sec i.e. 313.14 x 0.01 x 9.80665 = 30.70 kw because 1 tonne force = 9806.65 Newtons and 1 kw = tf x velocity x 9.80665.

4 nos. of bottom propellers may be used @ 2 on the P side and 2 on the S/B side both at bow and stern of the vessel so that each propeller generates a thrust of 313.14/4 = 78.285 tonne force in order to produce an up thrust of 78.285 x 0.01 x 9.80665 kw = 7.68 kw.

Therefore, each of the 4 bottom propellers will be required to generate at least 9 /10 kw.

Image 4: Vessel operating on River Danube, Germany.

TABLE 4

Sl.no.	Vessel Parameters	Value
1.	LoA	86.00 m
2.	Moulded breadth	9.50 m
3.	Max. loaded draught	2.50 m
4.	Minimum draught	1.90 m
5.	Propulsion power	750 kw
6.	DWT at max. draught	1,350 tonnes
7.	Velocity	15 m/hr.

4.2. Bigger vessel:

Following discussions are based on vessels operating on River Danube, Germany.

(i) For a similar max. lift of 0.6 m. in 1 minute the corresponding up thrust & kw of the vertical lift propellers shall be 384.32 tonne force & 37.68 kw respectively for a bigger 1,350 dwt vessel with LoA 86 m, breadth 9.5 m, max. draught 2.5 m, minimum draught 1.90 m following the above same calculation procedure for a smaller vessel.

(ii) 4 nos. of bottom propellers may be deployed @ 2 (1 on the P side and 1 on the SB side) on the stern hull bottom and at the bow hull bottom on the Port side as well as SB side so that each propeller generates a thrust of 384.32 tf /4 = 96.08 tf and corresponding power is 9.42 kw each.

> **Presently, the cost of Registration & Survey of vessels ranging from 650 dwt to 2,500 dwt varies between Rs. 1.50 lakh to Rs. 2.0 lakh and the cost of Annual Survey varies between Rs. 25 thousand and Rs.30 thousand only**

4.3. Evaluation of forward propulsive thrust for sailing after attaining the reduced 'empty draught' level using vessel's own propellers.

4.3.1. Example with smaller vessel as described in para 4.1.0

The max. loaded draught = 1.80 m and the minimum draught = 1.2 m.

The vessel requires a minimum depth of 2 m including a minimum safe keel clearance of 0.2 m in order to sail safely with stability at the maximum dwt of 650 tonnes. As such, the vessel can be lifted maximum by 0.6 m so as to sail on the minimum depth of 1.4 m (minimum draught 1.2m + 0.2m) with a keel clearance of 0.20 m.

We can evaluate the required forward thrust and hp of normal propellers after being lifted up by 0.6 m as below:

Here F, the buoyant force of water that the vessel has to overcome by her propulsive forward thrust equals to CB x 10.60 m (Breadth) x 1.2 m (empty draught) m. x the buoyant pressure of water ahead where C_B is the block co-efficient of the vessel taken as 0.784.

(i) The resultant buoyant pressure by water the vessel faces varying proportionately with water depth all along down her draught as the vessel sails ahead works out as Density of water x C_B x 1.2 m / 2.

In S I Units, it will work out as:

1 tonne per cubic meter x 0.784 x 1.2 (m) x 1 (m) / 2 = 0.4704 tonne f per sq. m

Therefore, total forward thrust (F) in tonne force produced by 2 propellers equals, = 0.4704 x 0.784(C_B) x 10.60 (m) x 1.2 (m) = 4.69 tonne force.

This works out to a kw power equalling F x v x 9.80665 (Equation no. 2) where v is velocity of the vessel in m per sec which is a reduced speed @ 8 km/hr. i.e. 2.23 m./sec to sail with caution over the shoals.

Therefore, total kw = 4.69 x 2.23 x 9.806650 = 102.56 kw.

According to the same calculation procedures, the maximum propeller power of the smaller vessel in question will be 503 kw against the rated power of 2 x 283 kw as per the Builder's manual for a max. speed of 17.5 km/hr. at max. draught of 1.80 m.

(ii) Squat: Vessel's speed will be very slow during this sailing forward over the critical shoals. A speed of 8 km/hr has been assumed. This is equal to 4.32 knots.

Roughly, the squat in meter is expressed by the following relation:

Squat (m) = 1 x C_B x v^2 / 100, where v is in knots (3)

As such, squat = 0.784 x $(4.32)^2$ / 100 = 0.146 m. So, as long as the vessel is maintaining a safe keel clearance of 0.2 m, there is no problem with the squat.

4.3.2. Bigger vessels:

(i) Similarly, for a cargo vessel as shown in **Table. 4** above of dwt 1,350 tonnes, 86 m (LoA), 9.5 m(Breadth), 2.50 (Max. draught), 3.0 m (water depth required), max. Speed 15 km/hr. and minimum draught of **1.9 m**, the following is corresponding values for forward sailing hp by the normal propellers of the vessel.

The cruising speed, of course, during crossing the shoal with LAD down up to 2.1 m (empty draught 1.9 m + 0.2 m safe keel clearance) is reduced to 7 km/hour i.e. 1.95 m/sec. for caution.

(ii) The resultant buoyant pressure by water the vessel faces varying proportionately with water depth all along down her draught as the vessel sails ahead works out to Density of water x 1.9 m / 2.

In S I Units, it will work out as:

1 tonne f per cubic meter x 0.784 ($C_{B,}$ Block-Co-eff) x 1.9 (m) x 1 (m) / 2 = 0.745 tonne f per sq. m.

Therefore, total forward thrust (F) in T f produced by 2 propellers equals, = 0.745 x 0.784(C_B) x 9.50 (m) x 1.9 (m) = 10.54 tonne force.

This works out to a kw power equalling F x v x 9.80665 where v is velocity of the vessel in m per sec which is a reduced speed @ 7 km/hr. i.e. 1.95 m./sec to sail with caution over the shoals.

Therefore, total kw = 10.54 x 1.95 x 9.806650 = 201.55 kw.

(refer Equation no. 2)

According to the same calculation procedures (Equation no. 2) the maximum propeller power of the bigger vessel in question at her max. loaded draught of 2.50 m will be **746.21** kw against the rated power of 750 kw as per the Builder's manual for a max. speed of 15.0 km/hr.

(iii) Squat: Vessel's speed will be very slow during this sailing forward over the critical shoals. A speed of 7 km/hr has been assumed. This is equal to 3.78 knots.

Roughly the squat in meter is expressed by the following:

Squat (m) = 1 x C_B x v^2 / 100, v is in knots. (Equation no.3)

As such, squat = 0.784 x $(3.78)^2$ / 100 = 0.112 m

So, as long as the vessel is maintaining a safe keel clearance of 0.2 m, there is no problem with the squat.

4.4. Effects of installation of hull bottom lift Propellers:

4.4.1. Effects on the loaded draught:

Let us first evaluate the buoyant force by water required to make the vessel floating with an enhanced draught of 2,41 m instead of 2.50 m in case of the bigger vessel in **Table 2**.

The total buoyant force required will be = 0.784 x 86.0 x 9.50 x 0.61(Lift 0.60 m +0.01 extra height) = 390.72 tonne force.

This according to Equation no. 2, will require a propulsive power of 390.72 x 0.01 m/sec (Lift velocity) x 0.80665

= 38.31 kw against 37.68 kw as calculated as total up thrust by 4 bottom lift propellers for the Bigger vessel in para 4.2.0 (i).

This 0.01 m increase in loaded draught is due to 6.40 tonne additional load of bottom propellers provided.

Therefore, we may safely install 4 bottom propellers as proposed earlier each with 10 kw capacity so that the total kw available is 4 x 10 = 40 kw.

The total weight of the 4 nos. propellers will be less than 4 tonnes.

4.4.2. Displacement of water as the bottom propellers' run:

It is seen from the above calculation that 0.62 kw will be required to lift the bottom of the vessel up by 1 cm only.

In case the displacement of water as the propellers run requires the bottom propellers to project 12 cms beyond the bottom i.e. beyond the loaded draught of 1.90 m, an additional 12 X 0.62 kw i.e. 7.44 kw will be required to lift her up at the draught of 1.90- 0.12 m = 1.78 m while crossing shoals.

In this case it is recommended to use 50 kw for each of the four bottom propellers.

Now there is a pertinent question here that up to what height a vessel can be lifted up by up thrust bottom propellers beyond her permissible lowest stable draught?

The answer is that a maximum loaded vessel can be lifted up till her Metacentre lies above the CG of the vessel for a stable equilibrium. But this is subject to necessary statutory provision of this Clause in the Inland Vessels Act by the Government of India and the States.

After all, while the vessel sails on a critical stretch of the fairway having a LAD (Least Available Depth) less than 1.2 m for the Small vessel and 1.9 m for the bigger vessel as discussed above, the Master of the vessel will have a greater responsibility for controlling the vessel's stability by regulating the up thrust generated by the PS & SB bottom up thrust propellers by means of remote control from his desk at the bridge of the Wheel House.

He is the best judge to decide what to do to restore vessel's stability based on the latest River Notice published by IWAI, Government of India and the instant actual LAD as indicated by the Echo-Sounder installed at the vessel's bottom.

Of course, on the NW 1 i.e. River Ganga or NW 2 i.e. River Brahmaputra the maximum length of one such critical stretch may be within 500 m and the number of such stretches in the leanest period in a year may be within 15 – 20 nos.

4.4.3. Effects on the cost of the vessel:

Presently, the cost of the Bigger vessel in **Table 2** will be around 25 crores.

The total cost of procurement and installation of additional 4 nos. bottom hull lift propellers each 10 kw as proposed will be approximately 1.00 crores including 4 nos. driving engines with all accessories like gear units, propeller shafts etc. As such, the proposed additional system constitutes about 4 % of the cost of the vessel.

However, in case the bottom hull propellers are driven by electricity, the cost will be much less than 4%.

4.4.4. Effect on the cost of getting approval from Classification Society:

The Inland Water transportation system within any State is under the statuary control of the **Indian Vessels Act of 1917** and further revised and notified in 2021 of the Government of India and every State is authorised to control the system on behalf of the Government of India.

In India States like Assam, West Bengal, Goa, Kerala, Maharashtra, and Gujarat etc. have full-fledged Inland Water Transport Directorate to control the movement of

2023

Warmest thoughts and best wishes
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HAPPY NEW YEAR

inland cargo vessels based on the I V Act for the safety of vessels moment. The statute specifies the qualification of inland vessel Deck crews and Engine Crews, construction of vessels with related safety requirement. Based on the examination of the vessels by IWT Surveyors of the Directorate the vessels are registered and permitted to operate with the design max. Dwt. Every year the vessel has to be examined by the IWT Surveyor for continuing the operation. This is called Annual Survey.

Besides, after every four years the vessel requires a Dry Dock Survey for hull and other component examination by the IWT Surveyors.

Presently, the cost of Registration & Survey of vessels ranging from 650 dwt to 2,500 dwt varies between Rs. 1.50 lakh to Rs. 2.0 lakh and the cost of Annual Survey varies between Rs. 25 thousand and Rs.30 thousand only. Of course, the cost is decided on the basis of no. of visits by the IWT Surveyors. But the Statutory Four Yearly Dry Dock Survey will include the Dry Dock charges to be paid in addition by the operator to the Dry Dock Yard.

As such, the component of the cost of Registration & Survey of a vessel constitutes a negligible component of the total procurement cost of a vessel.

5. Use of Artificial Intelligence for the Vertical Lift Mechanism:

Use of Artificial Intelligence can be very much thought of for providing a safer vessel manoeuvring specially over critical stretches of the fairway with less depth.

The depth of the fairway ahead may be monitored by an Echo Sounder Transducer fitted at the hull bottom so that the Master knows safe keel clearance below the hull bottom instantly.

There may be one lower limit for initiating automatic operation for starting the vertical lifting operation and the other upper limit for stopping any further lifting operation of the vessel as soon as the vessel reaches her designed minimum safe & stable draught.

For example, as described in para 4.0.0. above, for a smaller vessel with a max. loaded draught of 1.8 m and minimum stable draught of 1.2 m, the maximum height the vessel can be lifted up is o.6 m with of course maintaining the minimum safe keel clearance of 0.2 m all along for safety and stability.

For NW 1 and NW 2 and other NWs, the IWT Cargo vessels should maintain a safe keel clearance of 0.20 m.

The concept is that the moment the loaded vessel touches this minimum safe keel clearance level; the transducer will generate an additional signal to activate the hull bottom propellers to provide sufficient up thrust by automatically increasing the rpm of the hull bottom propellers. As a result, the vessel will be lifted up to sail ahead with reduced loaded draught.

The transducer signal at the hull bottom may also be used besides measuring depth below the vessel to operate the bottom propellers to lift the vessel up gradually so as to steer clear the river bed profile with the safe keel clearance.

In case when the fairway further ahead shows a LAD even less than 1.4 m. the system will automatically stop any further lifting up operation but the vertical up thrust propellers shall continue to provide up thrust to keep the vessel afloat at that location and may sail back way to return to a safe location and wait there for action by IWAI.

Master of the vessel will, of course, get all up to date LAD information from the River Notice published by IWAI based on the fortnightly Thalway Survey conducted by the IWAI.

In any case, there would be no chance of any human error whatsoever.

But if IWAI maintain their commitment for assuring a minimum guaranteed LAD of 1.2 m + 0.20 m (the minimum keel clearance) i.e. 1.40 m, there may not be any such incident.

This is, of course, an electronics system that needs designing by the Electronics Engineer.

6. Observations and recommendations:

6.1. It is observed that for a manoeuvring system for such an extremely low draught operating conditions at the minimum draught, the Pump-Jet Propulsion System is the best solution. In The Netherlands, many inland Tankers 2500-3000 dwt sail with the help of 2 x 370 kw Pump- Jet propulsion units each. The Pump-Jet propellers are built on the hull flushing with the bottom requiring a minimum immersion of 150 mm to 750 mm. These thrusters can provide full thrust in all directions. A minimum of 4 or more bottom pump jet propulsions may be built at the hull bottom symmetrically at the corners of the bow & stern depending on the max. capacity of the vessel and the max. lift required for lifting up to the vessels' empty draught while crossing the shallow stretches as discussed above. This refers to vessels without requiring any normal propeller at the stern.

6.2. During normal plying of the vessel at her max. draught without requiring any lift to clear any shoal, the bottom pump jet propellers will be kept inoperative except the pair at the stern may be operated (being rotated in such a way as to generate only a horizontal propelling thrust to the vessel for sailing with her design speed).

6.3. At the time when the vessel cannot sail ahead further due to inadequate LAD, all pump jets are to be made operational so as to provide the full vertical up thrust required to lift the vessel vertically up to the reduced required draught limited up to the minimum draught keeping in view the safe stability of the vessel. Once reduced draught up to the minimum draught to clear the shoal ahead is reached, the stern jet propulsion pair only may be given a slight tilt by rotating the pump-jet by a small degree anticlockwise from the horizontal position to produce a small horizontal component to generate a forward thrust to propel the vessel very slowly so as to cross the shallow stretch ahead with caution while the remaining pump jets will provide the required vertical up thrust to keep the vessel lifted as required. The duration of such crossing the shoals will be very short like several minutes at a stretch only on our National Waterways like Ganga, Brahmaputra, West Coast Canals of Kerala etc. This is, of course, for vessels built with only bottom propellers or bottom Pump Jet propellers without any conventional stern propellers.

6.4. In Europe and other countries, this jet propulsion system instead of normal stern propeller system is in use since long for various types of ferry, passenger and cargo/container/tanker inland vessels. Thrust as high as 450 kw may be produced by a single jet propulsion unit. Building new inland vessels with this type of Bottom Propellers or jet propulsion system as described above or installing the system additionally in our existing vessels will not attract any major additional cost.

7. Conclusion:

7.1. Once the above facilities are installed in the existing and the future inland self-propelled cargo vessels to sail on National Waterways and other rivers as proposed above in details, a minimum LAD of 1.4 m only will be required for the safe movement of a 650 dwt vessel from Haldia to Prayagraj throughout the lean season. This will save a huge amount of expenditure by the Government towards bandalling and dredging activities as the LAD committed will reduce to only 1.4 m instead of 2 m for 650 dwt vessels and likewise to a LAD of 2 m to 2.40 m only for bigger vessels of 1,500 – 2,500 dwt capacity to sail on almost the entire length of the National Waterways no. 1 & NW 2 and other National Waterways throughout the year instead of a LAD of 3.0 m now being maintained presently.

This will, undoubtedly, enhance the credibility of Inland water transport operations on our National Waterways compared to other modes of Roads and Railways.

7.2. But in any case, the feasibility of the concept can only be established after conducting an accurate Mathematical Modelling as well as a Physical Model analysis of the concept.

About the Author

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MAINTENANCE FEEDBACK ANALYSIS FOR EFFECTIVE ASSET LIFE CYCLE MANAGEMENT: A STUDY ON OFFSHORE WIND TURBINE

Prabu Duplex

1 Introduction

Reliability Centred Maintenance (RCM) is currently seen as an important approach to design / develop a maintenance concept. The application of RCM forms a basis for preventive maintenance activities and can therefore influence a significant part of the operational expenses. A very important aspect of the RCM methodology is Failure Mode Effect and Analysis (FMEA). FMEA was developed in 1949 by the American Army to evaluate the impact of system and equipment failures on mission success and the safety of personnel and equipment. FMEA can be defined as "a method of reliability analysis intended to identify failures affecting the functioning of a system and enable priorities for action to be set" (BS5760, 2009). By performing FMEAs, failure modes are identified. Failure modes are the ways, or modes, in which an asset can fail. The severity, probability of occurrence and risk of non-detection are estimated and used to rate the risk associated with each failure mode. Usual practice is to combine these elements in a risk priority number (RPN). Three factors are usually taken into account when evaluating the risk of failure: the severity; the probability of occurrence; and the likelihood of detecting the failure. FMEA can be performed in various phases of the life-cycle. Although the purpose, terminology and other details can vary according to type (e.g., Process FMEA - PFMEA, Design FMEA - DFMEA, System FMEA, Product FMEA, FMECA, etc.), the basic methodology is similar for all.

Feedback is essential for FMEA-based maintenance. According to [12] feedback is essential for the success of a living FMEA and an effective and efficient maintenance program. The FMEA is however not reviewed or updated anymore after its initial use [12]. In other words, FMEA is regarded as a one-time only exercise: not as an object of development. Because of the importance of asset information, asset information management can be viewed as enabler of feedback on FMEA and thereby as a precondition for continuous use of FMEA for maintenance improvement.

Therefore, the preventive maintenance plan might be inaccurate when used in practice. It is difficult to assess the exact impact of the inaccuracies, but it is likely that they will lead to unnecessary costs. Accordingly, this work aims to study the possibilities to improve asset information management in order to allow feedback in FMEA-based maintenance.

In line with the objectives introduced in the previous paragraphs, Reliability Centred Maintenance (RCM) analysis is performed in order to suggest a maintenance program, and identify improvement potentials for an offshore 2 MW wind turbine. Maintenance feedback analysis (MFA) is conducted, to find opportunities for continuous improvement and subsequent data collection. RCM analysis is performed in line with the guidelines of NASA [11] and MFA is conducted based on [12].

2 Reliability centred maintenance

Reliability Centred Maintenance (RCM) integrates preventive Maintenance (PM), predictive Testing and inspection (PT&I), repair (reactive maintenance), and Proactive Maintenance to increase the probability that a machine or component will function in the required manner over its design life-cycle with a minimum amount of maintenance and downtime [11]. Maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths, and maximise equipment reliability while minimising life-cycle costs.

The goal of this approach is to reduce the Life-Cycle Cost (LCC) of a facility to a minimum while continuing to allow the facility to function as intended with required reliability and availability. It also minimises the risk of failure and creates a hazard-free working environment. This goal is accomplished through identification of failure modes and their consequences for each system. This allows system and equipment functionality to be maintained in the most economical manner. The following are the key objectives of this method:

- To ensure realisation of the inherent safety and reliability levels of the equipment.
- To restore the equipment to these inherent levels when deterioration occurs.
- To obtain the information necessary for design improvement of those items where their inherent reliability proves to be inadequate.
- To accomplish these goals at a minimum total cost, including maintenance costs, support costs, and economic consequences of operational failures.

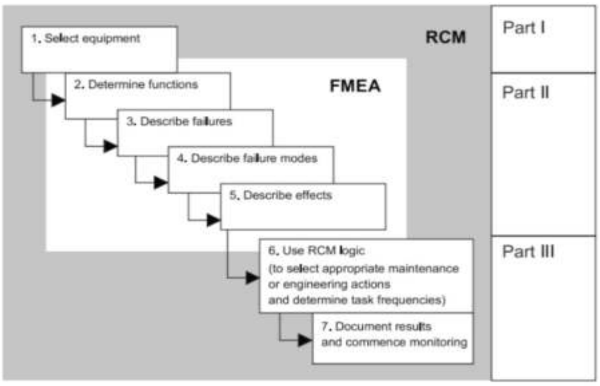

Figure 1: Failure mode and effects analysis [12]

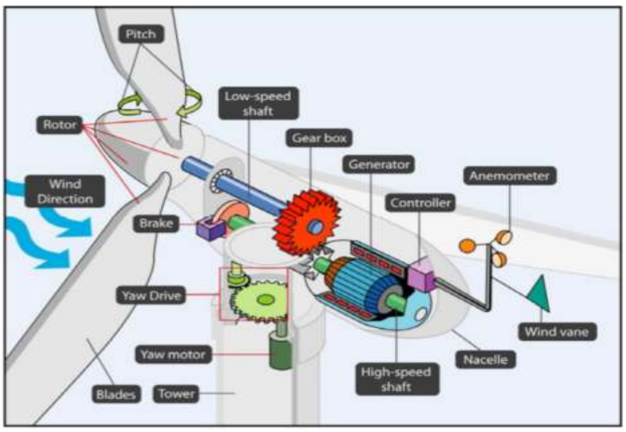

Figure 2: Wind turbine component [13]

3 Failure modes & effects analysis

RCM programs can be conducted in several ways. One technique is based on Failure Modes and Effects Analysis (FMEA), complete with mathematically-calculated probabilities of failure based on a combination of design data, historical data, intuition, common-sense, experimental data, and modelling. This approach is broken into two categories: Rigorous and Intuitive.

Intuitive approach fits to this assignment because it is assumed that construction and failure mechanism are well understood. However, in reality **rigorous approach** needs to be implemented at the design stage, or to be ascertained that failure mechanisms are well understood.

Failure modes & effects analysis (FMEA) is a structured way to improve asset safety and impart cost effective maintenance methods. Failure mode describes the ways that a component fails. For every subcomponent, failure modes can be identified. Based on criticality, probability and detectability Risk Priority Number (RPN) is calculated. In this way critical and frequent failure modes are identified and steps can be implemented for its avoidance. Failure modes can be chosen from literature [2]. The causes and effects of these failures can be obtained from journals that focus on wind turbines [3] [4]. FMEA analysis can be implemented based on the following steps, and as explained in **Figure 1.**

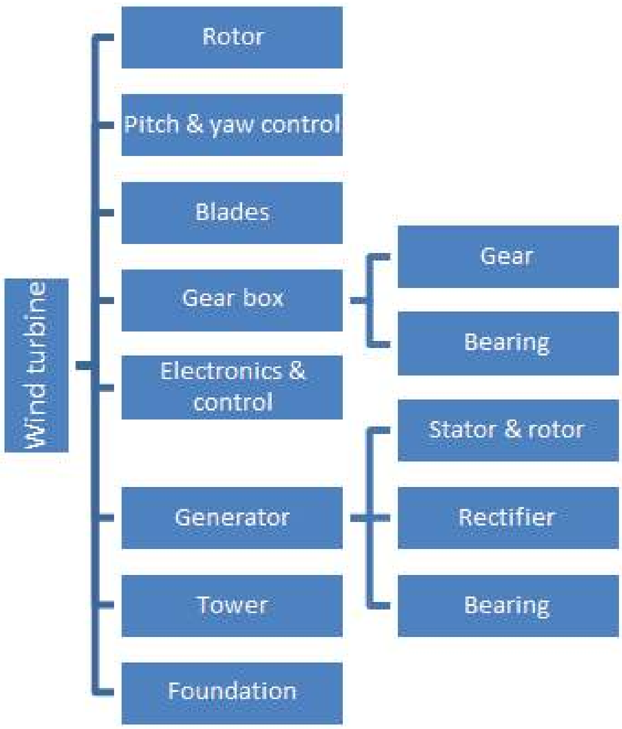

Figure 3: Wind turbine sub structure decomposition[4]

Table 1: System functions

System	Subsystem	Functions
Blade system	Blades	Aids in energy harvest from wind by transforming wind kinetic energy into shaft rotation
Control system	Sensors (anemometer)	Measures wind speed and transmits data to controller
	Pitch controller	Adjusts blade orientation to control rotor revolutions, according to wind speed
	Yaw controller	Orients nacelle and rotor in an optimum position to wind
Transmission system	Low speed shaft	Transmits torque and rotation
	Gear box	Connects low speed shaft to high speed shaft, and increases the rotation speed
	High speed shaft	It is connected to the stator coil of generator, which creates electricity
Electric generator	Stator and rotor	It is the main electrical part of the turbine that produces 60HZ alternating current
	Transformer	Converts three phase electrical power, to higher voltage of grid
Hydraulic system	Pump & piping	Circulates high pressure hydraulic fluid to controllers (yaw, pitch) and braking system
Structural system	Beam, stiffeners, plates.	Supports the wind turbine structure

Table 2: Detectability ranking

Detection rating	Description	Definition
10	Absolutely uncertain	Failure is not detectable
7	Moderate scope for detection	Failure can be detected by statistical correlations of operational parameters
5	Moderately high	Failure detected by monitoring methods (oil sampling, PTI techniques)
3	High	Can be easily detected with sensors and alarm monitoring techniques
1	Absolute certain	Defect is obvious

- Identify asset structure
- Define asset functions
- List probable failure modes
- Identify causes
- Describe effects of failure modes
- Assign risk priority number
- Plan maintenance, data collection or redesign activities

3.1 Equipment selection

Wind turbine is composed of various subsystems and its components. A break down structure of wind turbine sub systems can be seen in **Figures 2 & 3**. FMEA can be focused on system or subsystem level. In this work, it is performed in a system level. Major failure rates of subsystem and its components are chosen from literature [3] and analysed in detail. The listed components have high failure rate and its repair incurs increased down time.

Table 3: Probability of occurrence

Occurrence rating	Part	Failure rate/ year
1	Others	< 0.11
2	Yaw system	0.011
3	Brake system	0.012
4	Pitch system	0.012
5	Power converter	0.013
6	Main shaft	0.051
7	Transformer	0.121
8	Rotor blades	0.124
9	Gearbox	0.134
10	Structure (Tower)	0.151

3.2 Sub system function

The functions of typical major subsystems are presented in **Table 1**.

3.2.1 Failure modes and causes

Failure modes are the ways a component can fail. General failure modes are chosen from [2] and specific failure modes are found in [3] [4]. Failure modes which have high probability are chosen for analysis. Some failure modes could not be identified, and the same has been observed from other sectors such as ships, where hydraulic systems are very much similar to the wind turbine system. The failure modes are then ranked based on detection (**Table 2**), occurrence (**Table 3**), and severity (**Table 4**)

3.2.2 Effects

Analysis of effects forms the next aspect. Priority of components needs to be given to the one whose failure mode has larger impact on safety, health, environment or mission. As shown in **Table 4**, scale of 10 is assigned for highest severity, and 1 for non-critical failures. The scales are linearly interpolated between 1 to 10 based on intuition. Potential accident history and economic impact data are available [10] for majority of components.

3.2.3 Risk priority number (RPN) calculation

Failure modes are identified and ranked on criteria established in the previous sections. By multiplying severity, probability of occurrence and detectability scores, risk priority numbers (RPN) can be assigned to the corresponding failure mode. The failures with high RPN numbers can be prioritised in maintenance planning. Such failures modes are hard to detect, frequent in occurrence, and will impose safety and economic consequences. In order to formulate a maintenance technique for each failure mode, RCM logic as suggested by NASA [11] can be followed as shown in **Figure 4.** Condition based, interval based, redesign or corrective maintenance are the key outcome of this method.

3.3 Maintenance tasks

Maintenance tasks such as reactive, time-directed (PM), predictive (PT&I directed), and proactive maintenance methods are key outcomes of RCM logic. Run-to-Failure (reactive) is applied for non-critical and inexpensive equipment. Time-directed tasks are normally scheduled based on OEM instructions at periodic intervals. Predictive is a condition directed task, performed based on the observance, and are suited for equipment in which failures are random in nature. Proactive Maintenance implements root cause analysis, FMEA analysis and age exploration tasks, and aids in new design or innovative condition monitoring techniques. Run to fail decision is avoided in maintenance plan because, wind turbines are mostly unmanned. Minor equipment like lighting system can only be maintained with run to fail concept. More detailed explanations can be found in the FMEA sheet.

Based on the FMEA methodology maintenance concepts of top ranked components are discussed in the following paragraphs.

Table 4: Criticality ranking

Ranking	Effect	Definition
10	Hazard	Potential safety, health or environmental issue. Failure will occur without warning.
5	Moderate	Moderate disruption to facility function. 100% of mission may need to be reworked or process delayed.
1	None	No reason to expect failure to have any effect on safety, health, environment or mission.

Gear box

Gearbox is a critical and maintenance driving component capable of causing extensive stoppage and economic impacts [3]. Bearing and gear related problems are found to be excessive in gear box [14]. Effective PT&I technologies are available for condition monitoring.

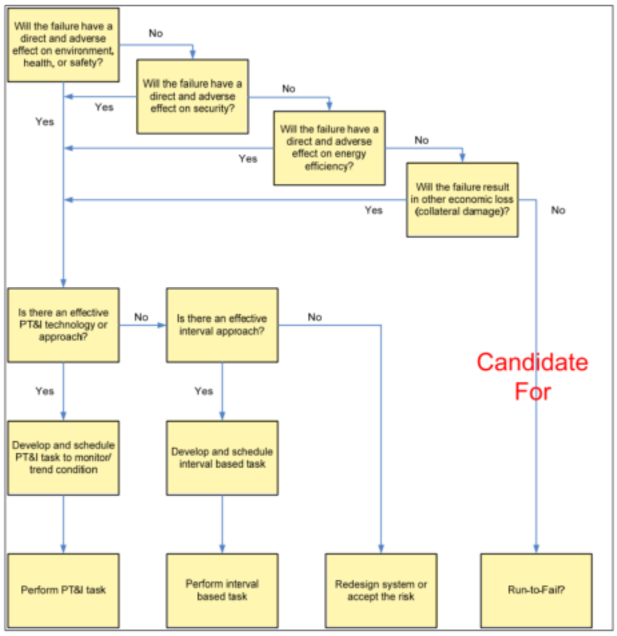

Figure 4: RCM logic tree [11]

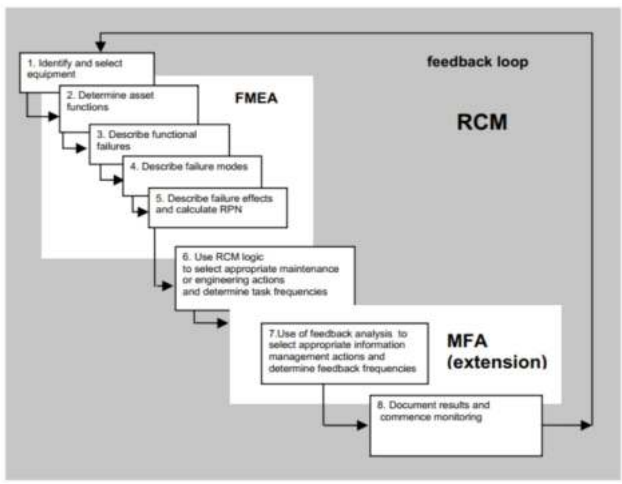

Figure 5: Maintenance feedback analysis [12]

Vibration pattern can be analysed at regular intervals with FFT analysers, in order to predict the condition of bearings and gears. In the meantime, clearance measurements, lube oil tests and lubrication replenishment activities needs to be planned simultaneously at periodic intervals.

High voltage transformer, generator, control unit, safety system

Electrical and electronics related failures have high impact on stoppage [3]. Generator related overhauls are expensive due to the size of components and associated installation complexities. PT&I technologies are available to monitor stator and rotor windings, by megger tests. For electronic components failure mechanisms are unknown, and hence PT&I tasks have limited scope in fault diagnosis. Periodical visual inspections are suggested. Redesign is suggested if failure rates are more than expected.

Pitch & yaw system

Components that wear out such as seals, gaskets and piston rings are attended by interval based tasks. Effective PT&I tasks are not available for monitoring such components. Bearings and motors can be maintained with PT&I tasks as mentioned before. Hydraulic oil degradation can be monitored with intermittent lube oil analysis.

> **Reliability Centred Maintenance (RCM) integrates preventive Maintenance (PM), predictive Testing and inspection (PT&I), repair (reactive maintenance), and Proactive Maintenance to increase the probability that a machine or component will function in the required manner over its design life-cycle with a minimum amount of maintenance and downtime**

Blade

Blades can only be inspected with interval based tasks. PT&I tasks are still in development stages for blade condition monitoring. Interval base tasks include surface polishing, visual inspections with high resolution cameras, and repairs of delamination.

Structure

These are manufactured according to industrial guidelines, which are site specific. Therefore, failure history is assumed to be less for wind turbine supporting structure (only for this typical case study), and it reflects in RPN score with less hierarchical order. PT&I tasks for structures are still in development stages. Therefore, it is preferable to implement periodical maintenance tasks, such as painting and visual inspections. However, if cracks are identified in fatigue prone zones, PT&I tasks can be implemented to inspect crack growth. Strain gauges can be installed to implement real time monitoring if required.

Cooling & breaking system

Interval based tasks are effective in terms of cost and performance than PT&I tasks. It also ranks less in RPN order. Failure history and severity is very less compared to other components.

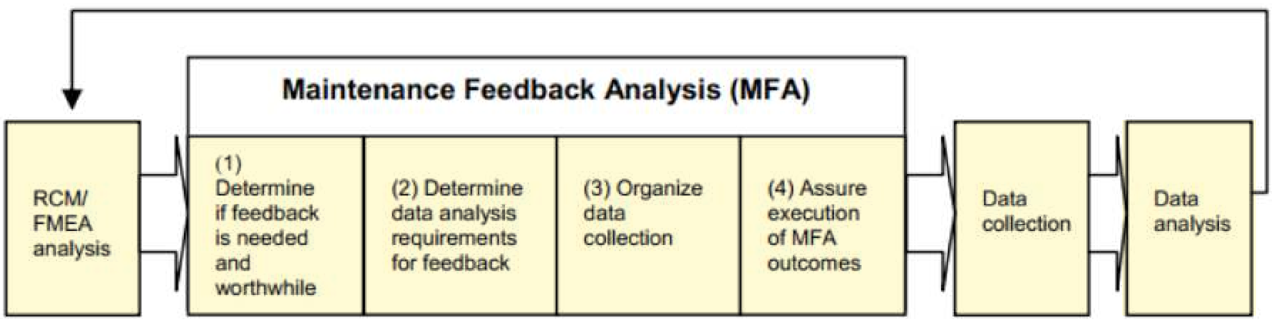

Figure 6: Steps of MFA [12]

Table 5: Turbine blade loads at different power settings

Power setting	Rotational speed (rad/s)	stress (mpa)	Gas temperature (°C)	Blade temperature (°C)
Low	597	102	500	500
Middle	733	154	750	750
High	1047	313	900	900

3.4 Maintenance feedback analysis

Research [12] shows that companies have a tendency to widen their safety margins and apply extra maintenance in case of inaccuracies or uncertainties in their analyses. In practice FMEA is not reviewed or updated anymore after its initial use. Information feedback is essential for the success and an effective and efficient maintenance program. Therefore, maintenance feedback analysis (MFA) can be added as an extension to FMEA method [12]. MFA enhances feedback on maintenance strategies and reduce maintenance costs. It helps to reduce the uncertainties involved while planning maintenance activities. Due to technological enhancements and changing working environment uncertainties needs to be addressed periodically, and implemented to enhance maintenance activities. Additionally, it improves data collection and management process for future decision making.

> **Generator related overhauls are expensive due to the size of components and associated installation complexities. PT&I technologies are available to monitor stator and rotor windings, by megger tests**

The steps involved after FMECA analysis is shown in **Figure 6**. First the uncertainties need to be identified, and determined whether it is worthwhile to solve. This step needs good working knowledge of the concerned asset. The second step is to determine the required data analysis required for feedback. New data collection and processing needs to be implemented that requires additional investment. Therefore, it is important to consider it is worth wile for investment. Finally, if preliminary steps are met, data collection and monitoring can be implemented to improve maintenance process.

When MFA is completed, the results can be implemented; subsequently FMEA needs to be reformulated. By implementing this approach FMEA will be up to date, and changes in environment, logistics, or regulations can be met easily. While implementing MFA priority can be given to the components which rank high in RPN number that influences on higher downtime, failure frequency and logistics costs.

3.4.1 Maintenance Feedback Analysis of selected components

Gearbox

Gear box failures cause high down time and economic impacts. They are monitored by PT&I task, by periodical vibration analysis with FFT analysers. However due to stochastic wind conditions failures can't be controlled. This can be avoided by physics based monitoring methods which is currently developed as a PhD thesis in DBM group [9], or by enabling real time monitoring system in combination with IOT technology which is successfully implemented by Siemens in Denmark [7]. Vibration, wind data and physical characteristics of components are key inputs for such model development. The same needs to be collected for prognosis methods.

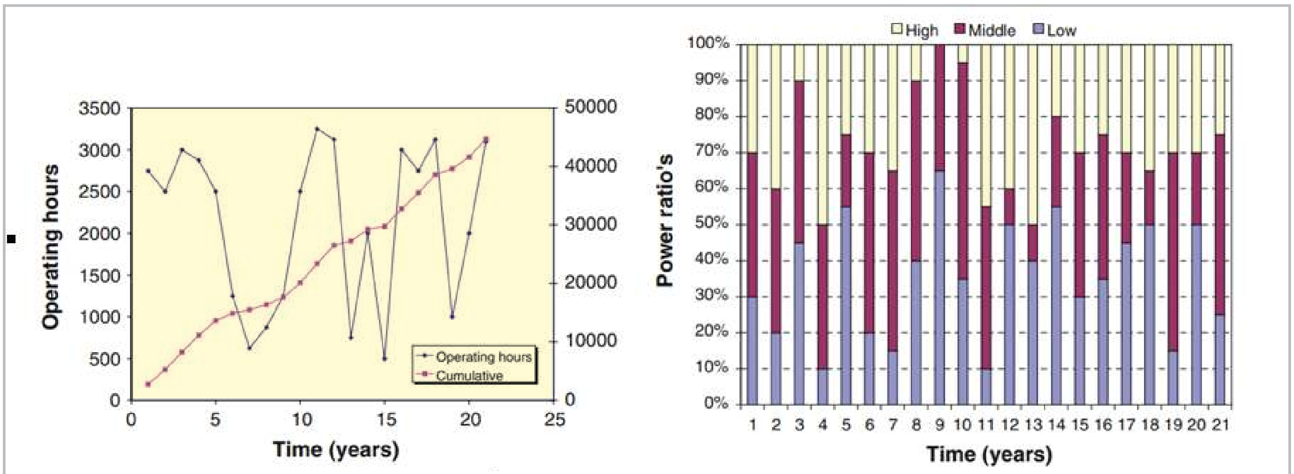

Figure 7: Usage history in operating hours/ year (L), variation of gas turbine in terms of power setting (R)[2]

Table 6: Turbine blade loads at different power settings

Power setting	Creep strain rate (h^{-1})	Failure time (h)	Damage accumulation rate (h^{-1})
Low	597	102	500
Middle	733	154	750
High	1047	313	900

Bearings

Bearing will fail in a random nature. Uncertainty exists because of manufacturing defects, dynamic usage and large variations in wind profile. Presently PT&I technologies are available to monitor them at intermittent intervals. However due to advancements such as big data analytics, internet of things (IOT) and advanced post processing algorithms, it is now possible now to combine them for real time diagnostics as proposed in [15].

Continuous monitoring of winding temperature and by correlating them with other parameters using data mining techniques, the performance of winding can be monitored in real time, and failures can be prevented in advance

As data is intensive, as a preliminary step, this technology can be implemented to components that has high failure frequency and operational down time. Bearings found in supporting system of high speed shaft and gear box are ideal candidate for implementing such prognosis methods. Later on it can be implemented for other components.

Motor windings

Manufacturing of winding cables has inherent uncertainty in material property. Its condition is currently monitored at regular intervals with megger tests in combination with pre-set alarms thresholds. Continuous monitoring of winding temperature and by correlating them with other parameters using data mining techniques, the performance of winding can be monitored in real time, and failures can be prevented in advance. Data collection and recording is similar to the one explained for bearing, except thermostats will be used for temperature measurement.

Semiconductor devices

PCB boards have wide range of components and interconnections. It is highly uncertain how each component will fail. Physics based models [1] can be developed, which considers thermal fatigue and vibration level incurred in the component. By installing a vibration sensor and acquiring working profile of the components, PCB life can be estimated.

Blades

Accelerometers can be installed *in situ* of blades to monitor the condition of blades. This will replace current periodic preventive maintenance tasks.

Anemometer

Anemometers are operated in aerodynamic wake profile; therefore, a redesign is needed to improve its performance, instead of investing in sophisticated maintenance methods. Nacelle mounted devices [8] has proven efficiency, which operates free of wake and the same can be installed by replacing the current type. Until then present PT&I tasks are sufficient to ensure its performance.

3.5 Key assumptions and improvement potential

FMEA is executed based on NASA guidelines and thesis of Jan Braaksma [12]. As components of wind turbines are limited, compared to assets such as ship propulsion system, wind turbine as a whole was considered in this analysis. However, few sub systems and its components were considered, based on failure rates published in literature. For such components few failure modes were considered based on intuition and literature, because of limited available resources.

Failure modes may vary depending of the operation terrain of wind turbines. Therefore, an accurate analysis

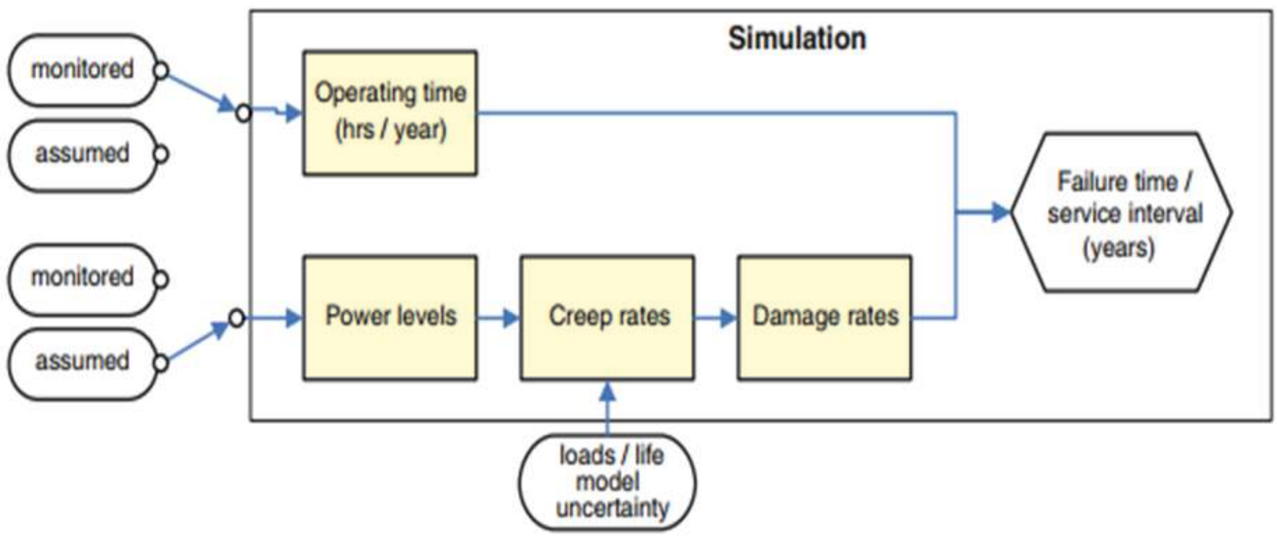

Figure 8: Schematic representation of simulation [2]

can be made by consulting maintenance managers and technical experts. In case proper data is collected in CMMS system, that can be retrieved for accurate analysis. This may have larger impact on the outcome, and RPN numbers may vary up on it. NASA FMEA guide lines were followed to a larger extent. Additional columns were added to detectability score.

Probability of failure scale was modified to suit failure frequency. MFA columns were added in the end. Intuitive RCM approach is implemented, and it was assumed that asset functions and historical data are well understood. Rigorous RCM is not followed because of time and knowledge constraints. Scales 1 to 10 were difficult to make judgements, which can be reduced to few intervals.

Historical data analysis or discussion with experts will reduce the uncertainties in the analysis. Subject knowledge is vital to make a detailed analysis. Past experiences, design knowledge, and statistical operational & failure data are vital to implement new methods. It is important to include people with different expertise such as technical expert, reliability engineers, maintenance managers in order to achieve good results. In subsequent iterations uncertainties can be removed in FMEA analysis.

4 Relevance of MFA for the maritime sector and a case study

Maritime companies can take forward this MFA analysis introduced in this work and review their asset management philosophy. For example, if we consider steam turbines, gas turbines and turbochargers on-board ships, maintenance practices are still conservative by following usage based (running hours) maintenance practices as per OEM guide lines. On occasions managers postpone this maintenance schedule based on the experience gained in operating such assets.

Information on the specific usage or loading of the system is presently not considered in decision making. This decision could have been taken at a time advanced PT&I techniques were not matured or due to conservativeness. However, there is a possibility of new algorithms available now or change in mind-set to do things differently. One such promising PT&I algorithm [2] is demonstrated in this case study.

Let us do a case study on gas turbines (which is monitored under usage based approach), to demonstrate the benefits of physics based damage detection algorithm and considering information on the specific usage or loading of the system. A gas turbine blade has been chosen, since the service life can easily be related to one single failure mechanism (creep). Physical models are required for both the usage-to-loads and load-to-life relations. In this way, the loads and damage accumulation are related to the usage of the gas turbine.

The components rotate at higher revolutions per minute (rpm) and due to the rotation, a centrifugal force (F) acts on the turbine blades, causing radially directed normal stresses in the root of the blade. The magnitude of this stress (r) depends on the mass (m) of the blade, the rotational speed (ω), the distance from the blade to the engine centre axis (r) and the area of the blade cross section (A) in the following way

$$\sigma = \frac{F}{A} = \frac{m\omega^2 r}{A} \tag{1}$$

The rotational speed and gas temperature depend on the power setting of the gas turbine. The typical values for the three power settings shown in **Table 5**.

For the present component, creep is the life limiting failure mechanism. It results in inelastic deformation of the blade, which could lead to failure in two ways: either the elongation of the blade causes it to touch the casing or a locally high creep strain initiates a crack, which leads to fracture of the blade. Modelling of the creep behaviour can be performed with simple power law relations (this demonstrates that simple methods can already provide a large improvement of the efficiency). The creep strain rate for the present material is described by a Norton creep law and depends on the temperature (T) and stress () as follows

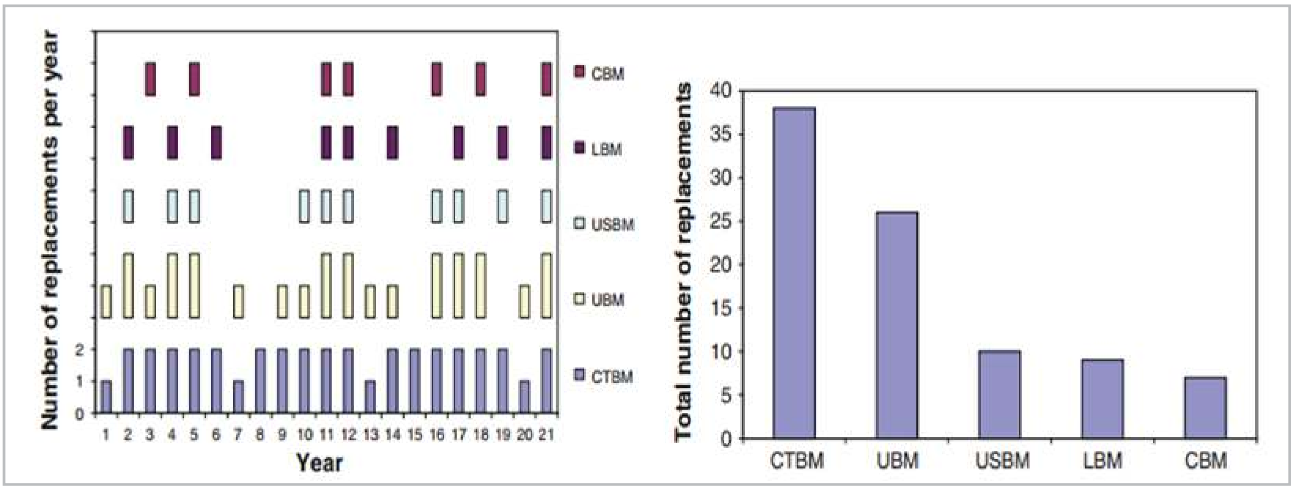

Figure 9: Overview of blade replacement moments for five different maintenance strategies(L)
Comparison of total number of replacements during a period of 21 years for the five different maintenance strategies (R)[2]

$$\dot{\varepsilon_{cr}} = \frac{d\varepsilon_{cr}}{dt} = AT^4\sigma \quad (2)$$

With valid assumptions the time to failure (t_f) can then be calculated as

$$t_f = \frac{\varepsilon_{crit}}{\dot{\varepsilon_{cr}}} \quad (3)$$

The accumulated amount of damage (D) can be obtained using Robinson's damage rule as follows.

$$D = \sum_i \frac{\Delta t_i}{t_{f,i}} \quad (4)$$

where is the time period spent at some conditions (stress and temperature) and the failure time at those conditions. Failure will occur when the damage parameter D attains the value 1. Using these equations, the damage accumulation for the three power settings can be calculated. The results are shown in **Table 6**. The assumed usage history of the gas turbine, the variation of the number of operating hours per year and the variation in the power setting of the machine (fractions of time at high, middle and low power) are shown in **Figure 7**.

4.1 Comparison of maintenance policies

Five preventive maintenance policies are compared in terms of effectiveness as shown in the subsequent paragraphs [2]. For each method, a criterion is derived to replace the turbine blades. Then, by applying the usage history from **Figure 7**, the moments of replacement are determined and the total number of replacements during the 21 years' history are counted and compared. Schematic representation of the simulation is shown in **Figure 8**. As shown, depending on the maintenance concept, either a monitored or assumed quantity is used as input and a specific model uncertainty is applicable.

Calendar Time Based: Here a fixed calendar time for replacement of the blades.

Usage Based: This approach takes into account the actual number of operating hours per year.

Usage Severity Based: In this policy, not only the usage of the system in terms of operating hours is taken into account, but also the severity of the usage. Therefore, the power settings are monitored in addition to the operating hours.

Load Based: In a load-based maintenance policy, the internal loads are monitored, which in this case means that the stress in the blades is measured. Practically, this is not very easy to achieve in a gas turbine, due to the high temperature and limited accessibility. However, for many other systems that is much easier and it is assumed here that it is technically possible to determine the stress.

Condition Based: The final step is to directly monitor the condition of the components, in this case the elongation of the turbine blades. In practice, the blades can be measured during periodic inspections, but it is here assumed that the elongation can be monitored continuously.

The five policies described above have been simulated using the operation history. The total number of replacements over a period of 21 years is shown in **Figure 9**. For the calendar time-based method (CTBM), one or two replacements are necessary for each year. Taking into account the usage in terms of operating hours reduces the number of replacements considerably, especially in the years with low numbers of operating hours (e.g. year 7 and 8).

The usage severity-based method (USBM), which also takes into account the variations in power settings, is again more efficient. By using the measured loads (LBM) instead of the calculated loads, the uncertainty in the life prediction is reduced, which yields another decrease of the number of replacements. Finally, CBM provides the most efficient replacement intervals, since in that method also the uncertainty associated with the creep calculation is absent. **Figure 9** illustrates that application of information about the usage, loads or condition yields a significant improvement of the efficiency of the maintenance process, while the effectiveness (probability of failure) remains the same. CBM is the most efficient method, but for many systems no suitable sensors are available or the accessibility of the system is too limited. In that case, usage- or load-based methods are interesting alternatives, since loads and especially usage are much easier to monitor. In this case study, the largest improvement is obtained at the transition from usage based to USBM. Applying LBM and CBM does not yield a significant additional benefit. However, the relative efficiency gains depend on the uncertainties in the different models.

5 Conclusion

MFA helps the ship management firms to evaluate the possible implementation of more advanced predictive maintenance technologies and review their RCM-based maintenance program. The goal of applying these techniques is first of all to improve the reliability and availability of equipment and secondly to reduce maintenance costs as demonstrated in the case study.

6 Acknowledgement

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ALTERNATIVE FUELS FOR MARITIME DECARBONISATION – TECHNOLOGY ADOPTION & SHIP DESIGN ASPECTS

Sajeendra Kumar Nambiar

Abstract/Summary:

The Paris Agreement 2015, adopted by 196 parties at COP21, has set a goal to limit global warming to well below 2 deg. C, preferably to 1.5 deg. C, compared to pre-industrial levels. To achieve this long-term temperature goal, countries aim to reach global peaking of GHG emissions as soon as possible to achieve a climate neutral world by 2050. This necessitates the maritime transportation sector to switch over from fossil fuels to near-zero CO2 emission / carbon neutral fuels and renewable energy solutions. SeaTech Solutions is at the forefront of green ship design & technology and is working closely with vessel owners/operators, port authorities, classification societies and other stakeholders to adopt suitable green technologies towards development of bespoke environment friendly ship designs. The paper examines various extant transition and NZE fuels, their technology pathways, merits & disadvantages, technology adoption challenges, relevant IMO carbon efficiency indices and impact of alternative fuels on ship design aspects. An overview of various green design solutions currently being developed by SeaTech is also expounded.

Keywords: Green Ship Design; Near Zero Emission; Paris Agreement 2015; COP21; Renewable Energy; IMO; EEDI; SEEMP; EEOI; EEXI; CII; Biofuel; LNG; LPG; Methanol; Ammonia; Hydrogen; ESS; Fuel Cell

Introduction

The world energy demand has been increasing at an average of 2% per annum in the period between 2000 and 2019. In 2021 there was an increase of about 5%. The main source of energy being used to meet the demand still comes from fossil fuels which produces huge amounts of Green House Gases (GHGs) which eventually affect the climate

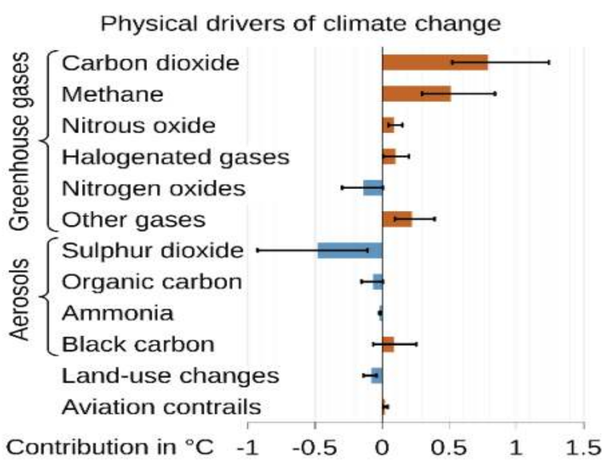


Figure 1 Physical drivers of climate change (Source: IPCC 2021)

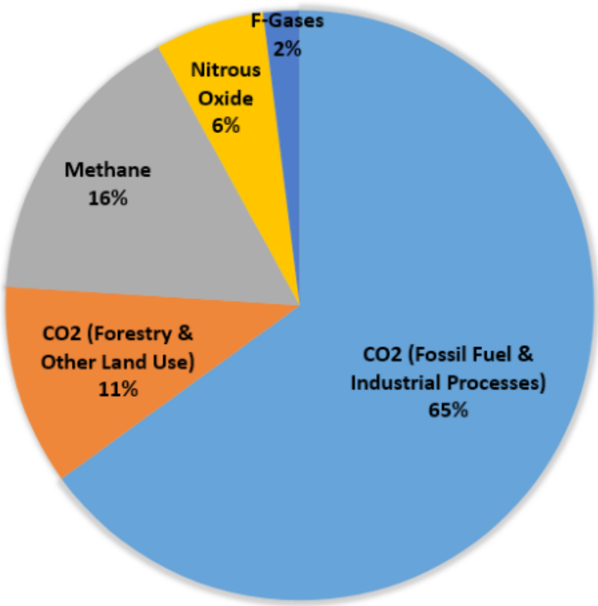


Figure 2 Global GHG emissions by gas (Source: IPCC 2014)

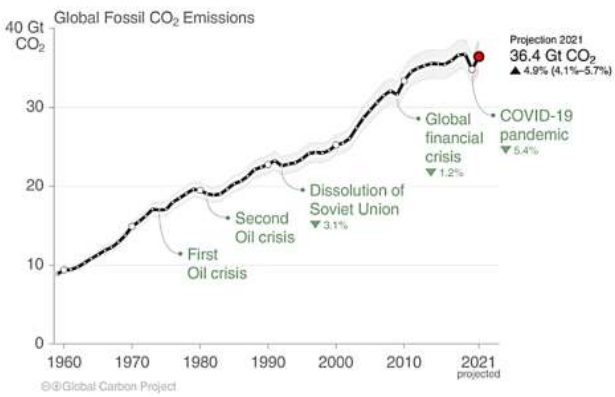


Figure 3 Progress of global fossil CO_2 emissions (Source: Global Carbon Project)

adversely. CO_2 is the major driver of global warming and is about 76% of all the GHGs in the atmosphere.

From 2010 to 2019, a 1.3% average yearly increase in GHG emissions has been recorded and the global CO_2 emissions is at its all-time peak. A major dip of about 5.4% occurred in 2020 due to the pandemic which disrupted all industries across the world. The major contributor of anthropogenic CO_2 emissions is the power sector followed by the transportation sector and the industry sector.

Climate stabilisation will require significant reduction of CO_2 emissions by year 2050. Towards this, there is a need to adopt a sustainable emission reduction program where the emissions are reduced in a continuous and effective manner in all sectors. One such important measure taken is the Paris Agreement in 2015.

Paris Agreement 2015. To address the rising issue of climate change, an international treaty was signed between 196 countries at COP21 which was held in Paris in 2015. The central aim is to strengthen the global response towards the threat of climate change by keeping the global temperature change well below 2 deg. C above the pre-industrial level and to pursue further to bring the change to below 1.5 deg. C. This agreement provides a framework for financial, technical and capacity building support to those countries who need it. After this treaty was established, more and more countries are coming up with low carbon emission solutions and opening up markets to cater to the demand.

Countries have started setting carbon neutrality targets for themselves and taking up initiatives to encourage the inputs of different parties towards the long-term temperature goal. On a general note, all countries are setting the goal of having a carbon neutral world by 2050. This follows the roadmap for Net Zero by 2050 brought out by the International Energy Agency (IEA) in October 2021.

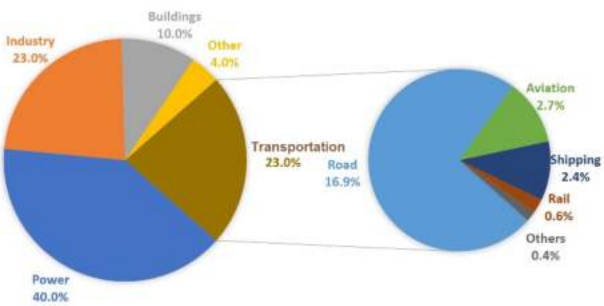


Figure 4 Global energy-related CO2 emissions by sector (Source: IEA 2021)

IMO 2020 Goal. In June 2021, IMO adopted measures to reduce CO_2 emission of all ships by 40% by 2030, compared to 2008 levels. This step again can be considered as a continuous measure of the progress towards the larger IMO 2050 GHG strategy to reduce CO_2 emissions by 70% and total annual GHG emissions by at least 50%, compared to 2008 levels. The short-term goals need to be kept in perspective to measure the progress at noted intervals and to change the strategy being used if needed. One such step is the IMO 2020 Goal where 0.5% sulphur limit entered into force cutting total SOx emissions from shipping by over 75%.

Effect on Shipping Industry. Among the different modes of transportation available, shipping is the most energy efficient mode as it can carry the highest amount of cargo for the least fuel consumed. Hence there is a continuous rise in demand for ships: seagoing, coastal and inland waters.

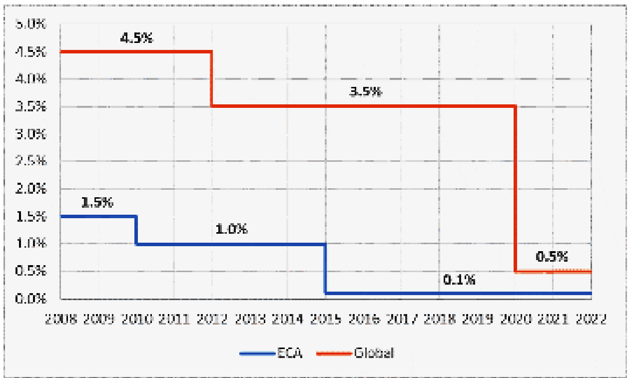
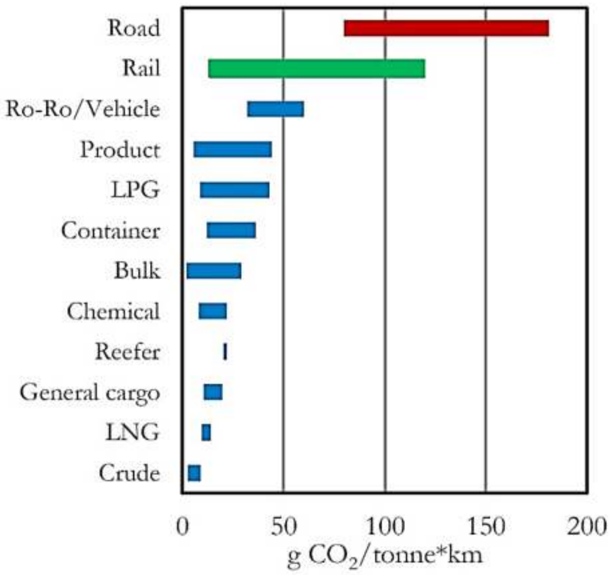


Figure 5 IMO 2020 SOx emission goal



Note: Air Freight is not represented. CO2 efficiency of Air Freight is calcuated in the range of 435 to 1800 g CO2/tonne*km

Figure 6 Typical CO2 efficiencies of ships compared with other modes of transport (Source: Buhaug et al, IMO 2009)

However, the energy currently being used to power ships are fossil fuels and this implies that the need for fossil fuels would increase and there would be commensurate increase in GHG emissions. According to a report by IEA in 2021, the international shipping industry accounts for about 2.4% of the global CO_2 emissions. This maybe a small percentage of the overall emissions at present, however if not contained, it has been projected to go up to 17% by 2050. Therefore, there is an immediate necessity to curtail the emissions in the shipping sector. One more reason which needs to be considered is that shipping plays a central role in the global supply chain which makes other industries to facilitate their Near Zero Emission (NZE) goals.

A report published by the International Chamber of Shipping (ICS) stated that with reference to the COP21 treaty, they are planning on achieving the following results: Ships built after 2025 will be 30% more efficient which is a mandatory IMO requirement; Bigger ships, better engines, cleaner fuels and smarter speed management; More fuel-efficient movement through water; and 50% CO_2 reduction by 2050. Various methods are being taken by different organisations to achieve the NZE goals.

Methods to Achieve the NZE Goal

Using Renewable Energy Directly as a Source of Power. Renewable energy like Solar, Wind and Wave energy can also be used to power the vessels. Since the continuous availability of renewable sources is unpredictable, relying solely on energy from the nature may not prove to be a good solution. This is the major reason there are not many vessels presently operating primarily on renewable energy.

Most vessels only consider it as its secondary source of energy or even if it is being used as the primary energy, there will be some secondary source from fossil fuels which is likely to dilute the whole purpose of carbon neutrality. Ongoing studies are trying to establish a widely accepted and feasible solution using renewable energy as a primary source due to its non-exhaustibility and abundance.

Use of Energy Storage Systems. Batteries are the next widely used source of power due to their large capacity for storage of energy. The Energy Storage Systems (ESS) using batteries has been a big relief for ships operating in the Emission Control Areas (ECA) due to the stringent regulations prevailing in these areas. However, the energy source being used to charge the ESS also need to be green to achieve complete carbon neutrality.

Use of Fuel Cell Technology. Fuel Cell is a widely accepted solution for use in the ECAs which can generate energy for long period as compared to HFO of the same quantity. There is no GHG emissions in the process of generating energy, though emissions may be produced in the fuel extraction stage. The process is environment friendly as the output of the process is heat and water vapour. The cells continuously produce energy as long as the electrochemical reaction continues and does not require any additional fuel space or holding storage for energy generated.

Modifying Ship Parts to Improve Efficiencies. There are many losses which are being accounted for from the engine to water which are denoted in efficiencies as engine efficiency, transmission efficiency, propeller efficiency and hull efficiency. Modifying these efficiencies to its maximum possible value would enhance the overall efficiency of the vessel and hence optimum use of energy. For example, adding parts to the propeller such as boss cap fins, to improve the propeller efficiency.

Consuming Less Fuel through Efficient Operation. Methods such as speed optimisation, weather routing, hull monitoring, etc. that comes under the Ship Energy Efficiency Management Plan (SEEMP) which can help with optimising the amount of fuel required onboard and making the maximum utilisation of the engine in the manner in which the engine is run during the course of the vessel operations.

Use of Alternative Fuels. Heavy Fuel Oil (HFO) and Diesel Oil (DO) powered engines in ships produce higher CO_2 emissions as compared to alternative fuels like LNG, Ammonia, Hydrogen etc. Most of these alternative fuels promise about 50% reduction in the CO_2 emissions which is a very huge step that can be taken towards the larger goal. Though it involves some problems and complications with regard to its use and sustainability, once solved they can be the fuel of the future or even they can be used as a means to reduce the CO_2 emissions till a fool proof solution found which does not give out emissions at all. Various aspects and feasibility of technology pathways for adoption of alternative fuels is discussed in the following section.

Alternative Fuels and Powering Solutions – Technology Adoption

To achieve the long-term NZE goal, various solutions are being developed which involves use of less to no amounts of fossil fuel for powering ships. Some of these are transition fuels which still are of fossil origin but less polluting than HFO, while some others are greener in their “well to wake” path. Most of the latter solutions are still in the research and development stage, it may take years to come up with an actual solution. Hence waiting for these solutions to come up is not a wise strategy to adopt and instead the shipping industry needs to go with transition fuels or strategies which can cut the present emissions by a considerable amount. Fuels and technologies that are being taken to cater to the transition are discussed below.

Liquefied Natural Gas. Pure natural gas is methane (CH_4). LNG is a fuel which has been in the shipping industry far longer than the other alternative fuels. It emits about 25% lesser CO_2 than HFO and provides the same amount of propulsive power. LNG completely eliminates SOx, particulate matter and also reduces NOx emissions by up to 80%. LNG is generally extracted in its gaseous form and is cooled to about minus 162 deg. C or at high pressures to bring it to liquid form for use as fuel in ships. The volume that LNG occupies in its liquid form is about 1/600 times that in its gaseous form and hence helps with storage. The proven reserve surpasses that of petroleum fuels and its ability to provide a stable long-term supply for many decades is a key advantage.

The availability of LNG bunkering infrastructure is a must for extensive use of LNG fuelled ships. This requirement has been receiving the necessary funding and promotions from

different organisations. As a result, bunkering infrastructure is not a key challenge anymore. Due to the use of LNG as a fuel for a longer time compared to other alternative fuels, robust rules have been developed over the period. Also, the crew has become well aware of the precautions and safety measures to be taken in an LNG fuelled vessel.

Though having the above merits, it also has a few challenges one being the safety of its use. LNG as a liquid is nontoxic, non-corrosive and also does not burn. Even in gaseous form LNG has a high diffusibility rate and hence in open areas it cannot catch fire easily or only lasts for short periods of time. In confined areas this can be an issue as the LNG vapours cannot escape and can cause explosions even due to a small ignition. As LNG is stored in liquid form, it becomes susceptible to explosions as it has higher specific density and hence does not diffuse easily.

Another challenge with the use of LNG is the methane slip involved while using LNG powered engines. Such engines designed for LNG generally have a 98% fuel efficiency, however, release the remaining fuel as methane. There are many organisations coming up with different technologies to reduce the amounts of methane slip. The capital investment required for the equipment like containment and bunkering systems also is a challenge. The volumetric energy density is also lesser as compared to HFO.

Another type of LNG, Bio-LNG is a greener pathway with massive potential and is made from renewable sources. Bio-LNG is a biofuel made by processing organic waste flows, such as organic household and industrial waste, manure, and sewage sludge. They can make use of the existing LNG fuelling infrastructure. Having these advantages, they can further reduce the emissions and can act as a carbon neutral fuel for the future. As it can be understood the status of Bio LNG is still in its development stages and requires more efforts in the form of incentives and funding to get better and faster results.

LNG is equally suitable for inland, coastal and ocean-going ships which makes its use an important factor for reducing the GHG emissions. India is equally contributing towards providing various incentives for the use of alternative fuels. The major LNG terminals in India are in Gujarat with a total operational capacity of 30 million tonnes as of 2020. Many LNG terminals are still under construction which would enhance LNG supply across India. India is also in the process of developing a pan India natural gas grid to enhance the distribution system.

Methanol. Many factors about methanol point to its suitability as a viable solution to current environmental and regulatory challenges. Methanol (CH_3OH) provides clean burning in the engine and produces low amounts of soot in combustion compared with HFO. Methanol produces no SOx, very less NOx and particulate matter emissions. The current fuel storage and fuelling infrastructure would require only minor modifications from that of LNG (requires refrigeration and high pressure) to handle Methanol.

The few vessels which have already been deployed on methanol are using dual fuel engines which are not specifically for methanol and hence do not provide the most optimised output. Further developments in methanol optimised engines would prove to provide better results with respect to efficiency. The energy efficiency in dual fuel engines itself is at par or even higher when compared to traditional fuels, so the use of optimised engines would provide better efficiency rates. But for the same energy equivalent density, the volume needed would be twice as compared to traditional fuels.

Short voyage vessels tend to have smaller hulls and a more compact arrangement, hence such vessels may not be able to replace conventional fuel oils with Methanol as it would require more space which may not be available in the vessel. Therefore, the use of methanol may be a better option for ocean going ships where the tanks are not very compactly arranged and there is a possibility to change the tank dimensions.

The barriers which stand in the way of methanol being used as a fuel are as follows:

(a) The price volatility of methanol causes ship owners to have only a partial faith and hence need to have dual fuel engines to use other fuels in cases of high methanol prices.

(b) Though methanol is biodegradable and does not cause any direct impact on the environment, when ingested by humans even in the form of gas is harmful. Since they have been used as chemicals and fertilizers, its effects

Table 1 LNG Technology Pathways & Challenges (Source: DNV-GL)

Converter	ICE (2/4 Stroke)	Fuel Cell
Components	Engine, Storage tank, Process system, NOx reduction system	Fuel cell, Storage tanks, Process system, Electric propulsion system, Reformer, Battery
Key Challenges	Methane slip for some of the ICEs, Cryogenic materials needed, Fuel storage tank 2-3 times larger than for petroleum-based fuels	

Table 2 Methanol Technology Pathways & Challenges (Source: DNV-GL)

Converter	ICE (2/4 Stroke)	Fuel Cell
Components	Engine, Storage tank, Process system, NOx reduction system	Fuel cell, Storage tanks, Electric motor, Reformer, Battery
Key Challenges	Fuel tank 2-3 times larger than for petroleum-based fuels	

Table 3 Biofuels Technology Pathways & Challenges (Source: DNV-GL)

Converter	ICE
Components	Engine, Storage tank, Process system, NOx reduction system
Key Challenges	Currently limited availability of sustainably produced biofuels, Fuel cost

Table 4 Ammonia Technology Pathways & Challenges (Source: DNV-GL)

Converter	ICE (2/4 Stroke)	Fuel Cell
Components	Engine, Storage tank, Process system, NOx reduction system	Fuel cell, Storage tanks, Electric propulsion system, Reformer, Battery
Key Challenges	Fuel storage is more massive and requires more space than petroleum-based fuels	

have been known and its handling has already been taken care of and is not considered a problem nowadays.

(c) Crew training needs to be done in the proper manner to keep the personnel safe from the possible effects.

There are steps taken by the Indian government like the *NITI Ayog Methanol Economy Programme* to slowly increase the use of Methanol. As per this, it is planned to add 15% of Methanol to Gasoline for attaining 20% reduction in GHG emissions.

Biofuels. Biofuel is the type of sustainable fuel derived from abundant biological sources. In the process where fossil fuel is replaced by organic material that includes vast range of waste and plants. It is an alternative source which can be used to replace petroleum-based fuel. The carbon footprint of biofuels is less than that produced by traditional forms of fuel when burnt. Biofuels include oxygenated biofuels like Straight Vegetable Oils (SVO), biodiesel, fast pyrolysis bio-oil, hydrothermal liquefaction bio crude and hydrocarbon biofuels. Of these, the most commonly extracted and used ones are bioethanol or simply ethanol and biodiesel. It can be blended with gasoline and can be used as an alternative fuel.

Biofuels are promising candidates for the next generation marine propulsion systems due to reduced life cycle emissions, high energy density, compatibility with existing marine engines and bunkering infrastructure. Moreover, commercialisation of biofuels to support marine sector foster the development of domestic bio economy, promoting regional job creation and economic growth. Biofuels can be sourced from an array of lignocellulosic biofuels, wastes and non-food feedstock, thus reducing risk and diversifying the fuel mix.

Large scale industries meant for churning out biofuel are known to emit large amounts of emissions and cause small scale water pollution as well. Certain biofuels face consistency and stability issues. The other limitations in implementation that have deterred some owners from switching to biofuels include:

(a) A lack of long-term biofuel engine testing data

(b) Concern about fuel storage

(c) Oxidation stability

(d) Limited commercial biofuel supply

Biofuels provide potential pathway towards emission reductions, improved energy security and reductions in carbon intensity of shipping. Without financial and market-mediated measures, biofuels must exhibit price parity with fossil resources to be economically competitive. Indian government is continuously working on various fronts to make the "Waste-to-Wealth" concept a reality and transform the energy sector into a more affordable and sustainable one.

Ammonia. On direct use as a fuel, ammonia (NH_3) does not produce CO_2 emissions. The industrial method of production of ammonia at present is through *Haber-Bosch Process*. In this process atmospheric nitrogen is converted to ammonia by reacting it with hydrogen sourced from natural gas (methane) or coal or crude oil. Hence, the production of ammonia contributes towards CO_2 emissions. Ammonia production presently accounts for about 2% of the global CO_2 emissions. If hydrogen can be extracted from green methods like electrolysis of water using renewable energy, the entire life cycle of ammonia can be made carbon neutral.

The volumetric energy density of ammonia is equivalent to that of Methanol and higher compared to hydrogen making onboard storage feasible but not as compact as the HFO or MDO. Hence ammonia fuelled vessels also will require larger tanks as compared to HFO tanks for accommodating the fuel and may be a better solution for ocean going vessels due to their larger size. Ammonia is stored in its liquid form at about minus 33 deg. C, hence no advanced containment system is required. Though being abundantly available and lower in cost as compared to methanol, ammonia still has the problem of being highly toxic, flammable and corrosive. Hence sufficient training is to be provided to the crew and necessary safety standards are required to be followed.

When used as fuel in IC engines, ammonia combustion mainly produces water and nitrogen. Ammonia as a fuel is difficult to burn. To overcome this issue and use it in the best way possible, specialised IC engines are needed which can make the burning of ammonia easier. These engines are in their development stages and a better fuel-efficient engine could be available in the near future.

Ammonia is not a new concept as it has been used in the manufacture of chemicals and fertilizers. Therefore, its storage, transportation and bunkering requirements could be handled in the maritime industry as well. However, as a fuel it needs to be properly understood and handled.

Liquefied Petroleum Gas. Petroleum gas is a propane (C_3H_8) - butane (C_4H_{10}) mixture. LPG produces almost 99%

Table 5 LPG Technology Pathways & Challenges (Source: DNV-GL)

Converter	ICE
Components	Engine, Storage tank, Process system, NOx reduction system
Key Challenges	Fuel tank 2-3 times larger than for petroleum-based fuels

lesser SOx, 15% lesser CO_2, 10% lesser NOx and 90% lesser particulate matter emissions compared to HFO. This meets the IMO 2050 GHG strategy and is a good transition fuel to adopt from an environmental perspective. Moreover, the storage facilities and bunkering vessels which are available at the moment provide an upper hand considering the fact that most fuels face challenges regarding their storage. It is also widely available for use at a cheaper cost compared to other solutions. Considering the distribution and storage advantages it poses, it can be said as one of the fuels which is highly likely to offer a practical and immediate solution in the transition stage.

Methods have been established to use waste materials and produce a renewable form of LPG called Bio-LPG or Renewable LPG which undergoes a series of sophisticated treatments to purify its energy content. This type of LPG is likely to reduce CO_2 emissions further by 80%. The supply of feedstock could vary from time to time which might cause short term disruptions. Production of Renewable LPG from Green Hydrogen is still under its research stage which could provide a carbon neutral fuel for the future.

Presently the number of vessels running on LPG is limited mostly to LPG Carriers as the fuel can be directly used from the cargo and hence no problem of bunkering arises. Even if non-gas carriers use LPG as fuel, it is not any different compared to the usage of LNG as long as the crew is properly trained. LPG has high flammability and most ship owners tend to back out due to this reason. Due to its high flammability, leakage needs to be given special attention. Special measures have been taken by many Classification Societies to cater to this issue, a few being:

(a) Installation of fuel supply and conditioning system

(b) Installation of additional gas detection systems

(c) Installation of double walled piping

(d) Flushing of annular spaces and continuously monitoring for leakages

NOx emissions are mainly dependent on the engine used to run the fuel and it has been identified that LPG engines could further help in reducing up to 20% of NOx emissions. The engines used also have lesser maintenance cost which forms a part of the OPEX.

LPG is a non-toxic fuel making it safer and easier to handle while protecting the environment from harmful toxins in case of accidental leaks or accidents at sea. It does not have safety risks like methane slip as in LNG fuel. This is an appealing option in protected and environmentally sensitive areas of all types of ships and engines.

The supply chain and infrastructure of LPG is robust. With the low investment cost and reduced operating costs, LPG is likely to be a main component of the alternative fuel scenario.

Liquid Hydrogen. Hydrogen is gaining a lot of attention as a clean fuel since it can be produced from water through electrolysis using renewable energy (mostly solar power at present). However, the most common method of extraction of hydrogen currently being done is from fossil fuels due to the energy intensity required for the electrolysis process.

Practical methods of obtaining hydrogen from renewable sources are under supervision as to how they perform. A number of demonstrations have already been conducted for making liquid hydrogen a viable option but the major problem is not the production of hydrogen from renewable means, rather it is the storage of the fuel.

By weight, hydrogen is an excellent energy carrier but under normal atmospheric conditions the total energy content is only about 3 WhL^{-1} compared to 10,000 WhL^{-1} for diesel. To deal with this low volumetric energy content, different methods are being adopted to use hydrogen in its compressed form, liquid form etc. In liquid form, the energy density of hydrogen is only about $1/4^{th}$ of diesel fuels and hence this method is commonly adopted. It is stored at a cryogenic temperature of about minus 253 deg. C. Storing at such low temperatures involves sufficient insulation to be provided so that the heat flux inside the tanks could be kept low.

Liquid hydrogen has a high degree of flammability and is highly explosive due to which it needs to be handled with special attention. It has a high propensity to leak and materials which come in contact turns brittle. Detection of leaks is difficult, and the flame is not visible in daylight making it a bigger problem. Another issue being posed by the tanks is that there needs to be larger amounts of the fuel to be carried. One solution to this can be to make larger tanks which can accommodate more volumes with better insulation to protect the vaporisation of fuel.

The infrastructure needed to manage the distribution and storage of liquid hydrogen is an area requiring further development. Ensuring a robust supply chain and bunkering

Table 6 Hydrogen Technology Pathways & Challenges (Source: DNV-GL)

Converter	Fuel Cell	ICE
Components	Fuel cell, Storage tanks, Process system, Electric propulsion system, Reformer, Battery	Engine, Storage tanks, Process system
Key Challenges	Fuel storage is more massive and requires more space than petroleum-based fuels, Cryogenic materials needed for Liquid H_2	

facilities is the need of the hour to promote use of liquid hydrogen as a prospective fuel for the maritime sector.

The availability of liquid hydrogen as such is less but the resources available to make it is abundant. Hence, at present the intensive energy required to produce it makes its cost high, hence having a higher CAPEX. Due to its large availability and possibility of clean source, Indian government has put forward the National Hydrogen Mission which aims to convert India to a green hydrogen hub. Accordingly, the objective is to produce five million tonnes of green hydrogen by 2030.

Battery Systems. Though not coming in the bracket of alternative fuels, battery systems are a suitable NZE power solution. Batteries or Energy Storage Systems (ESS) are ideal for short sea routes and for fulfilling peak power needs (peak shaving). Running a ship on battery power comes with environmental and operational benefits. One of the key benefits of battery is the ability to hybridize its use. Variations include ships fitted with lithium-ion batteries charged from onboard diesel-driven generators or from shore power supply. Batteries make it possible to shut down diesel engines when onboard consumption is low.

Batteries based on lithium-nickel-manganese-cobalt-oxide chemistry are affordable, tried-and-tested form of ESS and market dominant but the progress is hindered by capital requirement. Economic feasibility is currently compromised by their price, poor reliability and availability of alternatives.

Making battery the primary source requires less space as tank requirements and subdivisions are less compared to IC engines. The spaces occupied by conventional propulsion equipment can be utilised to accommodate the batteries or its spares without modifying the basic design of the vessel. Separate electric modules and spacing is to be added to accommodate a battery unit based on size requirements. Because of its low energy density, employing batteries to propel ocean-going vessels is challenging and sometimes unrealistic. A flexible approach to use this technology as a power source for large, oceangoing ships is only beginning to emerge. The method spares crew and vessel from engine noise and exhaust emissions thus providing greater efficiency and significant emission reductions. Batteries require less maintenance and manual labour to keep them running. Fully electric operations remain in developmental stages.

Fuel Cell. A technological path based on zero-carbon fuel is needed to achieve the NZE goal. Fuel cell powered ships are the outcome of this thought. Fuel cell is one of the most viable solutions to meet the emission targets set by IMO. However, the technology lacks the safety experience of traditional IC engine ships**.** A fuel cell is a device that converts chemical energy from a fuel into electricity through an electrochemical reaction with the help of an oxidising agent. Cells operating on H_2 are more efficient and environment-friendly. These have been recently developed and further research is going on to obtain better results.

Commercialisation of H_2 fuel cells can help reduce pollution levels considerably. The concept upon complete implementation can provide well-to-wake zero emission target as the end products are only water vapour and heat, and not GHG or air pollutants like particulate matter, SOx, NOx etc. The cells can be stand-alone or combined as hybrid models that can provide advantages like longer range and innovative design concepts which can be implemented in flexible configurations to meet any vessel's space constraints.

H_2 fuel cells are better in terms of endurance and refuelling time. Design aspects involve a separate pressurised storage facility for hydrogen; an enclosed space to keep fuel cell; and a large amount of ventilation for clearing out leaks and smokes. The fuel cell space is regarded as hazardous and all devices inside must be explosion proof, making the design complex. Though use of H_2 fuel cells on ships extend a possibility of low flash fuel leakage even in normal operating condition of cell module, a certain amount is likely to leak and accumulate in cell space leading to risk of explosion. Other limitations include:

(a) Lack of sufficient prior experience of the technology
(b) Difficulties in handling liquid hydrogen
(c) Low durability
(d) No IC engine availability at present
(e) High ventilation and fan power requirement
(f) Higher CAPEX requirement

However, the use of fewer mechanical components with better noise reduction and lesser space requirements is a major attraction, making fuel cells a promising alternative. Among them the Proton Exchange Membrane Fuel Cell (PEMFC), Solid Oxide Fuel Cell (SOFC) and Molten Carbonate Fuel Cell (MCC) are considered to be the frontrunners.

Relative Performance and Prognosis of Alternative Fuels. A comparison of the overall performance of alternative fuels with respect to one another and with the traditional fuels i.e. HFO and diesel is given in the following table.

The use of LNG is expected to increase until 2035. It is likely that tankers carrying LPG and methanol as cargo would use them as fuel for propulsion and power generation. Methanol has a higher potential to reduce "well-to-wake" emissions as it can be produced renewably. The use of ammonia and hydrogen as fuels would accelerate in future. Ammonia has less challenging distribution, storage and bunkering requirements compared to hydrogen. Its suitability with existing and emerging propulsion and power generation technologies is likely give ammonia an edge over hydrogen in the coming years.

An anticipation on the development of marine fuel use till year 2050 is given in the following table.

Table 7 Battery Technology Pathways & Challenges (Source: DNV-GL)

Converter	Battery
Components	Battery, Electric motor, Battery management system
Key Challenges	Size and weight, High power charging requirements, Cost

Table 8 Overall Performance of Alternative Fuels (Source: The Shipowner' P&I Club)

Fuel	Vessel Hazards	Environment Hazards	Applicable Regulations	Training Requirement	Carriage State	Fuel Availability	Adoption Trends
HFO	Very Good	Very Poor	Good	Very Good	Good	Very Good	Good
Diesel	Very Good	Poor	Good	Very Good	Very Good	Very Good	Very Good
LNG	Moderate	Very Good	Very Good	Moderate	Very Poor	Good	Poor
Methanol	Good	Moderate	Poor	Good	Moderate	Moderate	Very Poor
HVO	Very Good	Moderate	Poor	Good	Good	Poor	Good
Ammonia	Moderate	Poor	Very Poor	Very Poor	Poor	Good	Very Poor
LPG	Good	Very Good	Good	Moderate	Poor	Good	Moderate
Liquid H_2	Very Poor	Very Good	Moderate	Very Poor	Very Poor	Very Poor	Very Poor

Ship Design Aspects of Adoption of Alternative Fuels

Ship Design involves addressing the interdependent functions of hull form, floatation, stability, powering, seakeeping, manoeuvring, global and local strength of the structure, ergonomics, safety (against fire and flooding) and marine pollution etc., within the framework of relevant rules and regulations. In the final design, a ship needs to be optimised for:

(a) Lowest construction cost

(b) Highest carrying capacity

(c) Best operational efficiency / lowest required freight rate

(d) Highest safety and comfort of passengers & crew

(e) Minimum environmental impact

In the broader sense, green ship design entails incorporation of technologies with respect to low resistance hull forms and appendages, efficient propulsion devices including main & auxiliary power plants, improved steering configurations, reduced hotel loads such as lighting, HVAC etc., low ballast requirements, renewable energy based propulsion & powering devices and use of alternative fuels.

Adoption of alternative fuels would change the hitherto followed conventions and expectations regarding key design parameters such as deck area, volume, tonnage, deadweight, speed and endurance. The vessel sizing, layout & configuration of various compartments & tanks and safety requirements would need to follow the type of alternative fuel being looked at and other fuels and powering systems that may be incorporated in the future to ensure a degree of future proofing.

The conventional design equations for weight and volume may no longer be applicable when alternative fuels are considered in the design. The most significant issue a ship designer faces while incorporating alternative fuels is the storage space required for carrying the fuel. As the volumetric energy density of the alternative fuel is lower compared to diesel fuel, in order to keep the vessel endurance same, the storage space required will be more. The additional requirement of storage space eats into the cargo carrying volume which is undesirable for the ship owner.

Conversely, if the size of the vessel is increased to cater to the increased demand of storage space, the result would be the requirement of higher power to achieve the same vessel speed, or a lower speed if the installed power is to be kept the same. Increase in size of the vessel increases the Gross Tonnage, perhaps the Displacement and could increase the capacity of many deck machinery and seamanship equipment due to increase in the Equipment Letter. Eventually, due to multifarious considerations, the CAPEX and OPEX of the vessel increases. In case it is not allowed to increase the storage space proportionately and is retained same to that of the conventional diesel storage capacity, the result would be lower bunkering intervals.

The effect of various alternative fuels on the design aspects are discussed below.

Liquefied Natural Gas. The volumetric energy density of LNG is about 10 MJ/L whereas for diesel, it is in the range of 40MJ/L. Therefore, 4 times the tank space would be required to accommodate LNG to get an equivalent endurance given by the diesel fuel. Usually in small inland and coastal vessels, the arrangement of internal tanks is very dense and availability of space is at a premium. Hence, using LNG for such vessels may not give the desired endurance or would necessitate reduction of speed. Thus, LNG would be a better choice for larger vessels which have considerable empty spaces available inside the hull.

Another option is to mount bullet tanks (Type C tanks) at appropriate locations on the open deck. However, this

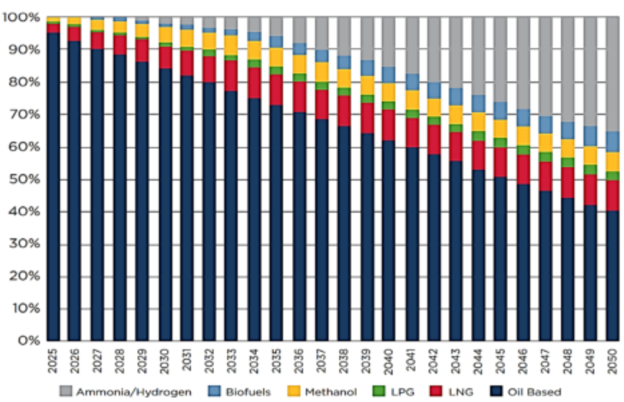


Figure 7 Prognosis of marine fuel use (Source: ABS 2020)

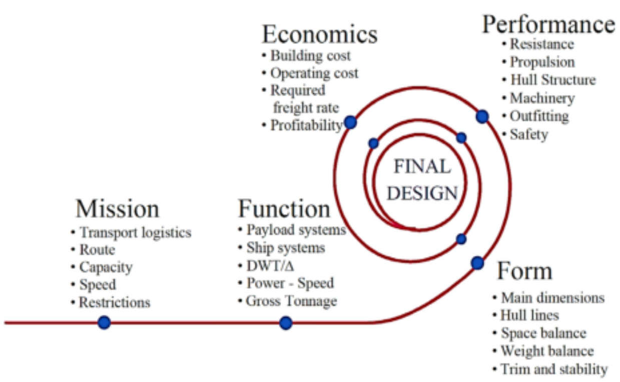


Figure 8 Ship Design Process (Source: Papanikolaou A., 2014)

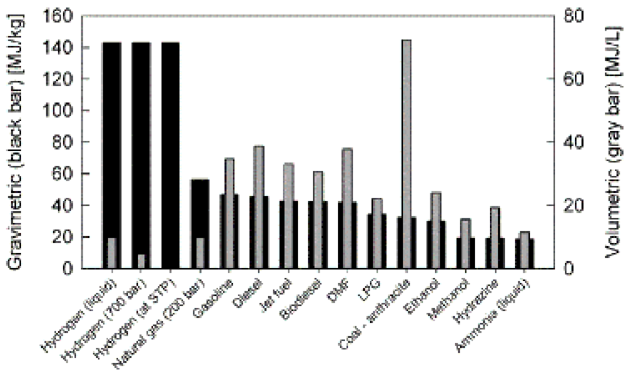


Figure 9 Comparison of Energy Densities of Fuels (Source: MDPI)

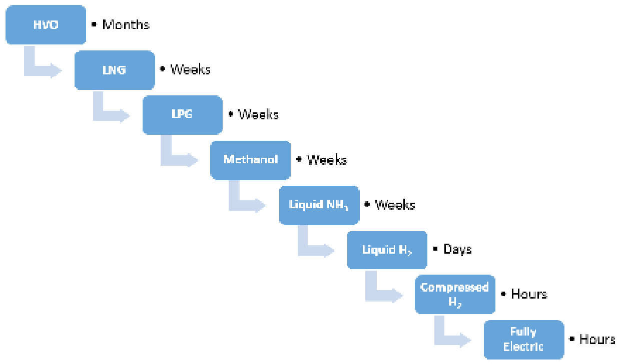


Figure 10 Typical bunkering intervals for various alternative fuels

arrangement would commensurately reduce the area available on the deck for cargo stowage and operational requirements. Purely cryogenic integral type LNG fuel tanks are not common. An integral tank is a membrane system which use the hull to provide structural integrity of the tank against various loads such as fluid pressure, sloshing etc.

Membrane tanks could be shaped to efficiently occupy the space available on a ship unlike Type C or other independent tanks, and therefore, could carry more LNG for the given envelope of space. Due to this, membrane tanks are extensively used in LNG carrier segment. However, due to higher surface area-to-volume ratio in the smaller tanks envisaged for LNG fuel storage, insulation requirements would be much higher. With advancements in insulation technology, membrane tank designs may become a good option for large vessels needing higher endurance.

The specific fuel consumption for LNG fuelled engine is roughly 150 g/kWh in comparison to about 185 g/kWh for engines running on diesel fuel. Therefore, use of LNG would enable about 20% benefit on endurance or speed for the same weight of fuel carried.

A robust ventilation system is to be designed to disperse the highly explosive gas vapor in the event of a gas leak. This requires a completely independent ventilation system for all double walled piping, gas valve units and machinery spaces. Care needs to be taken while drawing up the specifications of hazardous space ventilation systems, noting specific regulations for inlet and outlet locations, flow velocities, exchange rates and equipment. Further, the very low temperature and/or pressure of LNG necessitates designing all the components of the fuel system to the lowest temperature and highest pressure to which they are subjected. A full-fledged stress analysis of the system piping, flanges and other fixtures using FEM would be required.

The regulatory requirements for use of LNG as a fuel are stipulated in *the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code)*, which came into force on 1st January 2017. The IGF Code gives the framework of construction, arrangement, design, and installations, including alternatives taking into account the special nature of LNG.

Methanol. The volumetric energy density of Methanol is about 15.7 MJ/L which is almost 1/3rd that of diesel. Therefore, the tank volumes would have to be increased 3 times to accommodate methanol as a fuel to get the same vessel endurance.

Methanol has a fuel efficiency of about 99% as compared to 96% for HFO. Hence the weight of fuel required to be carried in the case of methanol is almost same as compared to HFO. Hence deadweight proposition would remain almost about the same.

Onboard containment of methanol is easier than LNG. As a liquid fuel, only minor modifications are needed to existing systems/ infrastructure used for conventional marine fuels. The modifications are mainly concerning the low flash point of methanol. Major design and safety considerations include:

(a) Location of methanol tank

(b) Inerting and venting of tank

(c) Spill containment

(d) Vapor and fire detection

(e) Firefighting

Recognising the applicability limit of IGF Code to natural gas, IMO issued the *Interim Guidelines for the Safety of Ships using Methyl/Ethyl Alcohol as Fuel* on 7th December 2020 vide MSC.1/Circ.1621. Various design considerations including provisions for alternative design has been set forth in these guidelines.

Ammonia. The volumetric energy density of ammonia is slightly above 10 MJ/L which is about 1/4th of diesel. Hence the tank dimensions will have to increase 4 times for obtaining comparable energy content. Ammonia has a gravimetric energy density of about 18.6 MJ/kg, which is lower than other alternative fuels. Hence, to achieve the same energy output, the weight of ammonia required is greater. Accordingly, the requirement for larger tanks for storage, their location and configuration onboard would be a critical design consideration. The design of the vessel would also depend on whether ammonia combustion engine or ammonia fuel cell arrangement is selected.

IMO has not yet codified the specific design requirements for use of ammonia as a fuel onboard ships. However, IGF Code allows for alternative design process to cater to the functional requirements which are stipulated. Such an alternative design is allowed if a level of safety equivalent to that of LNG is demonstrated. This involves a comprehensive risk-based design approach and approval process.

Due to the highly toxic and corrosive nature of ammonia, the design considerations include:

(a) Careful segregation of storage tanks to ensure high degree of safety in case of grounding or collision accidents

(b) Provision of automatic leakage detection systems with capability to automatically isolate leakages

(c) Double barriers and water curtains for fuel preparation areas and supply systems

(d) Reliable ventilation systems, including facility for purging leakages

(e) Avoiding materials that are corrosive to ammonia

Biofuel. Biofuel has a volumetric energy density of about 30 MJ/L which is very close to that of fossil derived diesel fuel. Hence smaller vessels can easily accommodate the fuel as the tank dimensions need to be changed only by a small margin as compared to other alternative fuels. There is also not much difference in its gravimetric energy density. Therefore, biofuels could be used in the same proportion as diesel fuel.

The systems for biofuel usage are also similar to conventional diesel. However, some minor upgrades may be required for replacing a HFO or diesel tank with a biofuel tank.

Liquefied Petroleum Gas. The volumetric energy density of LPG is about 20 MJ/L which is about half of that of diesel and hence the amount of LPG that needs to be carried will be twice that of diesel to get the same power output. The gravimetric energy density is about 35 MJ/kg which is close to that of diesel and hence will not cause much difference in the deadweight of the vessel.

Compared to LNG, LPG has fewer design challenges related to temperature as it is usually stored in pressurised tanks at ambient temperature for use as propulsion fuel. It can also be stored in semi-refrigerated tanks made of cheaper steel grades than for LNG. However, LPG has issues related to higher density as a gas and a lower ignition range. Hence, leakages need to be given high importance. The weight of the additional components used to prevent leakage needs to be accounted for in the design.

Liquid Hydrogen. The volumetric energy density of liquid H_2 is about 8 MJ/L. Therefore, for the same energy potential, tankage volume requirement would be about 4 times than that of diesel fuel. Though having a very low volumetric energy density, the gravimetric energy density of liquid H_2 is about 140 MJ/kg which is much higher than diesel (about 45 MJ/kg). Hence the weight of liquid H_2 being carried would be almost 1/3rd of the weight of diesel carried to produce the same power output.

Therefore, liquid H_2 would be a good alternative fuel for ships that carry high density cargo such as iron ore, finished steel products etc., where the reduced cargo carrying volume could be offset against the higher density of the cargo. However, it needs to be noted that practically the volume required to store liquid H_2 could be higher while considering the necessary layers of insulating material or vacuum insulation and other structural arrangements.

An advanced containment system is to be maintained at cryogenic temperatures to keep the hydrogen in liquid form. Such a containment system would be more complex and thicker than the LNG containment systems. Use of vacuum insulation could also be a viable option in the design. The increase in weight and volume due to such systems also needs to be accounted in the overall design of the vessel.

Selection of right materials for design of hydrogen systems is a crucial factor in fulfilling the functional and safety requirements. Hydrogen embrittlement, high temperature hydrogen attack and hydrogen permeation are some of the phenomena which makes the design of H_2 fuel system very complex and difficult. Understanding the leakage scenarios of liquid H_2 is also crucial to the ship design. If a leak produces concentrated pockets of H_2, the detonation risks are high and the design need to ensure that such an eventuality does not occur.

As in the case of ammonia etc., presently there is no regulatory provision for use of H_2 as a fuel other than the IGF Code. Therefore, risk-based alternative design philosophy may be applied. For the carriage of liquefied H_2 as cargo, the *Interim Recommendations for Carriage of Liquefied Hydrogen in Bulk, MSC.420(97)* is the only IMO instrument available that may be applicable.

International Organisation for Standardization's (ISO) *Technical Report ISO/TR 15916 Basic Considerations for the Safety of Hydrogen Systems* provides information towards understanding safety issues related to design of H_2 systems. The report aims to convey the best engineering practices to minimise risks and hazards from H_2.

Fuel Cell. The low exhaust temperature in fuel cells may limit the use of heat recovery, but also free up valuable space due to reduced need for insulation. Accordingly, higher payload could be added on the upper deck of the vessel. Fuel cells are flexible in shape and could be distributed around the vessel providing extra space for the machinery arrangements. If considering a H_2 fuel cell, a cryogenic system may be utilised for cooling with high efficiency, as the heat for the vaporiser could be extracted from the air conditioning system. The fuel storage and supply system also is different as compared to the conventional system.

Battery Systems. Lead acid batteries have very low energy density, whereas Lithium ion (Li-ion) batteries are about 10 times more potent. However, compared to other alternative fuels, vessels need to free up large volumes for housing the batteries to give out a similar output as compared to

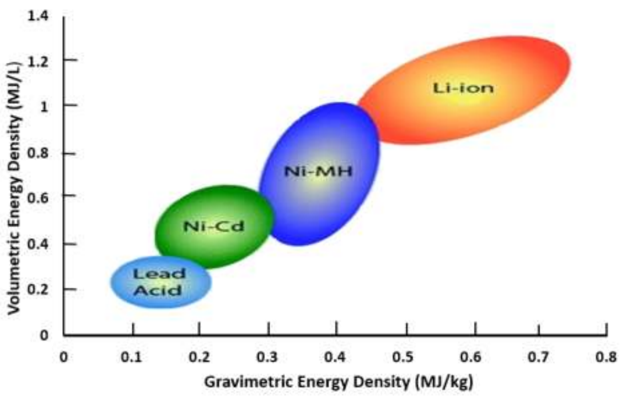


Figure 11 Energy Density of Batteries (Source: NASA)

diesel systems. Hence, battery systems are more suitable for vessels operating over short voyages or where they can be recharged using internal power generation or installed renewable energy systems.

Fast charging facilities are associated with large battery storages. Accordingly, attention needs to be given to the battery compartments housing Ni-Cd or lead acid batteries in terms of detection of H_2 gas with integrated alarms and sufficient ventilation even during normal operating conditions. Li-ion systems do not generate flammable or toxic gases under normal operating conditions. However, under failure conditions such as thermal runaway, Li-ion systems require additional ventilation.

Effect on Design Timelines. Though the use of alternative fuels and power systems have some challenges, their adoption is not likely to cause a substantial influence on the ship design timelines. They may however cause a delay during the initial phases of the design where the arrangement is not very familiar with the designers and sourcing of special systems and equipment may have larger lead-times. If there is a clear idea regarding the components and their arrangements, then the design timelines are likely to remain traditional.

Since these fuels and power systems are comparatively new in the industry, Classification Societies may give greater thought regarding their adoption in the design and may take more time in the plan approval stages so that important aspects are not missed out. As these fuels become more common in the industry in future, the design and plan approval timelines are expected to align with those for conventional designs.

Green Design Initiatives by Seatech Solutions

SeaTech Solutions International (S) Pte Ltd is a marine design expert at the forefront of green design solutions for the maritime sector. Some of the latest initiatives and bespoke solutions are:

Ammonia Bunkering Vessel Joint Development Project. Ammonia has started gaining popularity as an alternative fuel among ship owners. As a result, the market requirement for ammonia bunkering vessels is bound to go up in the near future. To cater to this upcoming requirement, SeaTech Solutions have already started designing an ammonia bunker tanker.

Figure 12 Signing of Joint Development Project for Ammonia Bunkering Vessel

The company believes that a pioneering development of ammonia bunkering vessel designs would increase the confidence of the shipping industry to embrace the fuel. This venture is a joint development project with SeaTech Solutions carrying out the concept development and design, RINA Class doing the verification of compliance with the regulations and Fratelli Cosulich SpA providing the operational data to support and validate sustainability and design.

Singapore's 1st Hybrid Electric Bunker Tanker. SeaTech is also part of Singapore's first hybrid bunker vessel development program. The 8000T DWT hybrid electric bunker tanker will have an Energy Storage System (ESS) comprising Lithium-ion batteries and Power Management System (PMS). The expected reduction in GHG emissions is about 10% a year.

Figure 13 Hybrid Electric Bunker Tanker

Asia Pacific's 1st Zero-Emission All-Electric Tug. SeaTech Solutions, American Bureau of Shipping (ABS), Vallianz Holdings Ltd and Shift Clean Energy have formed a pioneering industry alliance combining their respective technical expertise and engineering capabilities to design and construct the first all-electric, zero-emission harbour tug in the Asia Pacific region. The tug will have a length of about 24 m and bollard pull capacity not less than 60T.

Figure 14 Signing of Joint Development Project for E-Volt Tug

Asia's 1st ESS-based SOV and CSOV. The design of first future ready ESS-based SOV and CSOV in Asia is being carried out by SeaTech Solutions. The vessels will have the task of commissioning/ installing offshore wind farms. The hybrid battery-based ESS system is expected to reduce the fuel consumption and GHG emissions by about 15% to 20%.

Conclusion

Many steps are being taken to achieve the NZE goal with the primary one presently being the adoption of alternative fuels. Fuels such as LNG, LPG, biofuel and methanol have

Figure 15 Future ready CSOV design

already been in use for some time. Batteries and fuel cells too have been in use especially in ECAs where the rules are stringent regarding the allowable emissions.

The more environment friendly fuels such as ammonia and liquid hydrogen are rather new to the industry and hence face a few challenges. Once a solution has been established for these challenges, they can turn out to be the fuels of the future. To establish a solution, proper incentives and funding needs to be provided by government organisations. In this regard, the government in India is also actively working on various fronts to provide incentives and funding for research and development on various alternative fuels.

The progression of alternative fuels is reliant upon many factors such as ready availability of the fuel, intensity of carbon emissions, technology availability for pragmatic adoption, bunkering infrastructure, regulatory frameworks, and more importantly the value proposition of each fuel. It is evident that all the aspects involved in the application of alternative fuels, including ship design, are revolving around cargo carrying capacity and cost.

Cost is a fluctuating parameter which depends on the market conditions. Hence the parameter which could be optimised through efficient and innovative design solutions is the cargo carrying capacity. Many progressive efforts and pilot projects are underway in developing optimum design solutions.

Most alternative fuels use up more space in comparison to HFO/diesel and hence the tankage required is larger. This reduces the volume of the cargo which can be carried. For vessels which carry cargo below the decks, it is better to have tanks setup on the decks. Deck fitted tanks use limited space and there is no need to compromise on cargo spaces within the vessel.

For new vessels, this can be implemented by considering extra space for the tanks on the deck during the deck space allocation itself. For existing vessels, this may not be possible if the spaces are being used already and hence may require inserting a new block inside which could free up deck space and simultaneously increase the cargo capacity which is a win-win situation for the ship owner.

IMO has taken many measures to improve and monitor the energy efficiency of ships. Indices such as EEDI look at energy efficiency levels during the design stage. SEEMP, EEXI, CII, etc. look at the energy efficiency levels during operational periods and are recurring in nature. However, these indices are addressing only the "tank-to-wake" energy efficiencies. It is opined that instruments which look at a broader picture of emissions, including measurement of "well-to-tank" emissions, be included in the energy efficiency estimations and indices.

SeaTech Solutions are equally participating in the efforts towards IMO short-term goals and NZE 2050 goal by making available bespoke design solutions to the maritime sector which incorporate niche energy efficient features including use of alternative fuels, forming industry collaborations across the globe and also advising potential clients to embrace transition & alternative fuels for achieving a greener tomorrow.

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TECHNICAL NOTES

LUBE MATTERS # 19: ON FRICTION

Sanjiv Wazir

> Friction is present in many activities. By itself, friction is not good or bad. But, depending on the situation it could be too little or too much

Introduction

Friction is the resistance to relative motion of two bodies in contact.

In the 18th century, Amontons formulated some "laws" for dry friction and Columb brought out the difference between static friction and kinetic friction. The force (F) needed to move a body is proportional to its weight (W) (or normal load L). The proportionality constant, known as the coefficient of friction (μ) is

μ = Friction Force/Normal Load

The coefficient of static friction is used in reference to the initial movement of the object from its resting position. The coefficient of kinetic friction is used once relative motion is in progress.

The coefficient of friction can vary from 0.001 in a lightly loaded rolling bearing to greater than 10 for two identical clean dry metal surfaces sliding in a vacuum. For most common materials sliding in air, the value of μ lies in the range from about 0.1 to 1.

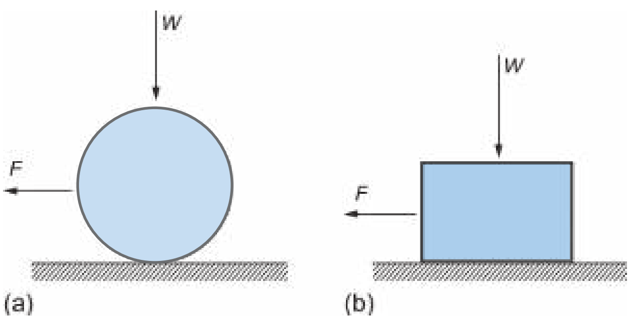

Figure. 1: A force, *F*, is needed to overcome friction and cause motion by (a) rolling or (b) sliding (1)

It should be borne in mind that friction/coefficient of friction is not an intrinsic property of a material or combinations of materials. It depends on many parameters including :

- contact conditions - load, speed, temperature, type of motion;
- nature of contacting materials – surface, substrate, adsorbed films, rigid, elastic, plastic, visco-elastic;
- surface interaction mechanisms – adhesion, cohesion, melting, welding, deformation; and
- scales – nanoscale to continental size.

Friction is present in many activities. By itself, friction is not good or bad. But, depending on the situation it could be too little or too much. Sometimes high friction is desirable and in other cases low friction may be desirable, e.g.,

- Force transmitting components: power belts, tyres on roads, press-fitted pulleys on shafts,
- Energy absorption-controlling components: Brakes & clutches
- Quality control components: sheet-metal rolling, knitting & weaving of fibres & textiles
- Low friction components: bearings, gears in watches, precision guides in machinery (1)

Causes of friction

Dry Static and Sliding friction

Even macroscopically smooth surfaces are microscopically rough, the surface topographies comprising of asperities and valleys (**Figure. 2**).

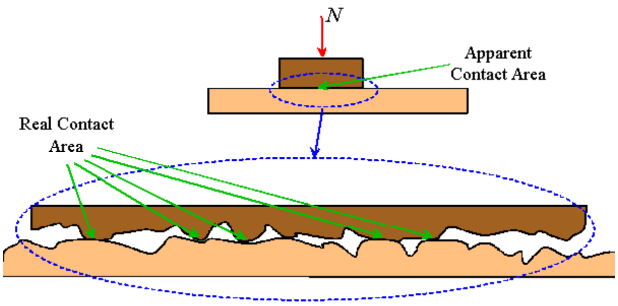

Figure. 2: Asperities, Valleys, Real, and Apparent contact areas (2)

Over time many theories have been proposed to explain friction between different combinations of materials, including adhesion, junction growth, interlocking of asperities, attractive forces, surface melting, etc

In the case of metals/elastically/plastically deformable materials, bodies are supported only at the tips of the asperities of the two surfaces that are in contact with each other. The real contact area, which is dependent on the total asperity contact area, is extremely small. Thus, the pressure at these contacting points is extremely high. Under high load, these points of contact undergo deformation until the real contact area is large enough to support the load (**Figure. 3 bottom**).

Figure. 3: (Top) Asperities under no load; (Bottom) asperities under load (6)

The extreme pressure at the contacting asperities may also cause adhesion between them by cold welding. These adhesive bonds need to be broken before motion can begin.

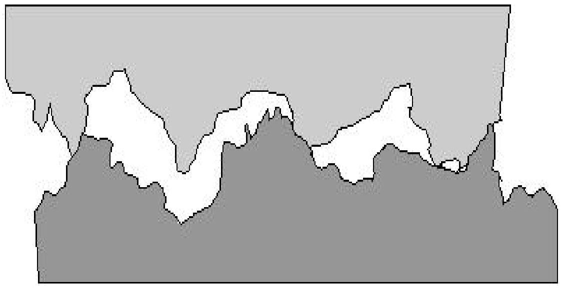

Figure. 4: Asperity interlocking (3)

Some of the asperities of the counter surfaces may settle into valleys of the other surface, causing the surfaces to interlock (**Figure. 4**). These interlocks need to be broken or deformed to allow motion to begin.

Static friction is caused by adhesion, interlocking, and deformation of the contacting surfaces.

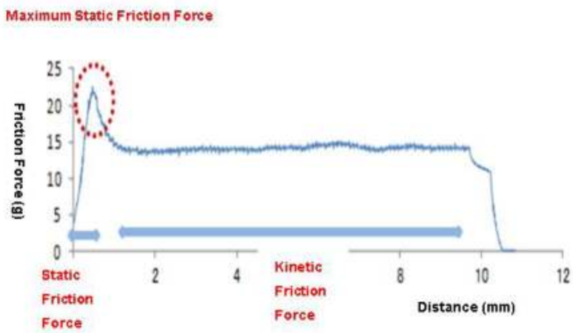

Figure. 5: The highest friction force is generated just before sliding begins (3)

Sliding begins once the adhesive bonds, interlocking, welds, etc that may have formed, have been broken/moved by the applied force. Under sliding conditions, the surface temperatures at the contacting points rise and may cause structural changes, such as softening of the asperities accompanied by local melting. This causes real welding, and adhesion, at the junctions. Force is required to shear these junctions to keep the body moving. This is kinetic friction (3).

Stick-Slip friction

Often bodies in contact might move in jerks, against each other. Spatial variations in roughness and elasticity may cause such "stick-slip" to occur whenever the coefficient of kinetic friction is lower than the coefficient of static friction. When a driving force is applied to one surface, high static friction prevents motion but may induce elastic deformation. Sliding will be initiated when the elastic and driving force overcomes the static friction force. Initially, the elastic force accelerates the surface while the potential energy in the elastic deformation rapidly drops.

The sliding body will come to rest when the driving drops below the level of the kinetic friction force. The elastic deformation force will have to build up again to overcome the increasing static friction, and the cycle

> The sounds made by bowed instruments (violins), heavy braking, rubbing chalk on a blackboard, squeaking from a rusty hinge, etc., are caused by stick-slip. Control of stick-slip is extremely important in areas requiring very precise movement such as machine tool slideways

repeats. Therefore, the relative motion of the surfaces is intermittent. Stick-slip is commonly observed in motion at nanoscales.

The sounds made by bowed instruments (violins), heavy braking, rubbing chalk on a blackboard, squeaking from a rusty hinge, etc., are caused by stick-slip. Control of stick-slip is extremely important in areas requiring very precise movement such as machine tool slideways.

Rolling friction

Rolling friction is experienced when a ball, cylinder, or wheel rolls over another surface.

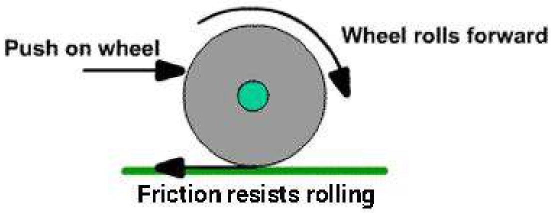

Figure. 6: Rolling friction

If the rolling body is assumed to be rigid, there will be a "point", or a "line" contact. This results in the ideal situation of "pure rolling" without slipping. The rolling body can be considered to be in pure rotational motion about an instantaneous axis that passes through the point of contact. The resultant normal reaction to rolling shifts forward in the direction of rolling motion, which is equivalent to a moment resisting rolling (1). A rigid roller rolling over a rigid surface experiencing no friction should keep rolling.

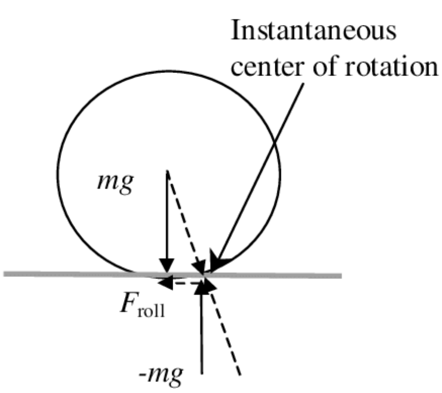

Figure. 7: The normal reaction shifts towards the direction of motion.

However, pure rolling does not occur in real-world applications. The rolling motion must be sustained by a tangential force or, in the case of a driven wheel, by a torque applied to the driving axle.

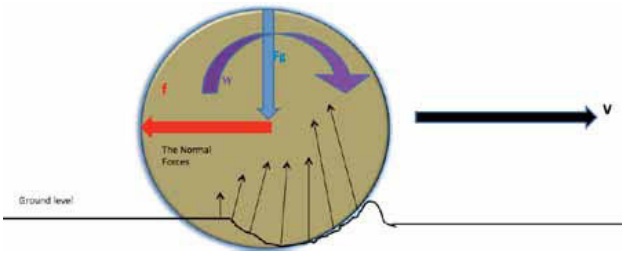

Figure. 8: Surface deformation at point or line of contact and load transfer (3)

Rolling friction is understood to arise due to the sliding of one contact surface along the other, and due to deformation of the surfaces. Rolling of a (non-rigid) sphere or cylinder along a flat (non-rigid) surface can be viewed as a series of indentations progressing along the counter surface (**Figure. 8**).

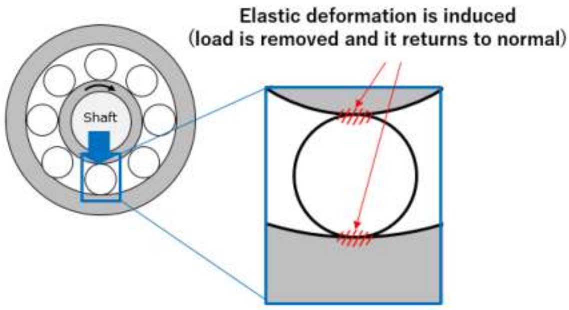

Figure. 9: Elastic deformation in the area of load (4)

The energy lost in the cyclic viscoelastic deformation of materials is a major component of rolling friction.

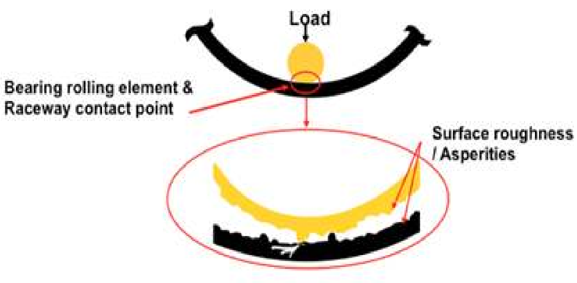

Figure. 10: Friction due to surface roughness (5)

Besides sliding and deformation losses, rolling may be accompanied by losses due to roughness (**Figure. 10**).

For corresponding materials, coefficients of rolling friction can be up to a thousand times lower than coefficients of sliding friction. Humankind recognised this quite early in history, leading to the transition from sleighs to wheeled transportation.

Fluid and Lubricated friction

Viscosity is fluid friction. Like friction between moving solids, viscosity transforms kinetic energy of motion into heat energy.

Consider a fluid sandwiched between two parallel plates, the fluid can be pictured as made up of many layers (**Figure. 11**). We have a solid in contact with a liquid at the top and bottom. In contrast to solid/solid friction, there is no such thing as static friction between a solid and a liquid.

The fluid in close contact with the bottom plate layer stays at rest, and the fluid in contact with the top plate moves at the same speed as that plate. In the space between the plates the speed of the fluid increases linearly with height. This is caused by the fluid friction between the fluid layers. Unlike solid/solid friction, since the liquid can flow, there is good contact over the whole common area, even for low pressures, hence there is little dependence on pressure (normal load).

Just as for kinetic friction between solids, a force is required to keep the top plate moving. The force is proportional to the total amount of fluid being kept in motion, that is, to the total area of the top plate in contact with the fluid. The important parameter here is the horizontal force per unit area of plate (say F/A). While this has the same dimensions as pressure, it is physically quite different, since in this case the force is parallel to the area, not perpendicular to it as would be the case with pressure (6).

Newton believed that the necessary force F/A would be proportional to the velocity gradient in the vicinity of the top plate. The velocity gradient is the same everywhere between the plates, V_0/d, so

$F/A = \eta V_0/d$

where η is the *coefficient of viscosity*.

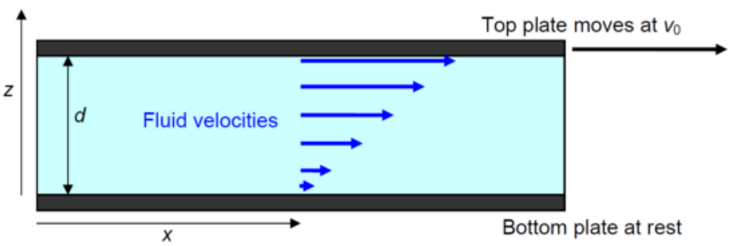

Figure. 11: Fluid velocity under shear for Laminar Flow (6)

This molecular picture of sheets of fluids moving past each other helps explain why viscosity decreases with temperature, and at different rates for different fluids

Quantum origins of friction

The classical "laws" of friction hold over a remarkably wide range of loads, speeds, and materials. However, they begin to fail at nanoscales. It turns out that characteristics of atomic scale friction are quite different from those features for macro levels in many respects, including the dependence on contact area, normal load, velocity, and temperature, as well as the relation between the kinetic and static friction. Stick-slip phenomena plays a significant role at nanoscale.

At a molecular level, solids are always rough. When two solids are brought into contact, even at the atomic level only a small fraction of the total area is really in contact. Due to their thermal energy the atoms are in a constantly agitated state. There is atom to atom interaction in this small area. Atoms from the opposing surfaces smash against each other causing loss of energy. At atomic levels, there are several types of short-range, attractive forces that act between the atoms and molecules, including van der Waals force, electrostatic force, chemical bonding, etc. In overcoming such adhesive forces, energy is lost in forcing the atoms to slide past each other. These energy losses manifest as static friction at macro scales.

When sliding begins, the two sets of atoms in the contact area are constantly colliding, loose bonds are forming and breaking, some atoms or molecules falling away. This causes a lot of atomic and molecular vibration at the surface. Some of the energy from the applied force is ending up as heat instead of adding to the moving body's kinetic energy. This is kinetic friction.

Similarly, fluid & lubricated friction is not (essentially) between the fluid and the plates (the molecules right next to the plates mostly stay in place), it's between the individual sheets throughout the fluid, caused by the molecules of one bumping against their neighbours as they pass. As they push past each other, on average the molecules in the faster stream are slowed down, and those in the slower stream speeded up. The macroscopic kinetic energy of the sheets of fluid is partially lost—transformed into heat energy.

This molecular picture of sheets of fluids moving past each other helps explain why viscosity decreases with temperature, and at different rates for different fluids. As the molecules of the faster sheet pass those in the slower sheet, they are also wiggling about with thermal energy. The wiggling helps break them loose if they get jammed temporarily against each other. As the temperature increases, the molecules wiggle more rapidly, unjam more quickly, and the fluid moves more easily— i.e., the viscosity drops (4).

With the advent of nanotechnology, understanding the quantum-mechanical origins of friction forces is under intense focus.

Conclusion

Friction is a primary cause of energy dissipation (usually in the form of heat). It also results in damage to working components through wear and tear.

About one third of energy used to drive an automobile is used to overcome friction in its engine, transmission, tyres, and brakes. Often large mechanical assets(e.g. vehicles) are discarded/lost even if only a few of their components are badly worn.

In the marine field, the approximately 90,000 ocean-going fleet, burning about 330 MMT of fuel, is estimated to be emitting 3.5% to 4% of all GHGs. Most of the energy in shipping is used to overcome surface (fluid) friction in the water. An effective way to reduce frictional drag in water could significantly reduce marine fuel consumption, making the shipping industry more efficient and environmentally friendly.

The cost of undesirable (i.e., too much) friction in modern society is staggering. Better fundamental understanding of friction will be a key step towards sustainable energy consumption in every field of human activity.

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Kolkata Port was born in 1870 and was put under the administration of Port Commissioners, that later became Port Trust. This was also the first port to be born in India under British rule and for years it remained as the second largest and busiest port in the British Empire after London. Even in 1920s, a few years after the end of World War I, Kolkata Port kept on handling nearly half of India's trade. ***Courtesy:- GetBengal***

GOING ASTERN INTO MER ARCHIVES

MER... Four decades back...
The January 1983 Issue

The January 1983 issue: The Editorial has a poser, '**Do seagoing engineers possess entrepreneurial skills?**'. I would say, Yes, with full power and thrust. There are few names mentioned then, but I guess the list would take much more than this space.

The first technical read is about modifications to steam turbine propulsion arrangements on container ships from a fuel savings perspective. Are there still such trains on the box ships or we have migrated to diesel engines fully? Sailing marine engineers may provide some talking points.

This is followed by interesting descriptions of thrusters employed for manoeuvring and propulsion. There is a discussion on Magnus effect (Flettner Rotors on Deck getting attention now) also. Couple of extracts are inserted to get your attention and interest.

The waste sludge treatment system (and chemicals/ rotary cup burners) helping to burn it in boiler will be of interest, especially to the marine engineers from the 1980s period.

And there is a short article on hull designs of energy carriers.

The Post Bag has one very interesting case (Wise User) of piston pin retaining screws coming loose/pounded and finding their way to the filters! Sounds familiar? Yes, there are bound to be similar stories. There is one letter observing that deck personnel must get technical training. The debate on this must be still on...

Thruster manoeuvring systems

Any device which produces a thrust may be called a thruster, including all propellers, water jets and other methods of moving water to produce an effect on the vessel. More specifically, the thruster is a device that is optimised for low-speed operation and used in docking and manoeuvring.

Thrusters can theoretically use any permutation of the following alternatives: fixed pitch or controllable pitch propeller; retractable or non-retractable into the hull; fixed in a duct or freely azimuthing; intake and/or outlet in the ship's bottom or sides. Any ducts can be simply athwartships mostly for side-thrusting; or take various Y or T shapes as compromises between forward/aft and side thrusting.

In practice the main types of thrusters today are:

- Gill jet
- Cycloidal propeller
- Ducted jet
- Azimuthing steerable ducted propeller
- Fixed or controllable pitch, tunnel type
- Hydrojet (side thrusting or propulsion).

All these devices have various ways of moving water but all have some common elements, and problems. Among these cavitation is one of the limiting factors.

Design considerations

All propellers or impellers can be over-driven so that the blade tip produces cavitation. This absorbs excessive amounts of energy and causes physical deterioration of the blade.

Cavitation depends on the vapour pressure of the water and the dissolved gases in it, as well as the tip speed. As a general rule about 5000 ft/min blade tip speed is the maximum desirable, assuming that the degree of blade submergence and the net positive suction head of the pump are feed into the intake of another, reducing net thrust.

Power ratings

To determine the size of the thruster necessary to manage the vessel during manoeuvring, it is necessary to estimate the amount of force needed to offset the disturbance elements, particularly aerodynamic and hydrodynamic.

Usually the aerodynamic forces are predominant in the open sea while in rivers and tidal areas current forces are strongest. One can estimate the maximum 'sail area' presented to the wind by analysing the drawings of the ship, and then determining the corresponding forces. The effects of gusts are more complex and require further analysis. A power increase of 10–20% is usually added in order to partially compensate for moderate gusting.

Wind pressures increase much faster than velocities: 5 Kn gives 0·1 lbf/ft^2 while 60 Kn corresponds to 12·3 lbf/ft^2. Derived from tables, the wind pressure, multiplied by the area and the cosine of the angle of attack, gives the total force acting on the 'sail area' of the vessel. The thruster must overcome this at a given speed of advance or against a given current. This simplified approach is sufficient in most instances.

Tidal and estuarial currents can be extremely strong, running at 6 knots or more. The effect of currents is a function of the draught, bottom condition, and hull form. There are many formulae for determining the net result, all based upon empirical data. The best way to determine them is from actual sea trials. Thus, a precise choice of thruster size requires detailed analysis but many engineers simply refer to similar vessels that are already operating, using reports from the crew on how the thrusters are working. The more rigorous analytical approach is usually employed with vessels such as drill ships where great accuracy of positioning is essential.

We can now consider how the various types of thruster can closely meet these considerations.

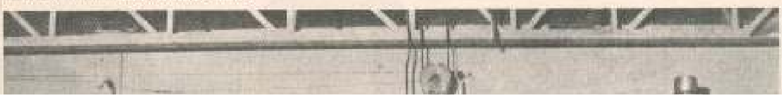
Gill jet thruster

Shown in Fig 1, these thrusters are made by at least two manufacturers. They produce a reaction against the gill fins, and eject water obliquely through the bottom of the vessel. Almost any type of prime mover can be used. The gill can be rotated to eight fixed positions, allowing thrusting to eight directions.

In the model shown in Fig 1 the intake is near the waterline and the outlet is at the very bottom of the keel. Specific thrusts of 14–16 lbf/hp (6–7·5 kgf/hp) are generally advertised.

Gill jet machines produce forward propulsion as well as side-thrusting and are often used in applications where position-keeping is desired. The newer types are

An Omnithruster JT1300IB thruster for an ice-breaking supply tug. On the right is a steering valve control for ice lubricating.



Magnus effect rudders and propellers

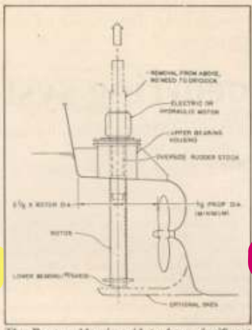
Since 1926, when Anton Flettner proved that the Magnus effect could be put to good use with sailing vessels, research into utilising the effect has continued. It will be remembered that Flettner's cylindrical rotor was used instead of sails on the vessel *Baden Baden* during a passage across the Atlantic Ocean.

Development now continues with Magnus effect rudders and propellers. The Borg/Luther Group in the USA has designed the Borg rudder—a rotary unit that has apparently achieved remarkable performance on smaller craft that require maximum manoeuvrability while operating at low speeds and while carrying heavy loads. They are now developing a cylindrical propeller.

A simple explanation of the Magnus effect is that a cylindrical body, rotating in a fluid (water or air) develops a high lifting force at 90 deg direction to the flow on the side of the rotor turning in accord with the fluid flow. Lift increases rapidly as surface speed of the cylinder increases.

The conventional rudder has many disadvantages, claim the company. It tends to act like a flap when moving astern, building up heavy forces on the rudder stock and tiller arm quadrant.

Also, as rudder angle is increased with respect to the ship's direction of travel, it tends to produce a breaking effect, thus leading to increased propulsive power requirement. Over excessive rudder angles also causes increased fuel consumption.



The Borg rudder is said to have significant advantages over conventional rudders.

The Magnus effect rudder, consisting of a vertical cylinder with round plates top and bottom, has no such disadvantages. As a vessel moves forward, creating a flow around the cylinder, rotating the cylinder at right angles to the direction of travel a turning force is developed. Lift has been found to occur as soon as the rotor starts turning.

As the speed of the rotor increases, so does the lift. When its surface velocity becomes four times the flow velocity, the lift to drag ratio is said to be about 9:1. This compares with a ratio of about 4:1 for conventional rudders, claims the company.

As an example, two rotary rudders turning at 450 rev/min produce over 92 000 lbf of thrust at 10 knots, compared with only about 62 600 lbf with two conventional rudders. Also drag is considerably reduced. Only about 12 500 lbf of drag occurs whereby 56 000 lbf occurs with conventional rudders hard-over at 42 deg and 10 knots.

Another advantage with this rudder is that the turning force is produced in far less time than with a conventional rudder. Power for rotation can be hydraulic or electric.

Following successful trials with the first application of this rudder on a pushboat in 1980, the company investigated the feasibility of a Magnus effect propeller, in which normal blades are replaced by individual rotating cylinders. Current calculations indicate that 50 lbf of thrust per horsepower is obtainable with this type, compared to only about 25 lbf of thrust/hp with a conventional propeller. If this proves correct in practice, a vessel needs only half the power it requires normally. Development work continues. *Borg/Luther Group, 876 Elm Avenue, Carpinteria, California, USA, CA 93013. Tel: (805) 684 6193.*

POSTBAG

Conservative practices

Sir,
In response to Mr Makhija's interesting questions (Nov 82 Postbag). It has been the conservative practice of the Hong Kong owner that has enabled him to construct and consolidate his position in the world shipping market in the past, and it is the conservative policy of usually finding a long term cargo or long term time-charter, before concluding a newbuilding order, that has staved off serious problems while the market is depressed.

This method has been particularly effective when, during the strong market, the owner replaced older ships with newbuildings to maintain a competitive edge for his fleet.

Nevertheless, this present recession is undoubtedly hurting the Hong Kong owner, and he is no exception to the effects being felt by owners worldwide.

During the last recession of 1974–1977 no major Hong Kong shipowner incurred financial difficulties, and all were seen to uphold their commitments to their financial institutions and shipyards. I feel that this is a major reason why financial institutions express such confidence in Hong Kong shipowners, and it is also the reason why they are still able to obtain bank finance relatively easily for a sensible project.

This brings me onto types of financing. This conservative style of operation makes it possible to reasonably accurately present a cash-flow forecast, based on charter hire income, to financing institutions; hence cash-flow financing. Western operators tend to operate spot—or at least without a charter party attached to hire—and are therefore biased to equity financing as they have no means of pragmatically estimating their cash-flow over the period of loan repayment. The type of financing available to owners has nothing to do with the attitude of European banks or their structure.

Generally, the Western shipowners are much more speculative than the Hong Kong shipowners. However, conservative shipowners such as Bergesen in Norway, and Maersk in Denmark, are not suffering as acutely as others in this present poor market.

The weak Japanese Yen generally benefits owners who order their newbuilding in Japan and borrow from the Japanese Export Import Bank. Nevertheless, speculation in currency is always dangerous and, in general, is not advisable for shipowners. A currency switch cross facility is an asset to the shipowner, but is sometimes subject to availability. It may be used to great advantage if there is a large interest differential; for instance, last year the US$ interest rate reached 19.5% while the Yen rate was 8.5%. While the possibility of strengthening of the Yen against the US$ was not really significant, a currency switch would have been a tremendous advantage—especially from hindsight!

Finally, the Hong Kong shipowner can only survive if management and judgement is good, ships are competitively new and crews efficient. Without this totally professional outlook he will not survive as Hong Kong has very little cargo of its own. The Hong Kong owner will always have to work very hard in order to survive.

Frank S B Chao
Wah Kwong & Co (HK) Ltd
Hong Kong

Carbon spread

Sir,
The article on experience of warship gas turbines (Sept MER) reminded me of a superlatively cooked prime steak—easily chewed and eminently digestible.

A question always arises in one's mind, (envisaging the close confines of a warship engine room) of the consequences of air intake duct total rupture. Would the turbine air consumption requirements dangerously reduce the engine room ambient air pressure?

As regards water washing, one recalls hearing of a method of reducing or eliminating the growth of the carbon ring which often developed as a result of burning oil in a scotch boiler furnace. It was claimed that a constant drip feed of water into the air register prevented the ring growth: such rings growing to as much as 4 in thick longitudinally and, if not removed each watch, to almost unlimited radial depth.

C F Jones
Rochdale, Lancs

Wise user

Sir,
About two years ago the Diesel Engineers and Users Association tried unsuccessfully to establish contact with the users of diesel and gas turbine plant in ships. The intention was to extend the information contained within the annual Working Costs and Operational Report, published by us, into the marine seagoing field. It was thought that there was a need for this information from both the user and the manufacturer and Lt Cdr D P Fairbairn's letter (Oct 82 Postbag) has confirmed this need.

There is a remarkable similarity between the land-based and marine engine; they come from the same stable. Marine type engines are used in many land-based power stations operating under heavy duty for years on end. This top-line duty over long periods of time is a good testing ground for uncovering defects and establishing service reliability. A close study of the Report, even in its present form, would be of benefit to the marine user who wishes to do his homework. It would be even more enlightening if the experience of the marine user was included.

As a user, I am particularly interested in the Operational Notes contained within the Report. It is surprising how a relatively minor maintenance or operational defect can cause serious damage to an engine. For instance, the 1982 Report gave details of debris found in the crankcase of a 2650 kW diesel engine, caused by the piston pin retaining screws coming loose. The screws were pounded until they were small enough to escape via the oil drain hole in the pin to the sump where they were discovered by a routine check of the lube oil filter. The result was that the engine had to be removed from service and all pistons withdrawn and checked. One cylinder had to be renewed. Frank exchanges of information such as this are vital to the user who is able to benefit from others experience.

The DEUA would be pleased to prepare a Wise Practice for the Wise marine user if given the opportunity.

G Tubman
Diesel Engineers and Users Association
18 London St, London EC3R 7JR

Engine room safety

Sir,
I was very pleased to attend the reading of Dr J Cowley's paper on steering gears in Liverpool and to see how the new safety requirements had been met with clever thinking at negligible costs.

Marine accidents are much more frequent than they need be, so why can't we apply the same logic to other pressing safety requirements, many of which can be met with small expenditures.

Engine room fires, for example, are on the increase for two prime reasons: noise and heat levels often make it impossible to carry out maintenance in a satisfactory manner. Simple remedies, which could even reduce first costs, include eliminating the emergency alternator and installing a main alternator in a separate compartment; and installing turbochargers in the funnel, thus eliminating turbine blade damage and reducing ventilation fan requirements.

Many fires and engine breakdowns are caused by faulty fuel treatment. Who can look after purifiers installed in an enclosed compartment in temperatures of 45°C and a noise level of 100 dBA? Purifiers are safer and cheaper installed in the open engine room.

Furthermore, ship manning and operating methods are totally obsolete. We still do not give deck personnel any meaningful technical training but put them in charge of large floating engineering complexes where they are not in a position to make critical decisions. (95% of all ship operating costs and 60% of all casualties are of an engineering nature).

The method of recruiting master mariners at 16 effectively bars graduates from our industry, which again is disastrous for a technological industry.

If a sensible attitude was taken to integrated officer training, costs would tumble and safety improve. We might even regain technical advantage over competitors.

John F Birch
Liverpool

JANUARY 1983 MER

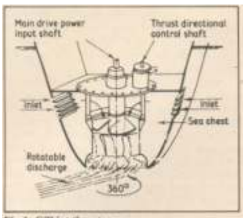


Fig 1: Gill jet thruster.

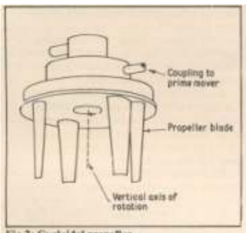
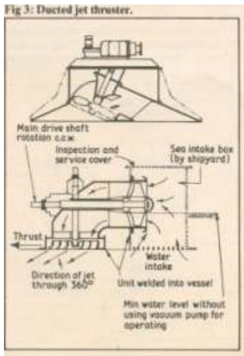


Fig 2: Cycloidal propeller.

Fig 3: Ducted jet thruster.



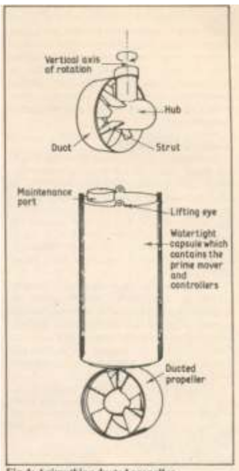


Fig 4: Azimuthing ducted propeller.

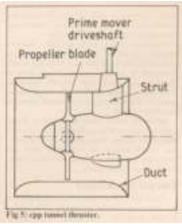


Fig 5: cpp tunnel thruster.

Fig 6: Omnithruster.

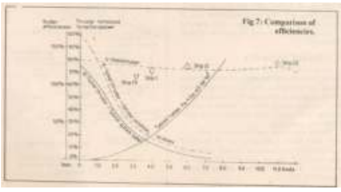


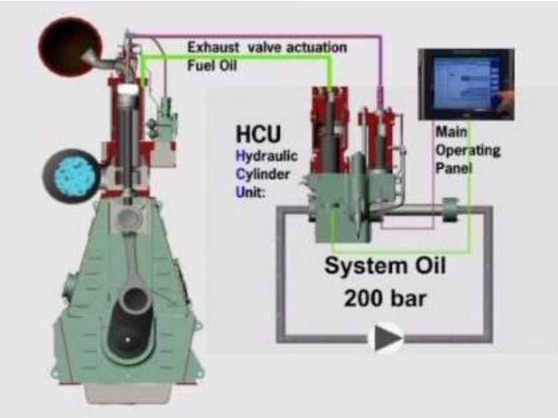
Fig 7: Comparison of efficiencies.

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

MASSA Maritime Academy, Chennai

The Institute of Marine Engineers (India)

Electronic Engine Familiarisation Course (ME-Type Engine) Delivered online with Cloud access to ME Engine Simulator



This 3 days course is designed for all Ship's Engineer Officers and Electro Technical Officers responsible for the operation of ME Engine. This course consists of technical lessons and practical instructions on the design, principles, operating procedures and maintenance activities for the safe, efficient and optimal performance of the engine system.

Course Aims and Objectives:

The course aims to provide practical understanding of the principles, design, operation and maintenance of the ME Engine System, enabling participants to safely and efficiently operate the engine and perform fault-finding in the control system.

Coverage / Program Focus:

This course deals with the following training areas:

- **Introduction to ME Engine**
- **Hydraulic Power Supply (HPS)**
- **Hydraulic Cylinder Unit (HCU)**
- **Engine Control System (ECS)**
- **Main Operating Panel (MOP)**
- **Standard Operation**

Entry Requirement / Target Group:

Entry is open to all Ship's Engineers and Electro Technical Officers with basic knowledge of diesel engines.

DATE & TIMING : **23rd, 24th, 25th January 2023/ 21st, 22nd, 23rd February 2023/ 21st, 22nd, 23rd March 2023/ 18th,19th, 20th April 2023/ 23rd, 24th, 25th May 2023/ 20th, 21st, 22nd June 2023 8:00 am - 4:00 pm IST**

VENUE : Web Platform / Zoom. **APPLICATION LINK:** https://forms.gle/e4As7kCucR5xoJBm9

REGISTRATION & PAYMENT : Rs. 15,000/- /- per participant – inclusive of taxes.
For IME(I) Members 13,500/- per participant - inclusive of taxes.
Payment to be made to: https://imare.in/buy-online.aspx
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