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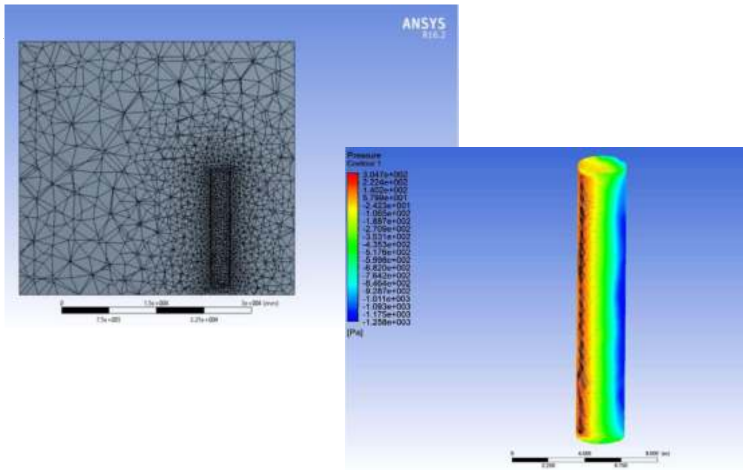

Rotor Sails on Research Vessels: Can it be real?

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EDITORIAL

The difference between war and peace ... I never see a war good.

- (attributed to) Confucius

The Indian exports have scaled a new height to US$ 400 billion while another US$10 billion awaits to be shipped out. Compared with the pre-pandemic levels this is tremendous growth of >40%. The imports are appearing to rise faster, and the trade deficit will remain at pre-pandemic levels, if not widen further. Shipping has a share to these...

The costs of crude, container have headed northwards. Rerouting for Black Sea trade, keeping shipping rates under control and easing up the container shortage appear to be the major challenges for shipping. Risk insurance rates are also pushing upwards as the conflict seems not abating. The seafarers' woes now include the drying up of Russian/Ukrainian seafarers apart from stranding. Resolutions on few fronts have been swift and effective.

To mention a couple...

Operation Ganga brought some Indian seafarers also (medical students and many more) back home. Russian oil at reduced rates to hold the fuel costs and the inflation.

But India needs to work harder... A good policy polishing, securing of other Trade Agreements and stimulate domestic manufacturing (chips etc.), energise sector focussed Economic Zones (e.g., pharma, chemicals) are some efforts worth working on. The pandemic and the peace-disturbed East Europe have become obvious excuses, of course.

While an outside the box solution for the pandemic was to have periodic hustings (for India, seriously?), to bring Putin and peace together might need more mettle. Even then it will not see this war good.

In this issue...

We are coming around revisiting technologies. Consequent to the climate concerns, the targets have become tighter and the quest for lesser emissions and greener energy options etc., has also gained traction. Dr. Rajasekhar *et al.*, present a simple study, with a Rotor Sail, supposedly fitted on a research vessel. The Lift, Drag and the Magus Effect discussions are at comprehensible levels. The supportive CFD study shows promise of Rotor Sails becoming a reality on compact, research vessels.

With the Magnus effect, we land into an interesting discussion on Marine Autonomous Surface Ships (MASS). Dr. Veda extends the reliability discussions from earlier Parts of the series and also lines up the IMO guidelines based Class recommendations for autonomous models. The evolution of MASS systems and the probable impact on the future designs are also touched upon.

The major takeaways: COLREGS and the possible algorithms. The discussion goes under water with ROVs, their tethering and of course, the reliability studies. This Part F1 goes just deep enough and brings us back to the surface on the happenings in the MASS studies.

In the Columns, Agaram Ramanujan pushes the keyless propeller with the Part 2 discussion on shafting. Sanjiv Wazir slides in with Base Oils on Lube Matters. And Saba Purkar presents the formidable Vijaydurg fort, a Maratha maritime fort believed to have supported a minor port in 2nd Century.

After all the mortal months, March has been logging a few zero death days here and there and we hope that April notches nil-death across the nation and further. On that note here is the April issue...

Dr Rajoo Balaji
Honorary Editor
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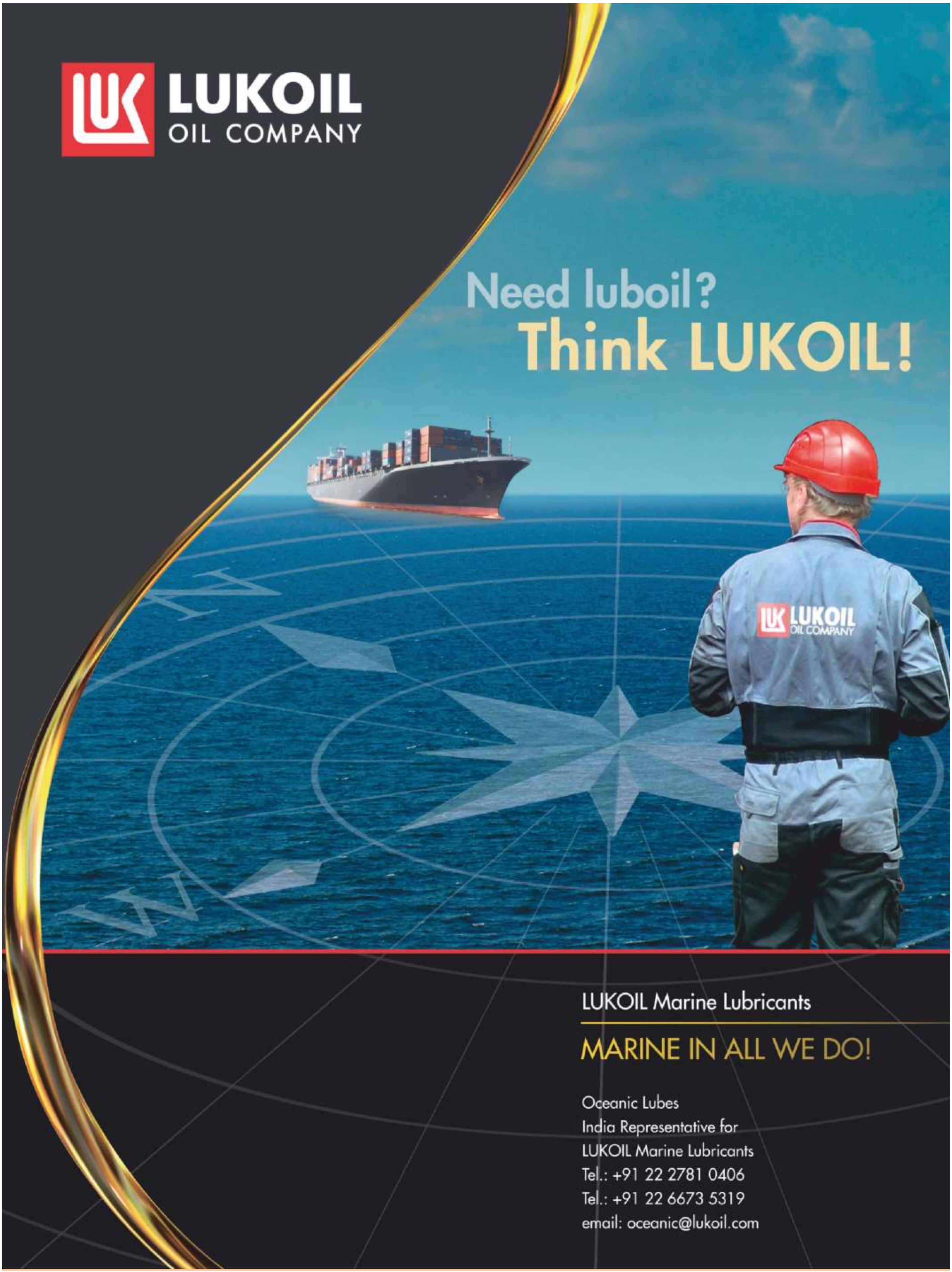
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In This Issue

ARTICLES

COLUMNS

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FEASIBILITY STUDY OF INSTALLING ROTOR SAILS ONBOARD RESEARCH SHIP

- A NOVEL APPROACH TOWARDS IMPLEMENTING GREEN SHIP TECHNOLOGY

Dr.D.Rajasekhar[1], Cdr.P.K.Srivastava[2], Aarushi Ajit[3], Vibha Dinesh Sharma[4], D. Narendrakumar[5], Ananthakrishna[6], P. S. Deepaksankar[7], Pratik Bose[8]

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Abstract: Global maritime sector is facing a gradual need of reducing the dependency on fossil fuels to comply with the prevailing international regulations for reduction of emission from ships. In order to harness the renewable sources of energy, one of the promising methods is wind-assisted propulsions where Flettner rotor sail are installed on board in order to enhance the operational efficiency. Rotor sails generates an additional lifting force by creating a pressure difference by manipulating the air, utilising the concept of magnus effect. Indian Research Ships play a vital role in supporting various scientific research and technology demonstration in national and international waters with the advantage of being exposed to abundant reserve of wind energy in ocean. The principal focus of this paper is to provide an insight about a conceptual study on installing rotor sails on board Ocean Research Vessel [ORV] Sagar Nidhi for optimisation of power management. Further, a computational fluid dynamic [CFD] flow simulations in Ansys had been done to study the pressure and velocity variations with absolute boundary conditions. The result portrays high influence of the interaction between ship course and wind speed and considerable amount of fuel savings.

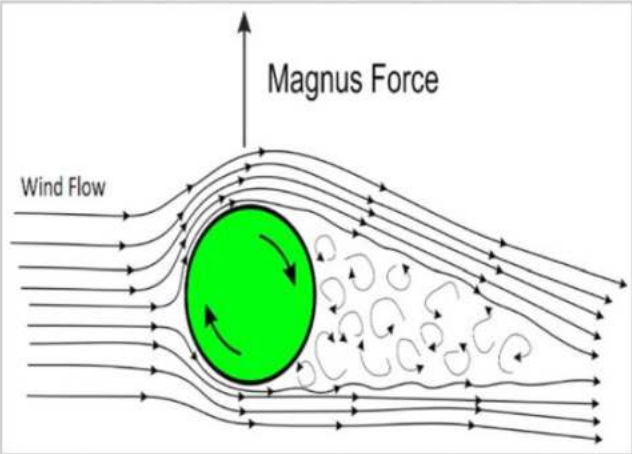
Keywords: Flettner Rotor Sails, Research Ships, Computational Fluid Dynamics, Ansys

Introduction

Maritime sector is the backbone of global trade and economy by keeping manufacturing supply chain running. But exhaust gases produced from ships are one of the key contributors to emissions. Hence, emissions from ships are of great concern. In this regard, International Maritime Organization [IMO] has implemented regulations to be followed globally in all ships so that emission from the ships can be reduced to a considerable extent. Reduction of harmful exhaust emissions can be achieved either by constraining the demand, by the optimisation of the operations, or by the implementation of new technological developments.

Marine cruising vessels are responsible for about 4 % of global emissions having impact on environment including greenhouse gas emissions such as SOx, NOx, and particulate matter (PM) emissions and large amount of CO_2, oil, acoustic pollutions endangering the marine life species. New regulations formed by IMO recently are being enforced effectively from 1st January 2020 to reduce the Sulphur limit, the fuel oil used on board ships operating outside the designated Emission Control Areas (ECA) must comply with global 0.50% m/m. Along with these regulations the high cost of the fuels is urging the maritime industry en route for the advancement of the energy efficient ships. It is becoming evident that a persistent approach is required by shipping sector to adopt renewable green technology solutions for propulsion system.

The transition from fossil fuel to eco-friendly technologies demands hybrid techniques. And wind assisted rotor sails, or '*the Blue Coal*' can be a notable contribution which has the potential to be a viable alternative by providing additional propulsion power.



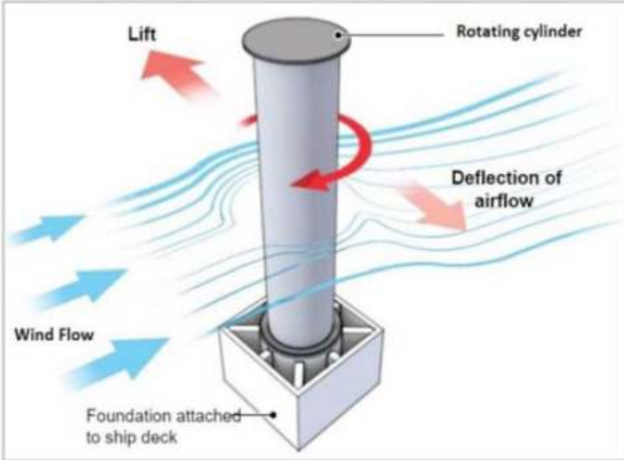


Figure. 1: Schematic of Magnus Effect on Rotor Sails

The wind energy over the ocean is in abundance and wind friction is small which makes it highly potential for the use in maritime sector. These are green energy generation systems that use renewable energy resource.

Rotor Sails

The working of Rotor sails is governed by a scientific phenomenon called the Magnus Effect. It was discovered by a German physicist Heinrich Gustav Magnus. The effect correlates with the velocity and pressure of the moving fluid [air]. When wind interacts with the rotating cylinder, it retards the air in one direction and accelerates it in the opposite direction creating a low-pressure region in one side and high-pressure region on the other half obeying the principle of Bernoulli's theorem as shown in **Figure 1**. Due to the difference in pressure, the lift and drag force is developed in the perpendicular and parallel directions of the wind flow for the moving fluid.

The lift and drag forces generated due to magnus effect are considered to be secondary forces for vessel propulsion if adequate rotor sails are installed

Rotor sail aims to harness these forces under favourable wind conditions to contribute in supplement thrust generation for the ship. It is a relatively simpler technology to extract energy from renewable sources in terms of construction and operation. This is viable method for shipping industry by harnessing wind energy and slashing down the fuel consumption simultaneously. The lift and drag forces generated due to magnus effect are considered to be secondary forces for vessel propulsion if adequate rotor sails are installed. Based on the thrust produced, the substituted propulsion power can be evaluated.

The rotor cylinders are constructed using modern materials like Carbon Fibre Reinforced Polymer [CFRP] and Glass Fibre Reinforced Polymer [GFRP] that curtail the weight by a factor of 3. Appreciated qualities of GFRP include high tensile strength, lightweight, durability and ease of moulding it in desired shapes. The other one is CFRP. It contains carbon fibres for strength and a binding polymer like Epoxy to keep the fibre together, maintaining its light weight nature. In most sails, CFRP is sandwiched between GFRP to get a light and strong structure.

Feasibility Study of installing rotor sails on board ORV Sagar Nidhi – An Innovative Approach

Ocean Research Vessel [ORV] Sagar Nidhi owned by National Institute of Ocean Technology, Ministry of Earth sciences is a state-of-the-art floating research platform and one the of the salient feature for the ocean-going ventures as shown in **Figure 2**. She can accommodate 30 scientists with an endurance of 45 days. She has a versatile ocean observing platform equipped with advanced scientific equipment and related facilities utilised for deployment & retrieval of met ocean/tsunami buoys, Deep Sea Mining, launching of Remotely Operable Vehicle [ROV], Autonomous Underwater Vehicle, manned submersibles and exploration of Gas Hydrates program. The vessel is designed with blue-water capability for voyages lasting up to 45 days to carry out Geo-scientific,

Figure. 2: Sagar Nidhi in Central Indian Ocean Basin

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The salient features of ORV Sagar Nidhi makes her a suitable ship to carry out the conceptual study and research work of retrofitting rotor sails on board. Interdisciplinary approach and related activities are being tested and validated in the ocean using this Research Vessels thus making an ideal for better weather exposure. This ship has witnessed tumultuous and turbulent weather and has ploughed through nature's harshest weather condition. The ships have huge working deck space as shown in **Figure 3**, thus smooth air flow without any hindrance can be ensured and no specific constraints on air draught. It is also pertinent to note that the deck is strengthened for carrying and installing various Scientific winches and handling equipment, thus a mounting site for Rotor can be easily found.

Analysis on Computational Fluid Dynamics of Rotor Sails

The Flettner rotor sails are subjected to magnus effect to enhance the lift force by harnessing the power of wind yields to reduce the fuel consumption, bunker cost and harmful emissions predominantly SOx and NOx. If a sensor is installed to monitor the wind in real time mode, then the starting, stopping and steering (while deploying the rotor sails) can be adjusted with the change of wind direction. It is important to understand the wind acting on the cylinder is a vector summation of the environmental wind speed and ship's speed. The Beaufort scale corresponding to the wind speed is elaborated in **Table 1**.

Figure. 3: Large working deck space on board Sagar Nidhi

If a sensor is installed to monitor the wind in real time mode, then the starting, stopping and steering (while deploying the rotor sails) can be adjusted with the change of wind direction

The objective of the present study is to provide an insight on the numerical simulation of rotor sails and seeks to explore the potential of utilising wind power. Numerical simulation of the Flettner rotor sails [rotating cylinder] installed on board ORV Sagar Nidhi was carried out on CFD code using Ansys fluent to analyse pressure and velocity variations with absolute boundary conditions for various wind speed conditions and better understanding of the effect of Reynolds number on the aerodynamic performance of flattener rotor. Reynolds number is defined as shown in equation 1.

$$Re = [V_a * d] / \nu \qquad (1)$$

Where Re = Reynolds number

Va = Apparent wind speed

d = diameter of cylinder

ν = Kinematic viscosity of air

The rotor analysed in this study is 18 m long and 3 m in diameter and considered to be made up of the carbon

Table 1: Beaufort Sea State Scale

Beaufort Sea State Scale			
Beaufort Number	**Wind Speed**	**Condition**	**Wave Height**
0	< 0.5 m/s	Calm	0 m
1	0.5 - 1.5 m/s	Light air	0 - 0.3 m
2	1.6 - 3.3 m/s	Light breeze	0.3 - 0.6 m
3	3.4 - 5.5 m/s	Gentle breeze	0.6 - 1.2 m
4	5.5 - 7.9 m/s	Moderate breeze	1 - 2 m
5	8 - 10.7 m/s	Fresh breeze	2 - 3 m
6	10.8 - 13.8 m/s	Strong breeze	3 - 4 m
7	13.9 - 17.1 m/s	High wind, moderate gale, near gale	4 - 5.5 m
8	17.2 - 20.7 m/s	Gale, fresh gale	5.5 - 7.5 m
9	20.8 - 24.4 m/s	Strong/severe gale	7 - 10 m
10	24.5 - 28.4 m/s	Storm, whole gale	9 - 12.5 m
11	28.5 - 32.6 m/s	Violent storm	11.5 - 16 m
12	≥ 32.7 m/s	Hurricane force	≥ 14 m

fibre composite material and the mechanical properties are mentioned in **Table 2**. The dimensions of the rotor sails and an aspect ratio of 1:6 is maintained based on detailed study, a thorough literature review and availability as per industrial standard.

In the Designer Window of Ansys workbench, a hollow cylinder of 18 m length and 3 m diameter with a thickness of 0.15 m has been modelled. Two enclosure bodies have been designed as shown in **Figure 4**.

The magnitude of Lift and Drag is independent of the angle 'W' (heading to wind direction) due to the cylindrical and symmetrical geometry of the rotor

- Rotating domain for assigning the conditions of Rotor and
- Static domain for assigning the surrounding environment conditions

Mesh sizing can be varied for various elements in the software. Since the study requires comprehensive results in terms of aerodynamic parameter and minute detailing, it is allotted a tetrahedral finer mesh size and the enclosure plates are allotted a coarser mesh as shown in **Figure 4** & **Figure 5** respectively.

The names are assigned to the required entities for the Set-up procedure for Inlet and Outlet velocities of the Air. In the Fluent window, cell zone conditions have been setup by assigning the Rotational velocity of the rotating domain. The Boundary conditions are set up by assigning the Inlet wind velocity of the air in the Static domain.

The calculations are done by giving the required inputs such as the Time step size, Number of time steps and the Max iterations per time step as shown in **Figure 6**.

As seen in the **Figure 7**, the rotor surface shows the static pressure developed and the plane shows velocity magnitude around the rotor. It is clearly visible that when pressure reduces, a high- velocity area is developed around it.

Table 2: Mechanical properties of a graphite-carbon fibre composite material

Bulk density (g/cm^3)	1.8 - 2.0
Young (elastic) modulus (Gpa)	13 - 16
Bending strength (Mpa)	80 - 120
Compressive strength (Mpa)	150 - 250

Thrust and Fuel Saving Calculations

A schematic representation of forces acting in the rotor is shown in **Figure 8**. Let us suppose that the wind acts at an angle 'W' with respect to the longitudinal axis of the ship. This causes generation of Drag in direction opposite to that of wind. Lift is generated in a direction perpendicular to the wind direction. The direction of Lift differs by 180^0 depending on whether the rotor is being rotated clockwise or anticlockwise.

The component of Lift and Drag forces in a direction perpendicular to the heading direction is the sideways force generated due to the Rotor

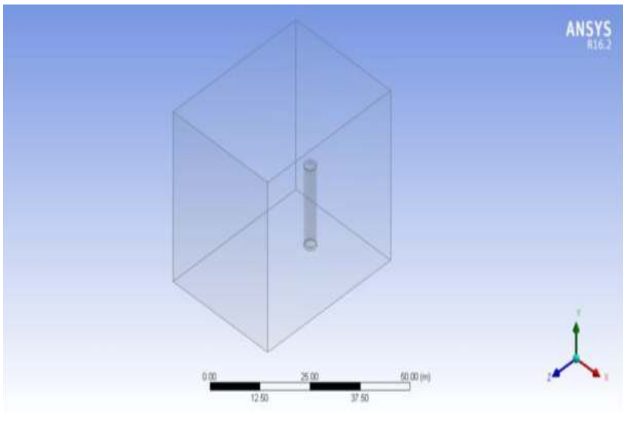

Figure. 4: Designer Window of Ansys

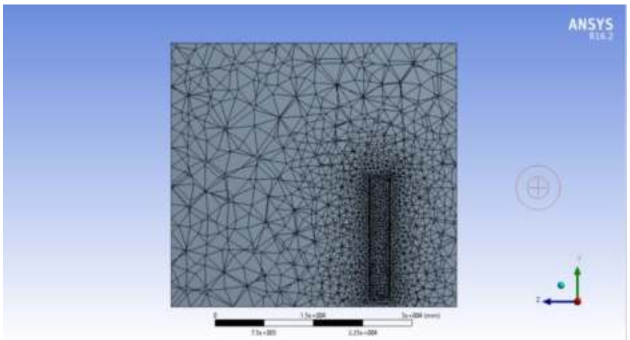

Figure. 5: Meshing of enclosure plate in Ansys

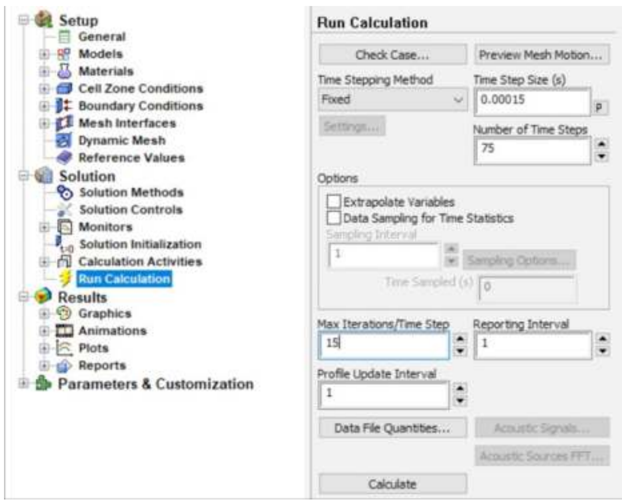

Figure. 6: Time Step iterations for analysis

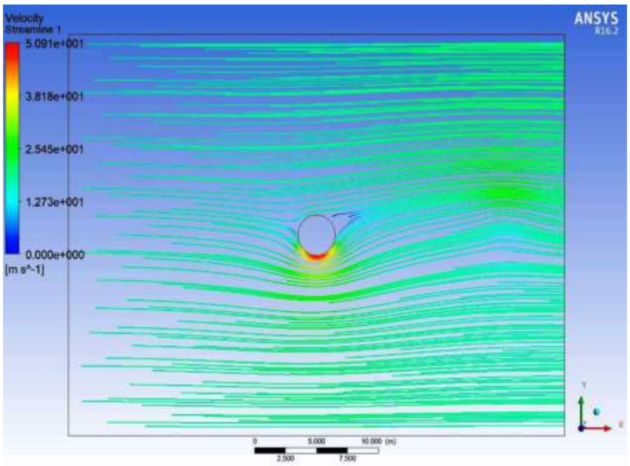
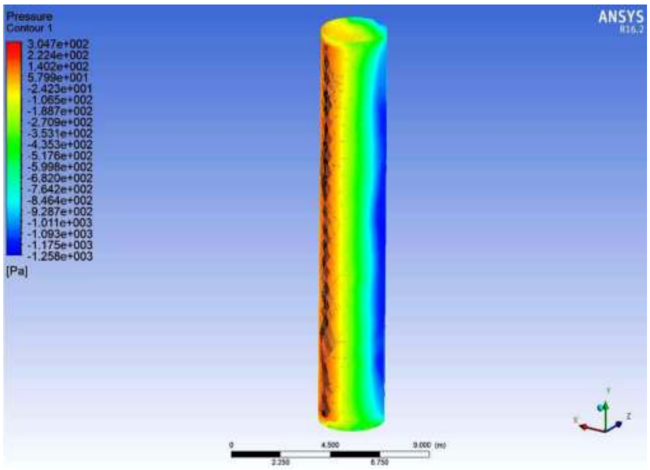

Figure. 7: Velocity and Pressure Contour of the rotor sails

Table 3: Variation of Lift and Drag forces with wind speed

Wind Speed [m/sec]	Lift [N]	Drag [N]	Upward Force [N]	Reynolds Number
1	2884.519	638.527	5.482	1047973
3	8777.811	1510.967	9.720	642568
6	17703.13	4771.4	19.192	34459
9	27289.55	7369.312	26.075	573648
12	37390.81	8455.804	27.594	1181757
15	46528.71	13680.27	27.858	1789865
18	55981.78	16489.85	41.177	2397973
21	67030.94	15989.92	44.034	3006081
24	76702.22	17632.14	40.561	3614189
27	87411.57	21519.66	48.850	4222297
30	95693.76	29010.68	20.508	4830405

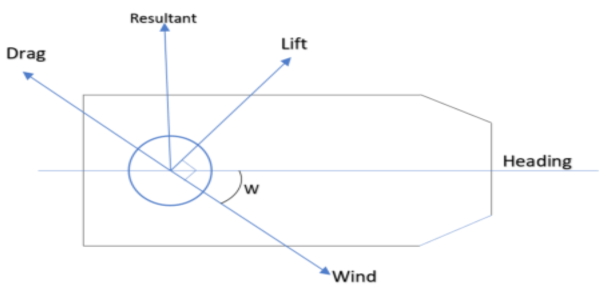

Figure. 8: Representation of forces acting on the rotor

The magnitude of Lift and Drag is independent of the angle 'W' (heading to wind direction) due to the cylindrical and symmetrical geometry of the rotor. It is only dependent on the wind speed. The simulation performed in Ansys and variation of Lift and Drag with wind speed are given in the T**able 3 and Figure 9** respectively.

The significance of angle *'W'* is highlighted when we calculate how much of this lift-drag output can provide supplemental thrust. The component of Lift and Drag forces in the heading direction of ship creates the thrust and can be termed as the 'Thrust due to Rotor'. This force will help to propel the ship forward, hence reducing propeller loads and saving fuel required. The component of Lift and Drag forces in a direction perpendicular to the heading direction is the sideways force generated due to the Rotor. The magnitude of Thrust and Drag forces when *'W'* is 90^0 and 45^0 is shown in **Table 4**.

Since we can obtain the thrust generated by the Rotor, we can predict the fuel savings. Sagar Nidhi is equipped with two Azimuth thruster of 1600 kW each and two Bow thrusters of 800 kW each. During steaming and scientific operations, ship utilises 14 tonnes of fuel per day to produce 1440 kW of Power at 90 % MCR achieving a speed of 12 knots. This technical data is used to estimate the Specific Fuel Consumption of the ship. Now if a Flettner rotor is retrofitted, some amount of required power will be fulfilled by the supplemental thrust that is been generated. Fuel saved per day, at various wind speeds and angle of attack is mentioned in **Table 5**.

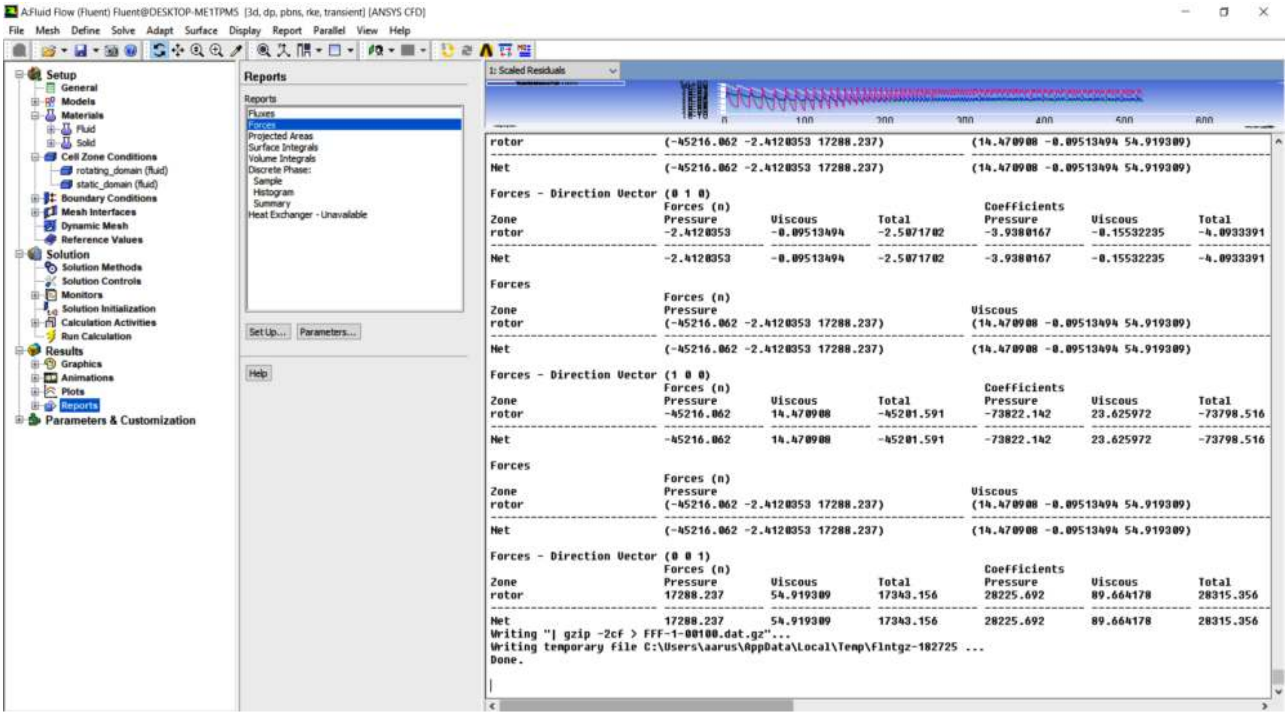

Figure. 9: Simulation performed in Ansys

Table 4: Magnitude of Thrust and Drag forces

Wind Speed (m/s)	Thrust at 90 (N)	Side force at 90 (N)	Thrust at 45 (N)	Side force at 45 (N)
1	2884.519	638.527	1588	2490
3	8777.811	1510.967	5138	7274
6	17703.13	4771.4	9144	15892
9	27289.55	7369.312	14086	24507
12	37390.81	8455.804	20460	32417
15	46528.71	13680.27	23227	42573
18	55981.78	16489.85	27925	51244
21	67030.94	15989.92	36091	58703
24	76702.22	17632.14	41769	66704
27	87411.57	21519.66	46593	77025
30	95693.76	29010.68	47152	88178

Table 5: Savings of fuel for various wind angles

Wind Speed	Fuel saved in kg per hr [for 90^0 Wind Angles]	Fuel saved in kg per hr [for 45^0 Wind Angles]
1	7.209582	3.969056
3	21.93931	12.84194
6	44.2473	22.85456
9	68.20765	35.20662
12	93.45479	51.13783
15	116.2941	58.05369
18	139.9212	69.79589
21	167.5375	90.20604
24	191.7099	104.3977
27	218.4769	116.4548
30	239.1775	117.852

From the above result tabulated, it can be inferred that significant amount fuel [approx. 3 - 30 %] can be saved with a rotor sail installed on board the vessel based on the variation of wind speed and angle of attack. It is pertinent to note that considerable amount of emissions predominantly NOx level can also be reduced simultaneously.

Conclusion

Incessant effort is in place for gradually substituting conventional fuels to mitigate the harmful emissions from ships and to comply the prevailing maritime standards set up by IMO. From the above feasibility study, benefits from using rotor sails by harnessing wind power has been demonstrated that could significantly reduce the usage of fuel. Numerical simulation aimed at gaining insight regarding the effect of aerodynamic interaction shows that retrofitting of rotor sails on board Sagar Nidhi has a significant effect on enhancing the operational efficiency by reducing the fuel consumption in turn the emission level from the ship. The output results showed the high influence between ship's speed and wind speed on the net output power of rotor sails. This analysis proves that pollutant level in the environment can be reduced considerably by encouraging and adopting innovative approach to make ships greener and cleaner for a sustainable future.

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RAMS CENTRED SYSTEM ENGINEERING AND OPERATIONS OF MODERN MULTI-MEGAWATT CAPACITY MARINE POWER SYSTEMS - PART F1

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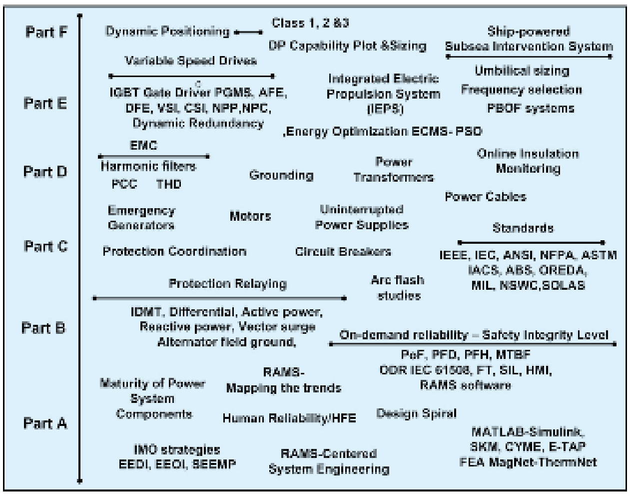
Abstract: Reliability, Availability, Maintainability, Safety (RAMS), operational efficiency and environmental performance are the key requirements for multi-megawatt marine power systems. The details presented in the previous five issues focused on safety and reliability-centred system engineering and maintenance planning of multi-megawatt marine power systems. This final part (published as two sections/ this is the first part **F1**) discusses the importance of RAMS in the strategic marine sector including marine autonomous surface ships and work-class remotely operated vehicles. The next part (**F2**) shall deal with subsea renewable power grids, subsea boosting stations and subsea power transmission systems.

Index terms: Autonomous ships, Reliability, ROV.



Strategic Marine Developments

Operations in demanding offshore/subsea environments, increased regulatory requirements, spiralling maintenance costs, higher customer expectations, enhanced Health Safety and Environment (HSE) requirements have led marine organisations to proactively manage their offshore assets and optimise their lifetime value. The objective is to identify a trade-off between the cost and the effectiveness, in terms of performance, reliability and safety, and to ensure that the risk to human, equipment and the environment are within the acceptable level.

Compared to the qualitative methods, Reliability, Availability, Maintainability and Safety (RAMS) assessment based on probabilistic methods is a robust and proven methodology that provides quantitative results that support asset owners in improving reliability and gaining visibility on the assets that are most critical for safe operations.

RAMS studies also help to identify technology gaps, plan technology qualification programs (TQP), integrating reliability and safety requirements during the design/ system engineering and operational phases to arrive at a trade-off between the system capital expenditure, operating expenditure, redundancy requirements and system modularity (**Figure 1**).

Marine Autonomous Surface Ships

Marine Autonomous Surface Ships (MASS) is gaining increasing attention due to the potential benefits of improving safety and efficiency. The European Commission under its 7th Framework Programme named Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) (2012–2015) with 8 research

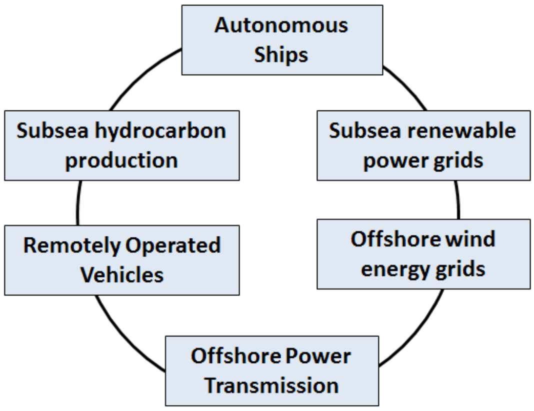


Figure.1. Strategic developments in the marine sector

Figure.2. Trends in MASS developments

and industry partners in Europe worked in developing technologies for unmanned and autonomous vessels.

During 2010-13, the EU-funded MONALISA/STM validation project involving a consortium of 7 partners demonstrated route planning, route sharing and situational awareness sharing between MASS. Situation sharing among MASS helps to classify the status of the sea objects, dynamically assess their likely future position allowing a risk-based approach to navigation, emulating a human navigator [1].

As a part of the Advanced Autonomous Waterborne Applications Initiative (AAWA) project, Rolls-Royce in

Marine Autonomous Surface Ships (MASS) is gaining increasing attention due to the potential benefits of improving safety and efficiency

cooperation with Svitzer demonstrated Sisu, the world's first remotely operated commercial vessel in 2017 and the world's first fully autonomous ferry Falco with Finferries in 2018 to develop solutions to optimise the safety and efficiency of MASS (**Figure 2**).

The Maritime Robotics in cooperation with Rakuten Institute of Technology developed a zero-emission unmanned surface vessel Rakuten for carrying out research of unmanned cargo ships. As a solution to the growing need for transport capacity, during 2014-18, the classification company DNV along with NTNU worked on the development of an unmanned, zero-emission, short sea vessel, ReVolt.

The Norwegian companies including Yara, Kongsberg Maritime, NTNU and DNV have designed an all-electric autonomous container ship. Yara Birkeland is 80m long, 15m wide with the battery capacity of 7MWh, service speed of 6 knots and max speed of 12 knots with a cargo capacity of 120 TEU [2][3].

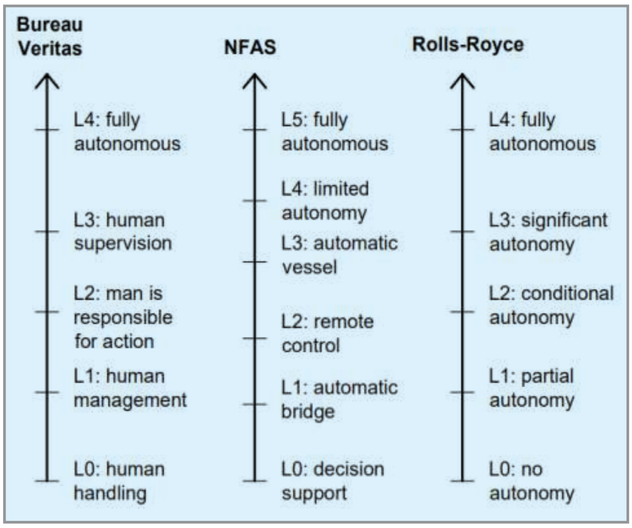


Figure.3. MASS developments strategies by various agencies [5]

Understanding the importance of MASS, the International Maritime Organization (IMO) as well as some flag states has started the scoping exercises and implementing preliminary national regulations. The IMO ensures that the regulatory framework for MASS keeps pace with rapidly evolving technological developments.

In 2018, the IMO's Maritime Safety Committee (MSC) approved the framework and methodology for the regulatory scoping exercise on MASS. In 2019, the MSC approved the interim guidelines for MASS trials with the scoping exercise including various marine regulatory agencies [4]. The scoping exercise was a starting point that touched upon a range of issues, including the human element, safety, security, liability and compensation for damage, interactions with ports, pilotage, responses to incidents and protection of the marine environment.

In 2018, the IMO's Maritime Safety Committee (MSC) approved the framework and methodology for the regulatory scoping exercise on MASS

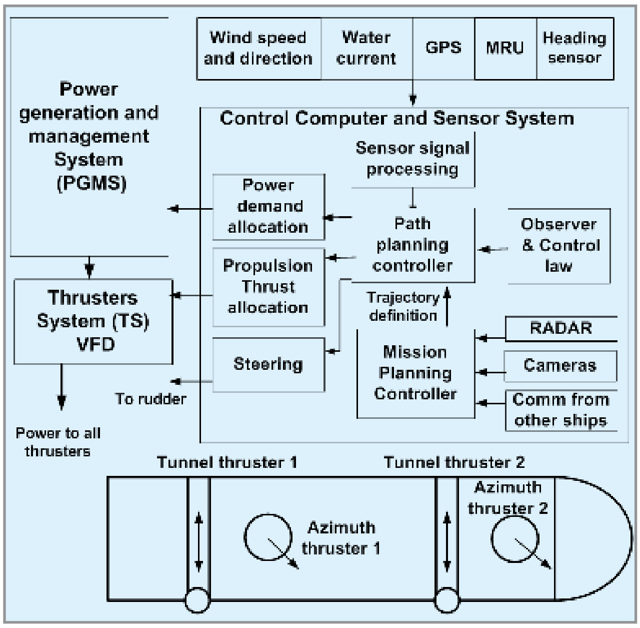


Figure.4. Architecture of MASS-GNCPP systems

Table.1. FIT data used for MASS-GNCPP reliability analysis

Component	FIT	Source of data
Power Generation and Management Section		
Diesel engine & Alternator	27530	OREDA
MV Circuit breaker	1552	IEEE 493
MV power bus	215	IEEE 493
MV bus duct	2157	IEEE 493
Power Management System	17370	OREDA
UPS	11400	IEEE 493
Propulsion Thrusters System		
MV AFE VDD with N+2 IGBT redundancy in inverter	8800	Vedachalam et al.
Thruster electric motor	12520	OREDA
Power cable	1609	IEEE 493
CCCS- Path guidance Systems		
PAC (with joysticks and interfaces)	17370	OREDA
Wind speed and direction sensor	51505	NIOT
Motion Reference Unit	11273	NIOT
Gyroscope	33333	NIOT
Water Current Log	63800	NIOT
GPS hardware	10200	Novotel
CCCS- Trajectory planning systems		
RADAR	200000	[7]
Cameras	5000	IEEE
Satellite modem	10000	NIOT

In May 2021, the MSC approved the outcome of the regulatory scoping exercise for the use of MASS and guidance to interested parties to decide future work on MASS with varying degrees of automation.

Based on the IMO guidelines, the Lloyds Register (LR), Bureau Veritas (BV), Norwegian Forum for Autonomous Ships (NFAS) and development agencies have proposed more specific definitions by presenting a system for classifying the MASS Autonomous Level (AL) taking into account the degree of each advanced function, the location where supporting function is provided, and the degree of human involvement (**Figure 3**) [5].

The architecture of the Guidance, Navigation, Control, Power generation and Propulsion (GNCPP) subsystems of a typical MASS is shown in **Figure 4**. Reliability assessment for the MASS-GNCPP system is carried out using GRIF-FTA [6]. The Failure-In-Time (FIT) data of the components/subsystems used in the FTA analysis is summarised in **Table.1**.

The architecture of the IMO-DP2 class architecture that is analysed in Part-E of the paper forms the basis of GNCPP reliability analysis. The Probability of Failure (PoF) of the Power Generation and Management System

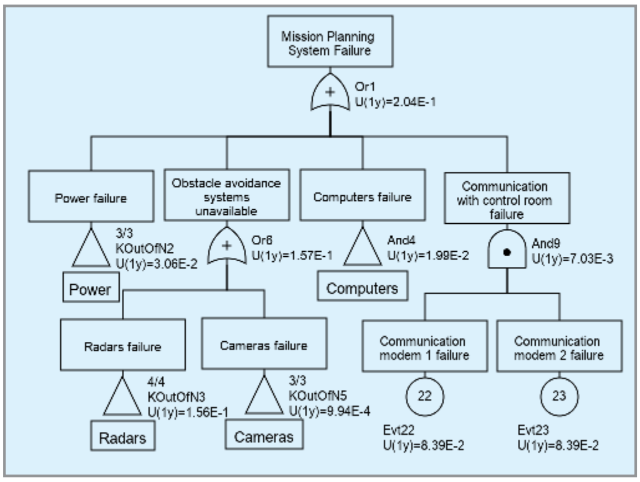


Figure.5.FTA for the mission planning system

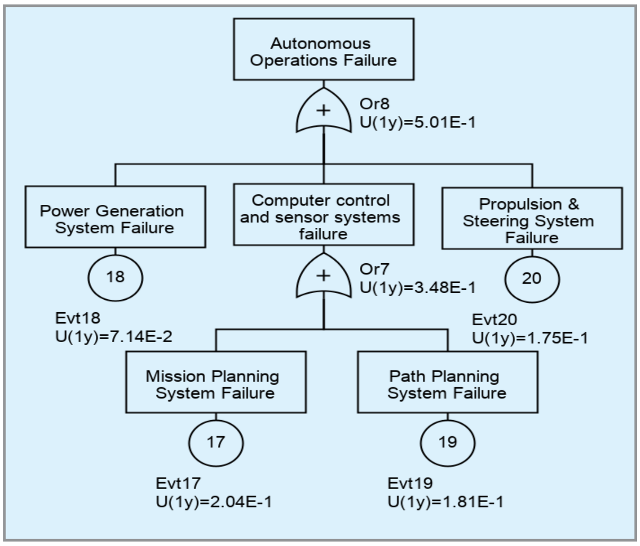


Figure.6.FTA for the autonomous operations

Table.2. COLREG rule details [8]

Rule	Risk prevention criteria
7	Risk of collision
8	Action to avoid collision
13	Overtaking
14	Head-on situation
15	Crossing
16	Actions by give-way vessel
17	Actions by stand-on vessel
19	Collision avoidance under restricted visibility

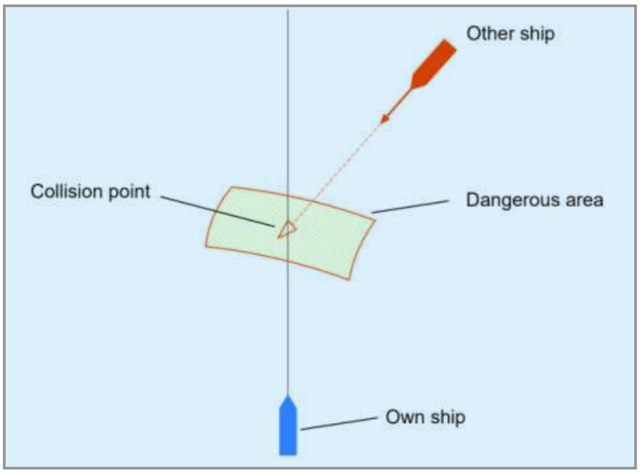


Figure.7. Identification of dangerous zone for collision avoidance

Table.3. Types of collision avoidance algorithms [9]

Methods	Algorithm
Geometric method	Distance at the closet point of approach (DCPA), Time at the closet point of approach (TCPA), Ship domain, Radar plotting, Dynamic window
Optimisation algorithm / bionic algorithm	Model predictive control, Distributed random search, Multi-objective optimisation, Particle swarm optimisation, Bacterial foraging optimization, Artificial fish swarms, Ant colony optimisation, Genetic algorithm, Genetic algorithm
Virtual vector / field theory	Velocity obstacle algorithm, Artificial potential field, Field theory, Dynamic prediction
Artificial intelligence method	Iterative observation and reasoning, Fuzzy neural networks, Game theory, Deep learning & Reinforcement learning

(PGMS), Thruster System (TS) and the Control Computer and Sensor Section (CCSS) are 71.14%, 17.55% and 18.11%, respectively.

In addition to the DP2 system, the MASS-GNCPP system features the Mission Planning System (MPS) as a part

Table.4. IMCA classification of ROV

Class	Details
I	Observation ROVs
II	Observation ROVs with Payload Option
III	Work-class Vehicles;
IV	Towed and Bottom-Crawling vehicles
V	Prototype Development Vehicles

of CCSS that includes RADAR, optical cameras, LIDAR and communication systems with the neighbouring ships. The GRIF-FTA for the CCSS_MPS is shown in **Figure 5**. The gate Or6 shows the PoF of the obstacle avoidance system comprising of triple redundant RADAR and optical cameras.

The RADAR system comprises of power supply, transmitter, antenna, receiver, signal processor, and environmental control unit [7]. The subsystems contribute to 18, 32, 3, 19, 12, and 16% of RADAR failures in a period of 1 year. Three RADARs (gate KOutofN3) and cameras (gate KoutofN5) together have a failure rate of 15.7% (Or6). With triple redundancy the PoF of the RADARs can be reduced from 60% to 15.6%.

The peer ship communication modems (And9) have a failure rate of 0.7%. The triple redundant power supply (kOutofN2) and the redundant computers/PAC (And4) have failure rates of 3% and 2 % respectively. Thus the failure rate of the CCSS_MPS in a period of 1 year is 20.4%.

The FTA for the vessel autonomous operations failure is shown in **Figure 6**. The simulation results indicate that the PoF of autonomous operations in 1 year is 50.1%, a corresponding MTBF of 1.2 years. The contribution of the PGMS, CCSS_MGS, CCSS_PGS and the propulsion system are 11, 33, 29 and 28%, respectively.

Way ahead

Even though autonomy-enabling technologies are expected to positively impact on the safety, efficiency and sustainability of vessel-based marine operations, the actualisation of the autonomous ship will pass through the interplay of several technical, social, economic and regulatory factors. The link between technology and regulations will be dominant, as computer systems replacing partly or fully the human operator should demonstrate total compliance with the existing international collision regulations (COLREG) (**Table.2**) addressing conflict detection and resolution between vessels.

Presently, radar systems offer very helpful decision support in collision-free navigation. But it is the professional navigator who interpreters the radar data and takes an ultimate decision to avoid collision. Hence, successful implementation of MASS requires reliable conflict detection and conflict resolution methods for collision avoidance with approaching ships. Artificial Intelligence (AI), data-driven methods based on Machine

Learning (ML) and data science are the key for implementing situation awareness and reliable collision avoidance algorithms (**Figure 7**).

As on date, there is no standardised or internationally agreed validation method for collision avoidance algorithm. Most of the investigated algorithms (**Table.3**) are not fully COLREG compliant, capable of handling typical encounter situation in high density traffic areas, traffic separation schemes and narrow channels.

As on date, there is no standardised or internationally agreed validation method for collision avoidance algorithm

The importance for the same is evident from a total of 4104 world-wide accident events (~ 66% were due to human erroneous actions) in which 42% of the events took place in port areas and 27 % in coastal areas. Recently, studies are reported comparing the collision risk cognition by machines and human, determining safe passage distances between vessels/obstacles, collision risk index calculation methods, risk level judgments and the evaluation of multiple AI-based automatic collision avoidance technologies [9].

Conflict resolution is the core of collision prevention that determines collision-free solutions for the ship. They include rule-based method, virtual vector method, discretization, continuous solutions with collision constraints, re-planning and hybrid methods. Risk assessment has to include no action required, obligation to avoid collision, last minute manoeuvre and last second manoeuvre.

The inertia and intrinsic knowledge of the own ship's states become progressively more important for autonomous execution of the safety-critical manoeuvers. Numerically computing the safest (collision-free) vessel trajectory on a finite moving horizon in high density traffic areas is an optimisation problem that require identification of fixed obstacles, prediction of dynamic obstacle motion with uncertainties, non-linear dynamic vehicle behaviour, steering, propulsion system, environmental forces, uncertainties associated with sensors and predictions, vessel operational constraints, planned trajectories of other vessels in the vicinity, their evasive manoeuvres and unexpected manoeuvers.

During failures in the MASS-GNCCP, as suggested by MUNIN project, the shore-based stations could extend support in ensuring safe operations at sea. The digital twin is a comprehensive mathematical model of the physical ship, including the ship-specific vessel dynamics, power, propulsion, navigation, positioning, ballast, dynamic positioning and other automation systems.

A digital twin of the vessel operating in the shore support centre could be programmed to operate in a simulated environment with real-time met-ocean conditions, its geographic location, including land masses, and other traffic so that it offers real-time support during a crisis.

The advances in sensor technology, vessel digitalisation, data analysis, autonomous path planning capabilities based on situational awareness, efficient collision avoidance algorithms and communication bandwidth to the shore are the future requirements.

The existing know-how on collision avoidance systems from the aviation and automotive industries can be adopted appropriately. Successful demonstration in harsh marine environments and congested ports are vital for complying with the stringent operational regulatory frameworks and increasing the public confidence.

Remotely Operated Vehicles

Underwater Remotely Operated Vehicles (ROV) are used in offshore industries, drilling support, seabed mineral exploration, oceanographic research and defence sectors. The classification of the ROV based on the Internal Marine Contractor Association (IMCA) R 004 Rev. 3 Code of Practice for the safe and efficient operations is shown in **Table.4**.

ROV are powered from the ship mains and controlled from the control console through the electro-optic umbilical (EOU). They have unlimited operation time, but limited spatial and intervention capability.

The deep water work-class ROV system comprises of a ship-based Launching and Recovery System (LARS) capable of deploying the ROV below the surf zone and recovering it back to the vessel in dynamic sea states, Tether Management System (TMS) with tether cable, near-neutrally buoyant ROV equipped with a syntactic foam, propulsion thrusters operating in multiple degrees of freedom (DoF),

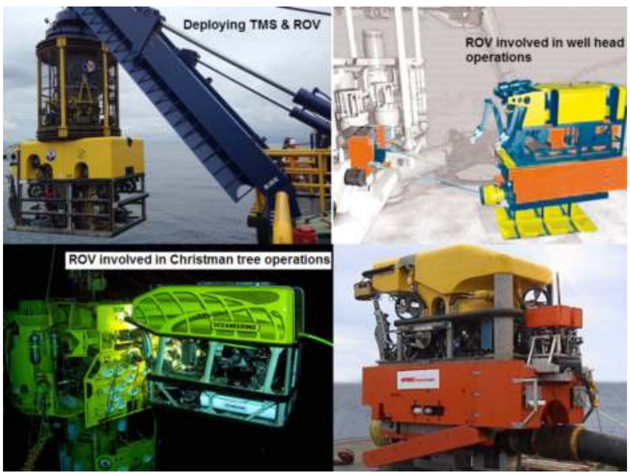


Figure.8. Work class ROVs deployed and in operation

imaging systems, acoustic positioning system (APoS), deck-based umbilical storage winch, traction winch, control console and power conversion systems.

During deployment, the work-class ROV and the TMS are docked together and launched from the deployment vessel using the LARS (**Figure 8**). The storage winch houses the long EOU and electro-optic slip ring, and its operation is synchronised with the LARS and other deck gear. The EOU is an electro-optic interface between the TMS and the ship, and is used to carry the weight of TMS and ROV during deployment and recovery.

The TMS comprises of a tether winch and the ROV docking systems that can be operated from the ship control console. The TMS weights about 2-3t in water and it protects the ROV from the umbilical hydrodynamic drag during deep-water operations. The electro-optic connectivity between the TMS and ROV is by the tether, typically 200-400-m long.

The LARS takes the ROV-TMS docked system below the splash/surf zone and undocks it. The umbilical is released and the ROV-TMS system is lowered to the location of interest. When the docked ROV-TMS system gets closer to the subsea target of interest, the pilot releases the ROV from the TMS. The ROV could be manoeuvred using the thrusters operated from the ship control console.

The cameras and the Sonar are used for visual navigation. The ROV on-board Integrated Navigation System comprising of Inertial Navigation System aided by Doppler Velocity Log and APoS is used for positioning and ROV navigation. The multi-function manipulators mounted on the ROV are used to carry out the required subsea operation. After completion of the task, ROV is docked back to the TMS in the subsea location, and the system is taken back to the ship.

The transmission voltage is a trade-off between the size of the umbilical/tether cables, voltage drop to be managed and the combined power requirements of the TMS and ROV. In case of deep-water work-class ROV, depending on the electric capacity, the ship power at 415 V at 50 Hz is converted into 3kV/6kV at 400 Hz, using a combination of standard frequency converter (usually Voltage Source Inverter) and a step-up transformer.

Subsea power converters in the TMS and ROV convert power at 6kV/3kV at 400Hz to the power level requirements of the subsystems (typically 24VDC). During operations, the voltage in ROV and TMS are maintained constant by an automatic voltage management system implemented in the ship side VSI. A frequency of 400 Hz is used to reduce the size and weight of the magnetic components in the ROV and TMS.

Figure 9 depicts the weight variation of power electronics-fed transformer weight with operating frequency. **Figure 10** compares the weight of a conventional 50Hz and 460Hz power electronics-fed transformers [10] [11].

The electronic controllers with input-output modules are used for interfacing with the field devices in TMS and ROV. Data formats are managed by using multiplexers and media converters. The ROV and TMS systems communicate with the ship system using the fibre-optic Ethernet link through the slip rings located in TMS and deck storage winches. The manipulators can be operated from the control console, and the control is interfaced to the ROV and shipside controllers [12].

Reliability assessment for the major ROV and TMS functions are carried out using GRIF-FTA software and the results are summarised in **Table.5**. The FTA for two critical functions including ROV-TMS docking failure and manipulator operations failure are described.

After completing the underwater activity, the ROV pilot carries out the ROV-TMS subsea docking process with the aid of camera and lights located in the TMS. The docking sequence includes piloting the ROV close to the TMS location; level-wind the already released tether back in the TMS winch, free from twist, by operating the winch in TMS; pilot the ROV vertically down the TMS and operate the top thrusters to produce a downward thrust (normally the ROV is upward buoyant by 20 kg) in such a way that the tether cable is held under minimum tension during winding; with the minimum tension in the cable, operate the TMS winch and wind the tether cable in a way that the cable is wound without any slack; continue winding until ROV enters the TMS cone and gets into the latches (which will be indicated by the limit switches inside the latches).

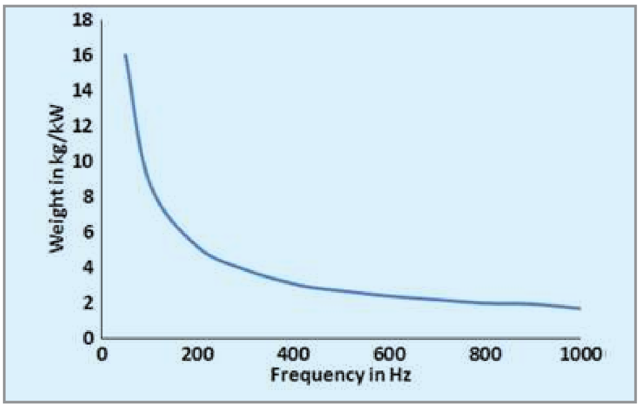


Figure.9. Transformer weight variation with operating frequency for power electronics-fed design [10]

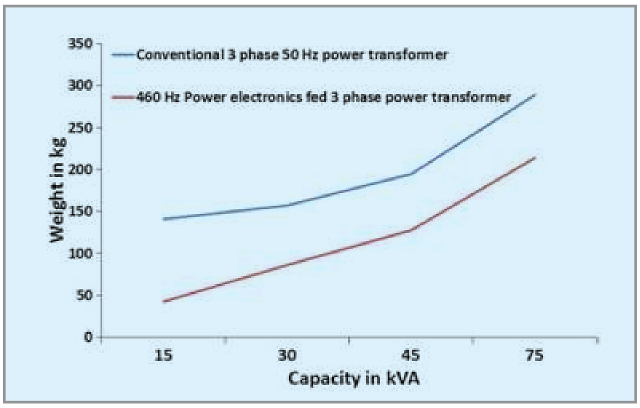


Figure.10. Transformer weight variation for conventional 50 Hz and power electronics-fed 460-Hz design [10]

Table.5. Standards from which failure rates are computed

Component	Standards
CPU,AC-DC Converters, DC-DC converters, Fuses, Electronics and Optical connectors, Ethernet Converters, Data and video multiplexers, Input and Output modules for Data acquisition cards	FIDES
MF Converters and Transformers, Isolators, Motors, Power Contactors, Cameras Lamps	IEEE
Umbilical, Tether, Terminations	OREDA

Table.6. PoF/MTBF for the critical ROV functions

Functional failure	PoF	MTBF
ROV Camera not operational	83.51 %	2.8 years
ROV light not operational	83.40 %	2.8 years
Visual survey failure	98.86 %	1.1 years
SONAR bathymetric survey failure	97.87 %	1.2 years
ROV-TMS subsea docking failure	92.48 %	1.9 years
ROV Manipulator operation failure	90.27 %	2.1 years

Failure to dock could be due to functional failure in the ROV systems, TMS docking vision, TMS tether winch, twist in the tether cable and human errors. In such a failure scenario, ROV has to be salvaged after bringing it to the water surface. This is done by winding the deck EOU until the TMS surfaces and docked with the LARS. As the ROV is linked with the tether cable, and as it is positively buoyant, it tends to surface.

This surfacing is detrimental for the ROV and the released tether cable, as there are increased chances of entanglement with the ship systems such as thrusters. This is an unsafe situation for equipment and human [13].

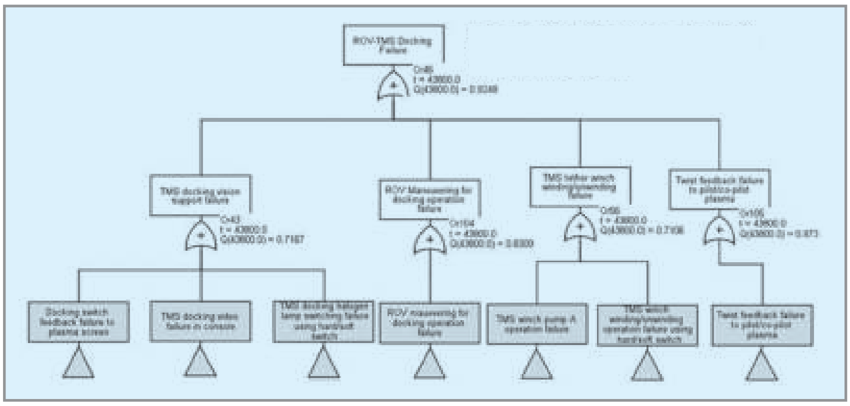


Figure.11. FTA for ROV-TMS docking failure

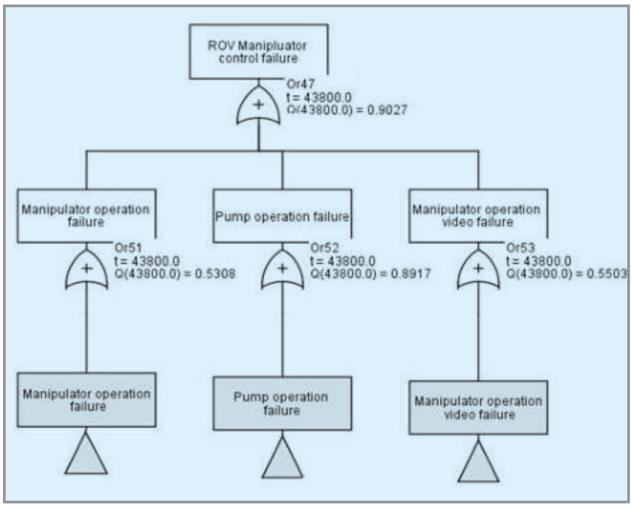


Figure.12. FTA for ROV manipulator operations failure

Manipulators on-board the ROV are operated by the personnel from the ship control console using joysticks. The manipulator arms are equipped with cameras which will give a real-time video feedback to the operating personnel. Subsea operations depend on the mission objective and may involve tasks such as electric wet-mate connector mate/ de-mate, pipe line valve operations, pipe line sacrificial anode fixing etc.

Thus, the risk involved in these subsea operations varies widely. **Figure 11** shows the ROV holding one end of the wet mate cable connector for mating with the fixed ROV panel. The other end of the cable could be a part of the permanent subsea installation. When the manipulator operation fails in this condition, the forced retrieval of the ROV by winding back the tether or main umbilical winch, could damage the subsea installation.

Thus, the ROV will be anchored to the subsea installation, with other systems connected to the ROV deployment vessel. Similar could be the condition, if the ROV is holding the oil pipe line valve which leads to damages and oil leakages.

The manipulator operations failure could be due to manipulator functional failure, ROV hydraulic system failure, manipulator camera vision failure and operator errors. Therefore, the failure of the manipulator system while in operation is a potentially unsafe scenario which needs to be managed using double barrier for all break-out in production and hydraulic path to facilitate safe intervention.

The FIT of the components/ subsystems used in the simulations are summarised in **Table.5**. The FTA showing the ROV-TMS docking failure (**Figure.11**) and the manipulator system functional failure (**Figure.12**) indicate MTBF of 1.9 and 2.1 years, respectively. The results serve as a basis of maintenance planning and

subsystem redundancy requirements during critical deep water work-class ROV operations.

Conclusion

RAMS studies based on field-failure data shall be of immense help in identifying a trade-off between the capital investments, operating expenditure, redundancy requirements, system modularity and maintainability, as well as meet the stringent regulatory requirements.

By probabilistic reliability modelling and simulations using field-failure data, it is identified that, with the present technological maturity, the vessel Guidance, Navigation, Control, Power generation and Propulsion systems involved in vessel autonomous operations could have a mean time to fail period of 1.2 years.

In order to comply with the stringent operational regulatory frameworks and increasing the public confidence, successful demonstration of autonomous operations in harsh marine environments and congested ports are essential. This require accelerated efforts in the development of standardised and robust machine learning aided conflict resolution methods, collision avoidance algorithms, effective modes of situational awareness sharing with nearby vessels and emergency support systems from the shore during system failures.

The RAMS results presented for the deep water work-class remotely operated vehicles could help in reliability-centred design, maintenance planning and integrity management based on the operational safety requirements. The final section (F2) shall discuss the developments in subsea boosting systems, renewable power grids and offshore power transmission from RAMS perspectives.

ACKNOWLEDGEMENTS

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LUBE MATTERS # 10
BASE OILS

Sanjiv Wazir

Introduction

Until the mid-19th century animal fats, vegetable oils, natural graphite, crude seepage from the ground – whatever happened to be locally available, were being used as lubricants. With the advent of modern machinery and industry, the properties of such lubes fell short of the requirements. Nowadays, the variety of lubricants available is humungous. Almost all the lubricants that we use today comprise of base oils and additives. Base oils may constitute 70-100% of a lubricant, the balance being additives. Both contribute to the desired properties required from the lubricant.

There are four main types of base oils: mineral, synthetic, plant based, and re-refined. Mineral base oils are made from petroleum crude oil. Synthetic oils are man-made fluids and can be designed to withstand extreme conditions. Modified plant-based oils are in use as bio-lubes. Some lubricants may contain a mixture of different base oils.

Mineral base oils

Over 95% of base oils used are mineral oil based. Mineral base oils are produced from the refining of crude oil. From the perspective of lubricant applications, the most important properties, besides viscosity, that directly relate to the base oil composition are viscosity index (VI), oxidative & thermal stability, cloud point/pour point, and additive solubility. The hydrocarbon composition of base oils is related to the crude oil source & the manufacturing processes used.

Crude oils contain thousands of molecular species comprising mainly paraffins; naphthenes; aromatics; asphaltenes; that differ in chemical structure, properties, and size (**Figure 1**).

Base oil manufacturing is a complex process that fractionates molecules based on molecular weight (size) and composition to yield a product with appropriate viscosity and chemistry. To remove or reform unwanted hydrocarbons and other impurities, the crude oil (or a stream of vacuum gas oil (VGO) from the crude refinery may be subjected to (i) Distillation; (ii) Deasphalting to remove very heavy fractions of the crude; (iii) Solvent Extraction or hydrogen refining to remove undesirable

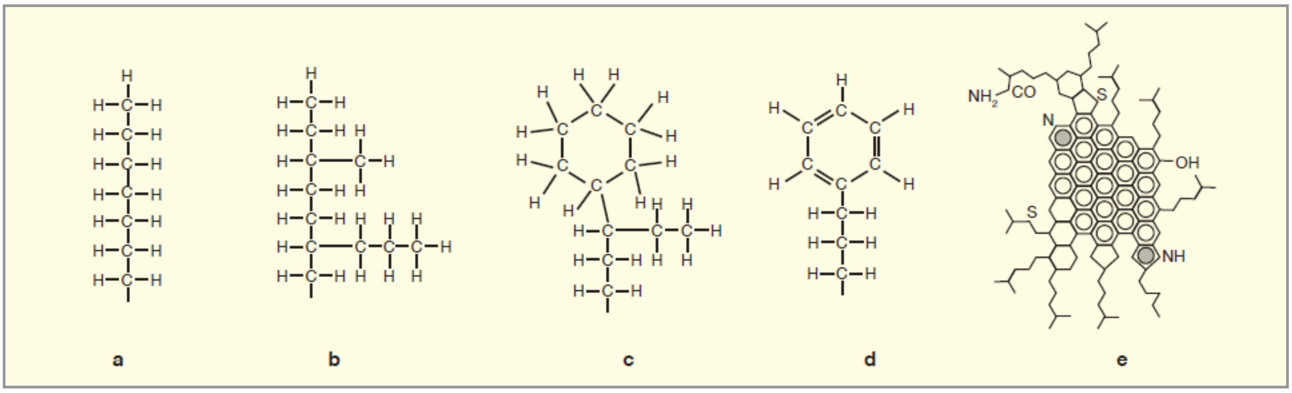

Figure.1: Schematic picture of (a & b) Paraffins, (c) Naphthenes (d) Aromatics and (e) Asphaltenes [1].

aromatic and asphaltene compounds; (iv) solvent or catalytic dewaxing to remove linear paraffins (wax) which can crystallise, causing poor flow properties at low temperatures; and (v) hydrofinishing/hydrocracking to remove trace quantities of asphaltenes, olefins, other molecules that could cause stability issues **[2] (Figure 2).**

Base oil Classification

Base oils are classified as per API 1509 appendix E into five groups based on the viscosity index, sulphur content and saturates content. Group I, II, and III are mineral base oils. Group IV is for the most widely used type of synthetics, Poly Alpha Olefins (PAO), and Group V includes all other base oils not included in Group I-IV (**Figure 3**).

Group I base oils are the oldest type of base oils around. Solvent-refining is used to remove the weaker chemical structures in the hydrocarbons (ring structures and unsaturated bonds) from the VGO. They range in colour from amber to golden brown due to the remaining sulphur, nitrogen, and ring containing hydrocarbons in the fluid. They are very commonly used in industrial and marine lubricants.

Group II base oils are made by using a hydrotreating process (instead of solvent extraction). Hydrogen gas is used to remove/reform the undesirable components from the VGO stream. This leaves a clear and colourless fluid with very little sulphur, nitrogen, and ring structures. Modern automotive engine oils are commonly formulated with Group II base oils.

Group III base oils are made by using a more intense hydro-cracking process (reacted with hydrogen at higher pressures and temperatures) to eliminate the undesirable components almost completely. The resulting fluids are clear, colourless & more resistant to oxidation. Usage of Group III base oils is growing with the requirement for fuel efficient lubricants, as automobile industry's demand for lower and lower viscosity multi-grade engine oils (0W-20, 0W-16, 0W-12, etc) increases.

Group IV base oils are polyalphaolefins (PAO). These are made from small alkene molecules. A wide range of PAOs can be made by synthesising mixtures of different alkenes. Hence, they can be tailored to have a structure with predictable and desired properties. PAOs have a wider operating temperature range and are useful in applications exposed to extreme operating conditions. Synthetic rotary/screw compressor oils, synthetic gear oils are often based on PAOs.

Group V contains all other base oils that are not included in Groups I, II, III, IV. Including:

Naphthenic: mineral refrigeration compressor oils (for R12/R22/R717), base oil for greases, etc.

Base Oil Property	Paraffins	Naphthenes	Aromatics
Viscosity Index	Excellent	Poor-Good	Poor
Low Temperature Fluidity[a]	Poor	Good	Good
Low Temperature Fluidity[b]	Excellent	Good	Good
Pour Point	Poor[a]/Good[b]	Good	Excellent
Oxidation/Thermal Stability	Excellent	Poor-Good	Poor
Solvent for Additives	Poor	Good	Excellent
[a]Unadditised [b]Treated with a Pour Point depressant			

Figure. 2: Performance characteristics of base oil components [2]

API Group	% Saturates	% Aromatics	% Sulphur	Viscosity Index	Viscosity Range, cSt
Group I	<90	>10	> 0.03	<120	10-1500
Group II	>90%	<10	< 0.03	80-120	22-100
Group III	>90%	<10	< 0.03	>120	22-68
Group IV	Polyalphaolefins (PAO's)				5-1000+
Group V	All other base oils that are not included in Gr I-IV (naphthenic, esters, polyglycols, etc.)				5-1000+

Figure. 3: API Base Oil Groups

Property	Unit	SN 150	SN 300	SN 500	SN 600	BS 150
Density	g/ml	0.86	0.89	0.9	0.9	0.91
K. Viscosity @ 100°C	cSt	5-5.5	7-8.5	10-11	11.5-12	28-35
K. Viscosity @ 40°C	cSt	30-35	60-65	95-100	125-130	520-530
Viscosity Index		>95	>95	>95	>95	>95
Flash Point	°C	>200	>225	>230	>260	>280
Sulphur content	%w	<1.0	<1.0	<1.0	<1.0	<1.0

Figure. 4: Typical properties of base oils used in marine applications. [5]

Synthetic esters: synthetic reciprocating air compressor oils, gear oils, EALs, etc.

Polyalkylene glycols (PAGs): synthetic high-temperature hydraulic fluids, gas compressor oils, etc.

Alkylbenzenes: synthetic refrigeration compressor oils (for R22, R502, R401A/B, R402A/B), etc.

Polyol esters (POE): synthetic refrigeration compressor oils (for R134a, R404a, R410c), etc.

Phosphate esters: synthetic fire-resistant fluids

Modified vegetable oils: Natural esters derived from vegetable oils are used in bio-lubes etc. **[3]**

Re-refined base oils: The reclamation of base oils from used engine oils and industrial lubricants has become an important process from an environmental and economic perspective. In some countries, legislations are to be taken into consideration for increased use of re-refined base oils in finished lubricants.

Base oils used for marine applications [4]

Most marine engine oils are formulated from high quality, solvent-refined, de-waxed, high viscosity index, paraffinic, Group I, base oils. Commonly known as SN oils (solvent neutral) they are manufactured by direct distillation of highly paraffinic crude oils or by solvent extraction of the VGO residue obtained from this type of crude (**Figure 4**).

LUKOIL and some other manufacturers use the higher viscosity SN800/SN850 base oil to make marine cylinder oils while other manufacturers use a mix of a lower SN base oil with a type of high viscosity base oil known as Bright Stock (BS) in the formulation of their cylinder oils.

Base oil market is changing

Over 95% of base oils are still derived from crude oil. Most are paraffinic and used to be solvent neutral oils derived from paraffinic crudes. About 15% of the world's base oils are naphthenic, made from naphthenic crudes.

The refinery industry has been restructuring for many years. In 2010, Group I represented > 55% of world base oil production capacity. By 2020 this had dropped to < 40%.

Solvent extraction units are more costly to run, have limited choice of crude feedstocks, lower yields, and lower value by-products. Traditional Group I plants manufacturing solvent neutrals have higher operating costs compared to modern hydro treatment methods employed in the manufacturing of Group II and III base oils.

The automotive industry consumes more than 50% of all lubricants. The base oil industry is evolving in response to the stricter performance demands from the automotive sector for higher specifications. To achieve better fuel economy, there is also a trend away from high viscosity to lower viscosity base oils. As a result, modern automotive lubes require hardly any Group 1 base oils. **[6]**

Hence older and smaller Group I plants are gradually being shuttered, while new capacity additions are usually for Group II and III base oils.

Conclusion

While the additive package used in the finished lubricant is very important, the first step to formulating a premium lubricant begins with selecting the right base oil for the application.

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TECHNICAL NOTES

STRESSES IN KEYLESS PROPELLER AND SHAFT ASSEMBLY PART 2

Agaram Ramanujan

HISTORICAL BACKGROUND

With the advent of super-tankers and bulk-carriers in the sixties of the last century, sizes of ships increased with proportional increase of required power and speed. Cargo ships which were cruising at 10 knots speed were increased to about 15 knots with increase in size and so also increase in shaft and propeller scantlings.

The use of higher scantlings involved more mass for the shafts and the propellers. During the early stages of their operation many propeller shafts developed surface cracks at the shaft taper and these were confirmed to be caused by fatigue and the cause for this fatigue is claimed to be the shaft key way which is an abrupt change in the shape at that section causing a break or discontinuity in the stress lines passing through the key. This leads to converging of the stress lines at the section and these lead to formation of surface cracks around the keyway.

This drawback is further enhanced by the noticeable and effective bending moments caused by the mass of the propeller attached at the end of the shaft. This aspect was not considered seriously in earlier designs because most of the cargo ships' propellers at that time did not weigh more than about 10 tons.

This problem came to light only when powers started increasing. Larger powers require larger diameter propellers for operating at the designed shaft speed. Proportionately the mass also increases considerably. A bulk-carrier or tanker of 80000 DWT will have a propeller weighing 35 Tons. Such a large mass contributes a sizeable bending moment on the shaft because of the overhang of the propeller from the stern boss on the stern frame.

This bending moment contributes to the torque causing an increase in the stress level at the surface of the taper. It is understood as follows.

The shaft torque formula is given by

$$T/J = f_t / R, \text{ Where}$$

T is the torque transmitted and resisted

J is the polar second moment of area of cross section of shaft.

f_t is the maximum stress (torsional) at the shaft surface.

R is the radius of the shaft.

This formula is true for only a torque to be transmitted, however when it is coupled with a sizeable bending moment the formula gets modified to:

$$\sqrt{(T^2 + BM^2)} / J = f_t / R$$

It will be observed that this f_t is larger than the previous f_t and is called the principal stress which is proportional to $\sqrt{(T^2 + BM^2)}$ and is represented by the vector diagram as shown in **Figure 1**, where F_T is the principal stress.

The bending moment causes the upper surface to strain in the tensile mode and the same surface when it comes down after half a revolution strain in the compressive mode. The Principal stress changes direction every half revolution or the alternating frequency is twice the RPM leading to fatigue condition at the area around the bigger end of the taper. This is true for large ships having heavy propellers. It may be concluded as follows:

Fatigue effects are predominant around the keyway because of sudden change of shape or surface, and around or throughout the circumference around the larger end of the taper because of change in direction of the principal stress occurring at a high frequency.

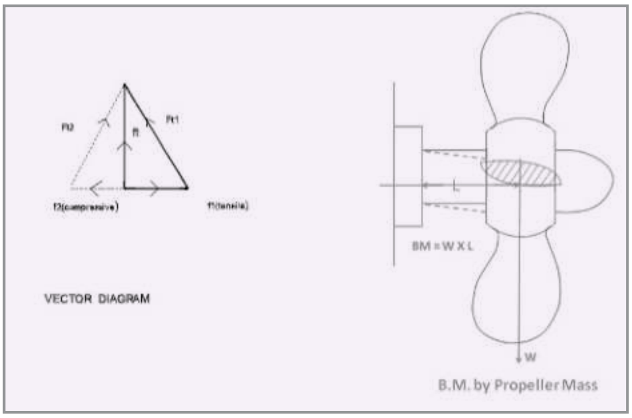

Figure 1

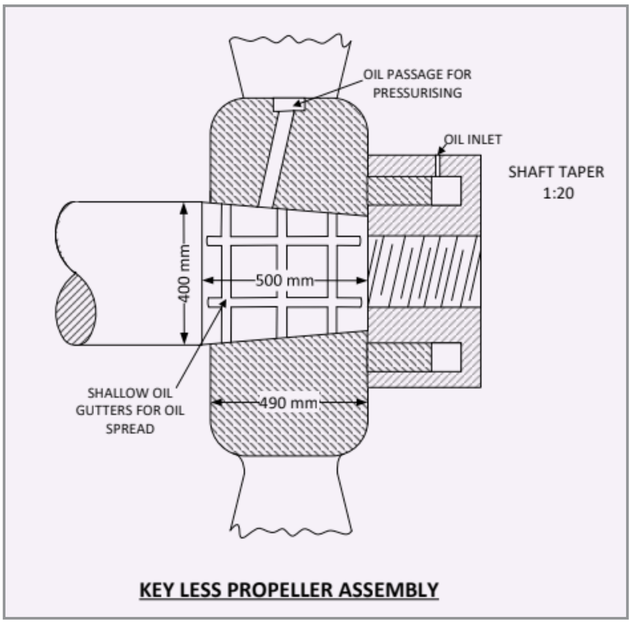

Figure 2

As a result of these considerations, the classification societies recommended that for keyless assemblies, the shaft taper should be reduced to 1:18 or 1:20, and the coefficient of slip friction be increased by fitting a cast iron taper bush between the shaft and the propeller taper. Cast iron has a good coefficient of friction and more than steel. The bush was attached firmly by a strong araldite resin. When this proved a failure, the bush was shrunk fit. This also proved a failure because of the non-uniform grain structure of the cast iron matrix. When both these failed, the classification societies recommended direct shrink fit with the above stated taper ratios and this system is presently followed for larger shaft assemblies. The reduction in taper ratio increases the radial reaction needed for a good grip to compensate the removal of the key and keyways.

MODEL SHAFT AND PROPELLER CONSIDERED

The shaft has a taper of 1:20 as per class rules. The taper ratio defines the taper angle and is the Tangent of the taper angle. The material of the shaft is medium carbon forged steel having a carbon content of 0.6 %, manganese 1.5 %, sulphur 0.4 % (max), phosphorous 0.4 % (max), silicon 0.45% (max). The residual alloying elements are copper 0.3 % (max),chromium 0.3 % (max), molybdenum 0.15% (max), and nickel 0.4 % (max).

The diameter of the shaft is 400 mm. The taper length at the propeller assembly end has a length of 500mm. The shaft end has a threaded end with a mean diameter of 200mm and provided with standard acme threads having a trapezoidal section. The trapezoidal section aids in providing shear strength to the threads, which is necessary to resist the high hydraulic force which occurs during the assembly of the propeller on the shaft. The propeller boss has an outer diameter of 800 mm and a width of 490 mm.

The taper on the shaft has shallow gutters on the surface for the spread of the pressure oil when swelling the boss. The gutter sides are properly filleted to prevent any sharp edges. The depth of the gutters are not more than 0.30 mm.

The propeller taper bore is bored 0.125 mm less than the shaft taper to provide the shrink allowance.

The shaft delivers 10000KW at its service speed corresponding to 110 RPM. At MCR of 11000KW, the corresponding RPM is 120. The maximum and normal service torques are 875 and 869 KNM respectively.

INITIAL ASSEMBLY PROCEDURE

- The propeller is mounted on the shaft taper. Using the Pilgrim nut, the propeller is forced in with manual effort using a suitable claw spanner impacted by a sledge hammer till it is sufficiently tight. The pilgrim nut is then pressurised with a moderate pressure of 100kg/cm^2 -200kg/cm^2 till the propeller moves forward to a position. A dial gauge is fitted between the aft flange face of the seal box and the forward face of the propeller to note the displacement of the propeller in stages.
- The position corresponds with the propeller boss taper midsection at a distance 1.25 mm aft of the shaft taper midsection and stopped. At this position, the propeller boss forward face is 6.25 mm from the forward end of the shaft taper.
- At this position, the propeller boss is pressurised by oil by starting its pump and simultaneously the propeller moved forward by pilgrim nut with increased pressure up to 500kg/cm^2, till the propeller boss forward face is 5mm aft of the forward end of the shaft taper.
- The extreme positions of the boss faces are marked on the shaft taper for future reference and the forward boss face is marked by a vertical line (etched on the face). This mark corresponds to number 1 engine unit (from forward) crank at TDC.
- This position is used for all future dismantling and assembly operations so that the mating surfaces do not change position and ensures optimum contact area.

- For future dismantling operations especially for survey purposes, the boss is pressurised by oil gradually to 1000kg/cm^2,and the boss pushed out using the pilgrim nut fitted in dismantling mode and the strong back rigged up as shown in **Figure 3**. The propeller easily jumps off the taper and can then be lowered. While dismantling the shaft is placed with number 1 engine unit crank at TDC.
- For future assemblies after completion of the survey, the procedure described under initial assembly is to be followed.

SHRINK FIT CALCULATIONS

(1) The mean diameter of the shaft taper is 374mm

The mean diameter of the propeller boss taper is 373.875mm.

Hence the shrinkage allowance is 0.125 mm.

The swelling oil pressure in the boss is 1000kg/cm^2= 98.1N/mm^2

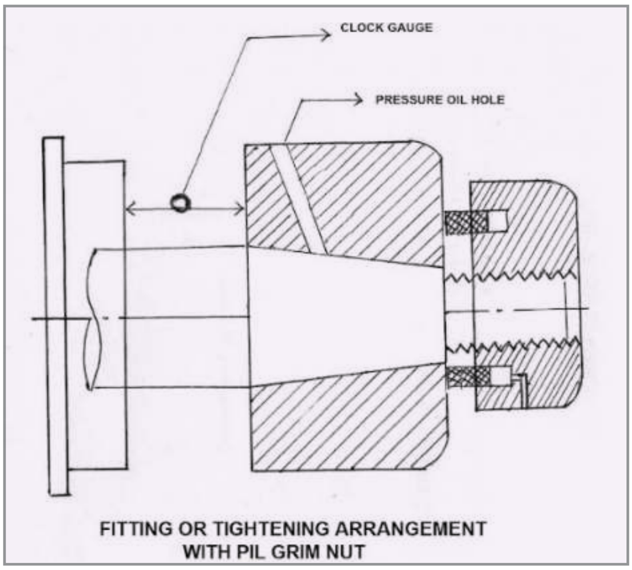

Figure 3

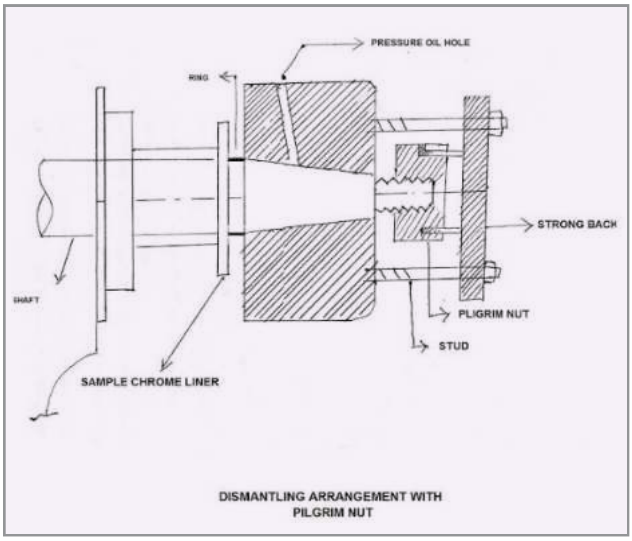

Figure 4

Let D_1 be the swelled mean diameter of the bore

Using the relationship between bulk stain and bulk stress, this swelled diameter D_1 is calculated.

$(D_1^2—373.875^2)/ 373.875^2 * 119000 = 98.1$ (1)

where 119000N/ mm^2 is the bulk modulus for bronze.

Which gives $D_1 = 374.02$ mm

(2) The oil pressure also compresses the steel taper portion of shaft.

Let D_2 be the shrunk mean diameter of the shaft taper.

Then, $(374^2 – D_2^2)/ 374^2 *165000 =98.1$ (2)

Where 165000N/mm^2 is the bulk modulus for steel.

Which gives $D_2 = 373.88$ mm

(3) When both oil pressure pumps are stopped, the swell in the propeller boss and the shrink in the shaft taper are stabilised and their mutual resultant radial stresses equalised.

Let D be the new interface mean diameter between boss and shaft taper. Since their mutual reactions are equal their relationship is given by

$(374.02^{2}\text{--}D^2)/(D^2—373.88^2)= 165000/119000$

which gives D = 373.94 mm

(4) The locked in radial stress in the boss is given by

$(374.02^2\text{---}373.94^2)/ 373.94^2 *119000$ which results in

The locked in tensile radial stress = 51 N/mm^2 (3)

The locked in compressive radial stress on the shaft taper is 51 N/mm^2

(5) To determine the maximum hoop stress in the boss taper the theorems of Lame are used.

The radial stress and the hoop stress are given by the following two equations

For radial stress at any radial distance from centre

$F = A/r^2 \text{ -- } B$ (1)

Where F is the radial stress at the radial location and A and B are constants defined by the end conditions

At the boss periphery, the radial stress is zero if we consider the sea water pressure to be negligible compared to the high radial stress at the boss taper. Then we have

$51 = A/ 374^2—B$ (a)

$0 = A/800^2—B$ (b)

Solving the equations a and b we get

A=9307838, and B = 14

Hence hoop stress at the boss taper which is tensile is given by 51 + 14 = 65N/mm^2

The maximum compressive radial and hoop stresses at the taper in the shaft are same.

They are considered as reactions.

The total radial reaction is given by:

Radial stress* area of internal surface of propeller taper

= 51* ∏*374*490 /1000 =29366 KN

The slip torque against frictional torque is:

29366*0.25* 0.184 = **1351 KNM**

Where 0.25 is assumed coefficient of friction reduced from 0.3 due to the oily surface between the shaft and propeller caused by the oil locked inside, and 0.184 M is the mean radius of the shaft taper.

The maximum torque or overload torque is 875 KNM.

The slip torque is 1351/875 = 1.54 or 50 percent greater than the overload torque, which is sufficient to prevent slip between propeller and shaft.

Torsional stress in shaft

Considering the mass of the propeller as 25 tons and the overhang of its length from the aft stern bearing in the stern tube to be 1meter, the BM = 25 TM=245 KNM

The vector sum of the torque and BM is the square root of

$875^2 + 245^2$ = 908.6 KNM

Using the above combined torque value in the shaft formula The maximum torsional stress is given by

$908.6*10^6$ * 400/{(∏*400^4)/16}= 72.3 N/mm.

The torsional stress in shaft at service speed is 71.7 N/mm²

CONCLUDING REMARKS

Although both systems are approved by class the keyed system is followed by moderate and smaller sized vessels, whilst the larger vessels prefer the keyless system for the following reasons:

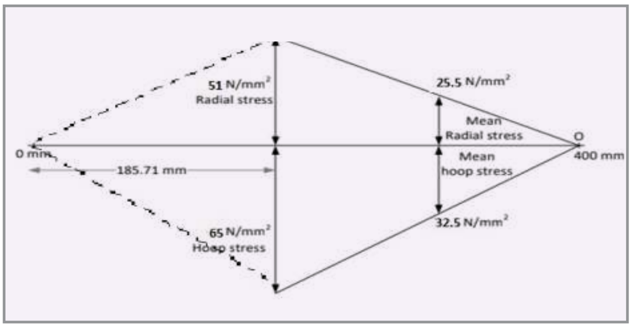

Figure 5 STRESS DIAGRAM

- The keyless system eliminates the probability of formation of fatigue cracks to a large extent because of the elimination of the keyway in the shaft.
- The normal reaction is made larger by the reduction in the taper angle. This gives a higher frictional slip torque and so increases the grip strength between propeller and the shaft.
- The grip strength can be determined as required by choosing the required shrinkage allowance.

A question that can be posed is why have a tapered shaft when a parallel shaft will optimise the normal reaction with the required shrinkage allowance. The answer is that the shrink fit by oil pressure cannot be employed because the ends in the propeller boss are open and with the initial shrink fit allowance, the propeller cannot be mounted on the shaft, unless the propeller boss is heated uniformly to the required temperature and this cannot be assured, hence the taper shaft is necessary.

It should be understood that although small leakage of oil under pressure is occurring at the boss ends the leak is compensated by increasing the oil pressure on the Pilgrim nut, during assembly, which helps in swelling the propeller boss.

Considering the above, favourable factors the classification societies have enhanced the inspection interval for surveys from 5 years to ten years with the following conditions:

- The stern tube oil is to be periodically tested for any contamination by sea water.
- At every dry docking survey the seals to be tested for oil leakage.

This article will not be complete without an explanation on the name **PILGRIM**. This nut which has an inbuilt jack is so called to honour Mr. Bunyon who was actively involved in the promotion of the keyless propeller assembly when he was principal surveyor in LLoyd's Register of Shipping. This nut is named after his ancestor Mr. J. Bunyon who was a Christian preacher and is the author of a popular ethical book named Pilgrim's Progress. This book was and is a moral science text book in many Christian educational Institutions.

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*Strength of materials by Paradise and Church.

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PROOF OF CONCEPT MODEL FOR DEMONSTRATING IoT BASED VESSEL CONTROL AND MONITORING

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Abstract: The internet of things has proved to be one of the most influential technologies affecting almost every other field, be it for remote control, monitoring or regulatory supervision. Similarly, maritime operation and management have the potential to be greatly influenced by IoT, making certain control and monitoring activities highly efficient and easy. This paper proposes a proof-of-concept design for controlling and monitoring the propulsion systems of an electric twin-screw vessel over the internet.

The idea is to have Wi-Fi connectivity node modules at the control units to receive and send information about the states of the electro-mechanical units to be controlled or monitored. It is a prerequisite that the vessel should have reliable and persistent internet connectivity for the setup to efficiently function in coherence with the onboard machinery.

Wi-fi node receives data from the cloud using TCP/IP protocol and MQTT library function formats are used to push and pull the information, to and from cloud servers. The Wi-Fi modules are connected to a locally established network of programmable microcontrollers via I2C protocol connection. The embedded controller in the Wi-Fi node decides the action based on the received information and instructs the PMCs accordingly. At the delivery end, PMCs control actuators and relays based on the received instructions, resulting in the change of state of machinery.

Machinery attributes like motor RPM and thermal state can be detected and published to thingspeak in real time through http post requests using another connectivity module. Thingspeak is an IoT service from Mathworks to record, display, publish real time data from various IoT devices. Data can be exported to Matlab for tasks involving computations and the results can be sent back to devices through TalkBack service.

I. Introduction

A. Introduction to Internet of Things

Information and data have always been counted as valuable entities by humans since antiquity. But the type of data and methods of gathering it underwent a revolution after the invention of information technology during the latter half of the twentieth century. In today's scenario, a major part of the income for IT giants like Google and Facebook is generated from the ads they run on their electronic media platforms that are targeted based on the data, collected from users.

Data is collected by many corporations through various digital impressions of users like search queries, likes, comments, preferences, and purchases. Highly comprehensive analytical tools like artificial intelligence, machine learning, and deep learning are used to boost the significance of such data by generating valuable insights that assist analysts to decide on customer interests and marketing strategies.

The fact that data can be collected only through digital impressions generated while using electronic gadgets like cell phones and computers limits many possibilities of extended applications. Humans interact with various physical entities daily, these interactions, if at all are documented as digital data can help us to reveal marvellous insights about human-object interactions.

Thus facilitating research, development, and optimisation of current systems resulting in better products and services for mankind. IoT is one of the possible ways to collect data from daily life interactions. Since various electrical and non-electrical objects of regular use are connected to the internet as a result of the Internet of Things, they generate huge amounts of valuable data related to daily life activities.

B. A Brief Description of IoT Integration with Existing Products

Primarily the data to be gathered is categorised based on continuity, periodicity, and amplitude of the output signal. The device from which data will be collected is defined. The data formats are settled based on the requirements and abilities of the system in use. The basic need to accomplish this is the need to have a reliable and secure internet connection. Up next, an intermediate connectivity system is required to connect devices to the internet.

Usually, this is accomplished by using connectivity modules like ESP8266, HC05 in combination with development boards from Arduino, raspberry pi, and Texas Instruments. These modules help us convert the data into digital formats and send it to the cloud servers via the internet. Further up, many systems support bidirectional communication, allowing us to control and manage a number of things wirelessly, making things more interactive and user-friendly.

All the data collected from the devices is stored on cloud platforms and can be made available for public use or kept personal. A lot of these cloud services facilitate cross-platform usage and provide computational services but at the cost of the privacy of data at most. Most of the IT companies now host IoT web services, which are mostly free for individual use and paid for corporate use, like Amazon Web Services, Things Speak, and Google Firebase to name few.

These technical leaps will entirely revolutionise the way people interact with their daily life commodities alongside while they gather huge amounts of useful data. This techno-economic real-life data gathering methodology can be very well implemented in the maritime industry. This will gather data generated by the operations of shipping vessels, utility systems, and port operations.

Data can then be used to train machine learning models, AIs and will act as a provision for research analytics. Machinery maintenance is an important aspect to be sure about before vessels leave to score through the vast isolating blue oceans. IoT can effectively enhance the easy to condition-based maintenance to monitor the state of machines onboard and simultaneously contribute to real-time machine data content, which can help gain insightful results to improve the design and amend service methodology.

Further, these results can assist regulatory authorities in drafting rules and setting standards. These applications promise a great deal of innovation and development in the near future but currently, the cons of this technology hold a seriously precarious reputation due to inappropriate security features.

C. Introduction to IoT in Shipping Industry

Just like any other industry, the maritime industry, extensively uses information services to collectively carry out various operations involved in efficiently maintaining the balance of marine transport and off-shore services. Thus, it is an undeniable fact that the shipping industry has plenty of room for a revolutionary innovation like IoT.

Introduction of IoT in ships will lead to the achievement of a certain level of automation in terms of the process control systems. Further, the shift of controls from the control room to the controller's mobile device will drastically reduce the space requirement for the control room while making the control interface easier and remotely accessible. Ships are relatively large floating structures that are in fact sometimes referred to as floating cities sailing in the vast blues.

All the data that these ships would generate will be immense in quantitative as well as qualitative terms. This data can be used in many ways like training optimisation models, building more autopilot systems and getting insights into the challenges involved in the practical implementation of complete autonomous vessels which in a broader sense has never been done before.

II. Description of proof of concept model

The model intends to prove the concept of implementing IoT in the remote and autonomous control of ships. It specifically focuses on propulsion control of a twin-screw vessel with the screws being rotated independently and in synchronisation with each other. This setup allows the user to rotate the screws at variable rotations and directions as the need comes. The propeller action can be manually operated or set for automatic action based on predefined triggers in the Arduino script using any terminal connected to the internet with an adafruit.io compatible browser.

III. Brief on model hardware and software

Propulsion and Powering

Propulsion consists of two fixed pitch propellers powered by two 12V DC motors and connected via a shaft of 6mm diameter and universal couplings. Starboard propeller is a right-hand screw and port propeller is a left-hand screw. Power source for the propulsion consists of a 12v,2200mAh LiPo battery powering an L298N dc motor driver module. propulsion motors are connected to the PWM enabled bi-directional motor driver outputs.

Connectivity and Control Module

ESP32 system-on-chip (SOC) microcontroller with built-in Wi-Fi module is used for IoT connectivity module for obtaining internet connectivity over Wi-Fi and controlling the L298N for direction and speed control using pulse width modulation (PWM). ESP32 is powered by a 5v, 1.1amp, 10000mAh battery pack through a male-male USB to micro-USB cable. The terminal here is an android device running android7 or above connected to the internet and has a browser installed which supports adafruit.io web application.

ESP32 Firmware and Software

ESP32 is flashed with Arduino firmware to run Arduino code. It runs an Arduino code to connect to Wi-Fi hotspot, subscribe to MQTT server from adafruit and control L298N using GPIO pins. The complete code is given in the appendix.

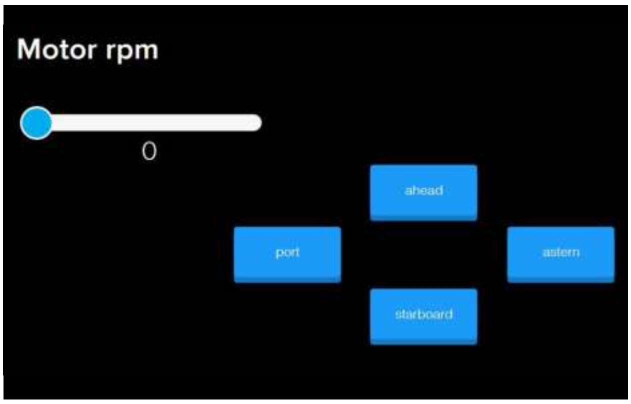
The Code is Structured as Follows

- Include the required libraries
- Define the GPIO pins, state variables, WIFI credentials, MQTT credentials and MQTT connect function
- Setup section consists of WIFI connect built-in function, assigning the in-out pins and subscribing data from the MQTT server
- Void loop consists of converting the characters received from MQTT into integers and control loops are used to decide the pin state outputs

IV. Web application for remote control

Adafruit has a graphic user interface web application for publishing and subscribing data from terminals. The UI has a variety of customisable data publishing and subscribing tools like virtual monitors, virtual plotters, buttons, sliders etc.

The data feeds can be connected to different display and control entities on the dashboard as it is convenient, depending on the purpose. Every user on adafruit is assigned a unique username and 32-bit authentication key. Device connects to the io.adafruit.com through port:1883 using the username and auth-key. The data is subscribed and published in character format.



"If security were all that mattered, computers would never be turned on, let alone hooked into a network with literally millions of potential intruders"
— Dan Farmer

V. Voice automation with Google Assistant

Trigger based publishing feature from adafruit is utilised to publish data using a third-party cloud platform IFTTT which can receive data from google assistant for specific predefined voice commands and activate the corresponding triggers to publish the associated data on adafruit.io.

For this to work all three platforms adafruit, IFTTT and google assistant must be using the same google account. IFTTT can be used to configure google assistant to respond accordingly to certain voice commands. We have set up four distinct commands for forward, reverse, port and starboard motion. Generally, a delay of 1-2 seconds from giving the command to getting the response in the dc motors.

Security concerns

"If security were all that mattered, computers would never be turned on, let alone hooked into a network with literally millions of potential intruders" — Dan Farmer

Anything hooked up to the internet, wired or wireless is at a potential risk of being hacked. But that doesn't stop us from using the technology.

Network security

Networks need to be secured from external penetration by employing firewalls to restrict, from and to communication passing through the network. Ports need to be actively monitored to limit unintended network intrusion.

Potentially harmful web resource locations must be restricted from access. All data must be re-routed through a proxy network like socks5 proxy to hide the IP address so as not allow outsiders to digitally document network activity.

Software security

Firmware and program on the IoT modules need to be updated regularly to keep it safe from vulnerabilities and bugs. Updates contain patches for codes, libraries and built-in functions diagnosed with vulnerabilities which can be exploited by hackers to partially or fully take over the system or network at stake. The update files need to be verified using digital signatures to confirm the originality of content and source.

Further use of good antivirus software with up-to-date virus and malware repositories help to keep the system safe from trojans, viruses, malware and ransomware attacks. All data needs to have a reliable backup strategy in case of a possible attack or mishap leading to partial or complete loss of data.

Web security

The web-communication can be secured with SSL encryption, using a secure web browser, blocking malicious scripts and having it tested by penetration testers. Offensive security techniques help in keeping the network, communication and system safe from external attacks.

VI. Current security scenario

A number of leaked documents and emails on WikiLeaks related to the secretive gatherings in Silicon Valley to discuss various issues regarding security of IoT-smart devices lead us to infer that improper security features of the IoT devices put forward some legitimate concerns that need to be met with before implementing them on relatively larger scales.

One of the newly emerged problems is that hackers can use the hacked IoT devices to send automated emails without the consent of the owner. This loophole can be exploited to imitate the situation of distributed denial of services and cause harm to large corporations by bringing down their stock rates and profits.

There have been reports of government agencies and other corporations spying on commoners by hacking their cell phones and computers. Considering the vulnerability of IoT devices, one can easily predict the massive advantage these entities will have, to exploit the privacy of large masses without any noticeable offense.

IoT is a multimillion dollar industry which has sought interests from big players of IT-industry like Google and Amazon. Thus, it will definitely grow into a much larger business by the end of this decade, possessing a potential to impact humanity in an unpredictably substantial manner.

VII. Conclusion

As intended initially, we have successfully developed a twin-screw vessel with IoT enabled propulsion control and tested its working in a well-connected space. The voice automation utility has also been successfully configured and tested with fairly satisfying results.

Appendix

Important terms

MQTT

MQTT is a machine-to-machine (M2M)/"Internet of Things" connectivity protocol. It was designed as an extremely lightweight

```
#include <ESP32Servo.h>

#include <WiFi.h>
#include "Adafruit_MQTT.h"
#include "Adafruit_MQTT_Client.h"


static const int servoPin1=2;
static const int servoPin2=4;
int in1 = 12;
int in2 = 13;
int in3 = 14;
int in4 = 27;

Servo servoObj1;
Servo servoObj2;

#define WLAN_SSID      "..."          // Your SSID
#define WLAN_PASS      "..."          // Your password

/************************* Adafruit.io Setup *********************************/

#define AIO_SERVER      "io.adafruit.com" //Adafruit Server
#define AIO_SERVERPORT  1883
#define IO_USERNAME    "..."            // Username
#define IO_KEY         "..."            // Auth Key
[illegible]

  WiFi.begin(WLAN_SSID, WLAN_PASS);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println();

  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());

  mqtt.subscribe(&Servo1);
  mqtt.subscribe(&Servo2);
  mqtt.subscribe(&Motor1);
}

void loop() {

  MQTT_connect();
//Input Check
int bs1,bs2,bs3,bs4=0;


  Adafruit_MQTT_Subscribe *subscription;
  while ((subscription = mqtt.readSubscription(20000))) {
    if(subscription == &Servo1){
      Serial.print(F("Got: "));

      digitalWrite(in4, HIGH);
      Serial.println(in1);
      }
      else if (motorState1==20){
        digitalWrite(in1, HIGH);
      digitalWrite(in2, LOW);
      digitalWrite(in3, HIGH);
      digitalWrite(in4, LOW);
      }
      else if (motorState1==30){
        digitalWrite(in1, LOW);
      digitalWrite(in2, HIGH);
      digitalWrite(in3, HIGH);
      digitalWrite(in4, LOW);
      }
      else if (motorState1==40){
        digitalWrite(in1, LOW);
      digitalWrite(in2, HIGH);
      digitalWrite(in3, LOW);
      digitalWrite(in4, HIGH);
      }
      delay (20);

      }
  }

  }

    int servoState1 = atoi((char *)Servo1.lastread);
    servoObj1.write(servoState1);


  }
  if(subscription == &Servo2){
    Serial.print(F("Got: "));
    Serial.println((char *)Servo2.lastread);
    int servoState2 = atoi((char *)Servo2.lastread);
    servoObj2.write(servoState2);

  }
  if(subscription == &Motor1){
    Serial.print(F("Got: "));
    Serial.println((char *)Motor1.lastread);
    int motorState1 = atoi((char *)Motor1.lastread);
    Serial.println(motorState1);
    if(motorState1==0){
      digitalWrite(in1, LOW);
    digitalWrite(in2, LOW);
    digitalWrite(in3, LOW);
    digitalWrite(in4, LOW);
    }
    else if (motorState1==10){
      digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
    digitalWrite(in3, LOW);
    digitalWrite(in4, HIGH);
    Serial.println(in1);
```

publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium.

For example, it has been used in sensors communicating to a broker via satellite link, over occasional dial-up connections with healthcare providers, and in a range of home automation and small device scenarios.

Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It's intended for anyone making interactive projects.

Adafruit IO

Adafruit IO is a platform designed (by us!) to display, respond, and interact with your project's data. We also keep your data private (data feeds are private by default) and secure (we will never sell or give this data away to another company) for you. It's the internet of things - for everyone!

IFTTT

IFTTT is the free way to get all your apps and devices talking to each other. Not everything on the internet plays nice, so we're on a mission to build a more connected world.

Arduino Code Excerpts

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Heritage Hourglass

PROWESS OF THE MARATHA NAVY: VIJAYDURG FORT

Saba Purkar

India's 7500 kms of coastline and her strategic positioning in the Indian Ocean has been both a boon and bane, as it brought profit to the country via trade, but the same exposure made it prone to annexations. The need to secure our coastal frontline became even more prominent during medieval times due to increase in trade and exposure. As the foreign lands saw revolution in maritime technology during medieval times and at the same time the lack of interest of Indian rulers in maritime activities weakened the seaward defence. However, the practice of building maritime forts in India dates back to the Harappan times.

Forts are fascinating feats of architecture, constructed to defend and protect the land. Mentions of forts can be found in several ancient texts such as '*Manusmruti*' and '*Kautilya's Arthashastra*' which elaborate on the types of forts and methods of construction. Forts have played a major role in trade as well as defence of the kingdom and most of them stand strong even today as they were designed to withstand the test of time. In case of Maharashtra, its 720 kms long coastline is scattered with different types of forts, including those built on hills and those that were constructed beside the coast. This article focuses on a particular coastal fort, constructed by the Marathas at Vijaydurg also known as *Gheria*, one of the most popular maritime forts of Maharashtra.

Brief History

Situated in the southern Konkan coast of Maharashtra, Vijaydurg (N16° 33'39.51" E73° 20'1.14") was believed to

Figure 1 Satellite Image of Vijaydurg Fort
Source: Google Maps

Figure 2 Vijaydurg Fort Bastions

be a minor port in the early historic period up to the 2nd century CE. It is believed that the fort itself was built by Bhojaraja of the Silahara Dynasty between AD 1192 and 1205. But the recorded history of the fort is available only from the 17th century onwards, when the fort was occupied by the Adil Shah of Bijapur, who upgraded it.

During the end of the Satavahana period, the Fort of Vijaydurg lost its glory due to political conflicts, but after the conquest and restoration of the fort in AD 1653, during the reign of Chhatrapati Shivaji, the fort was named by the Europeans as the 'Gibraltar' meaning an impregnable stronghold. Located in the district of Sindhudurg, in Devgad Taluka, the fort has withstood attacks of the Europeans and the Siddhis for 93 years. While seaward attack had failed, the Portuguese, British and Dutch also tried to capture the fort via the creek, but failed. The creek flows in the north to north-east direction, which was also the direction of stream. Therefore, understanding this

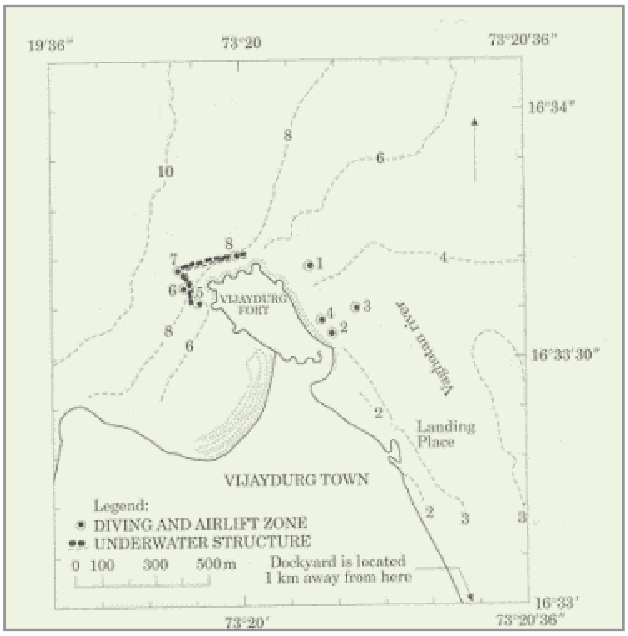

Figure 3 Map of Vijaydurg indicating the submerged wall
Source: NIO

weakness, the Marathas had excellently barricaded and fortified that side of the fortress. There are also records of flourishing trade on the ancient coast of Vijaydurg with Sopara and Kalyan, which lead to migration of population to Vijaydurg and its surrounding areas.

Fort of Vijaydurg

The fort is built on top of a hill on the southern shore of Vaghotana river. The rigid triple fortification of this fort and extensions of buildings were installed by Chhatrapati Shivaji. Later, few constructions and fine detailing was done by the Bijapur Kings and the Angre respectively. The outermost fortification walls comprised of seventeen big and small towers. The second defensive wall from outside had ten towers from which the two storied towers were used as observation posts with guard rooms at strategic points. Although the towers are completely damaged, their traces are still visible at the fort today. The bastions on western and southern part of the fort were mounted with guns and a moat is located on the southern part of the fort. The outlines of these can be seen in **Figure 1**.

If we examine and compare the other coastal and hinterland forts of the Konkan coast and compare them for their architecture with that of the Vijaydurg fort, we can safely date the fort's construction to the Shilahara period. Records also highlight Vijaydurg as a primary port where goods and material were shifted from larger to smaller ships. These goods were then carried on the internal waterways via Vaghotan creek towards the secondary port of Kharepatan and then transported via land all the way to Kolhapur.

Archaeology

Contemporary literature indicates frequent naval battles during the 17th and 18th centuries between the Europeans and the Marathas which led to the sinking of a number of ships in Vijaydurg waters. During a coastal zone survey of the region, a 17th century tidal dockyard was found about 3 km from Vijaydurg Fort. The naval strategy of the Maratha period can be understood by studying the construction of the dockyard and the archaeological orientation of the fort. Further, the study of the nearby archaeological site of Brahmapuri has resulted in the retrieval of coins from Satavahana period and thus reinforced evidence of local contact with Mediterranean kingdoms during the period of 200 BC to 200 AD. However, the retrieval of stone anchors from the surrounding shallow waters, are the only evidence to support Vijaydurg as a port during the Satavahana period.

In 1995, the onshore exploration and offshore excavation conducted by the National Institute of Oceanography (NIO) at Vijaydurg, revealed the existence of a stone structure on the north-western side of the fort. Following the excavation and exploration, an article published by NIO in 1998 presumed that the stone structure could be constructed to damage enemy ships as well as to protect the fort from waves and currents (**Figure 3**). As per the article, the submerged structure reflected high engineering skills of that period.

However, Dr Sachin Joshi in his article 'Myth and Reality: The submerged stone structure at Fort Vijaydurg' published in 2012, refutes the claims of this wall-like structure to be a man-made creation. He argues that the north-western seabed of the fort is highly rocky, making it impossible for any ship, large or small to approach the fort. So, it would be illogical to build an underwater structure on the north-western seabed, which is naturally unapproachable. Dr Joshi reasons that the underwater structure is most likely a natural geological formation of basalt which is commonly found in the coastal regions of western Maharashtra.

According to the report of onshore and offshore exploration and excavation conducted by NIO, Vijaydurg was identified as an early-historic site. However, Dr Joshi contradicts that there is no historical or archaeological evidence to support this statement, as no early historic artefacts were found in the vicinity of the fort.

The fort of Vijaydurg has a rich history due to its strategic position and is an excellent example of Maratha Naval prowess. However, the research conducted so far is clouded in theories. There is tremendous potential for further research to be carried out to create a timeline for the history of Vijaydurg as well as examining the underwater structure near the fort. Hence, it needs to be studied in depth, with meticulous onshore and offshore explorations by historians, archaeologists and experts from allied disciplines, to bring forth the legacy of Vijaydurg.

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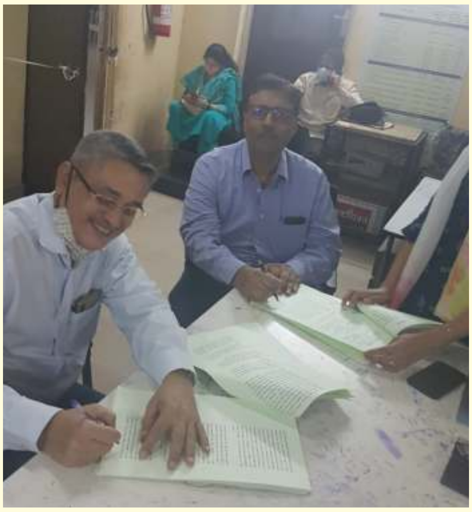
BOARD OF EXAMINATIONS FOR SEAFARERS TRUST GETS ITS OWN OFFICE SPACE

The Board of Examinations for Seafarers Trust (BES) was formed in the year 2005 by the Company of Master Mariners of India (CMMI) and Institute of Marine Engineers India (IMEI) under the authority of Directorate General of Shipping (DGS) to conduct "All India Exit Examinations for Ratings". BES started operating from the IMEI House in Navi Mumbai initially for about a year and then moved to a rented office in the year 2006. BES always desired to have its own office and this desire got fulfilled on the 23rd of March 2022 when it registered purchase of two office units 1007 & 1008 measuring a total of 130 sqm carpet on the 10th Floor in building named NMS Titanium standing on Plot No. 74, Sector-15, CBD Belapur, Navi Mumbai.

BES initially started conducting the exit examinations for the General-Purpose Ratings and then, added conducting the examinations for the Saloon Ratings. BES presently conducts the exit examinations for both these ratings twice in a year in June and December respectively . These ratings are those who are completing their training from DGS approved institutes located all over India and the examinations are conducted from six examination centers Mumbai, Delhi, Kolkata, Chennai, Cochin and Goa in fair, open, transparent and independent manner.

BES expanded its operations further by holding the examinations even for the inland vessels crew of Maharashtra Maritime Board in the year 2012 and added to its list of conducting the examinations for inland vessels crew of other states such as West Bengal, Andhra Pradesh and Karnataka.

In the year 2016, BES conducted the examinations for the marine crew of Cochin Port Trust. BES conducts the examinations for Chennai and Vishakhapatnam Port Trusts in addition to Cochin Port Trust.



BES is also actively involved in designing and developing course guidelines and materials. It developed guidelines for inland vessel courses for Maharashtra Maritime Board in the year 2020 and recently in the year 2021 developed materials for inland vessel courses for Indian Maritime University (IMU).

BES runs soft skill and hard skill enhancement programme for seafarers and distributes Training Record Books (TRBs) to ratings.

The acquisition of a larger office space of its own will help BES to explore new opportunities in maritime education in India and abroad for expansion of its operations.

CHANDIGARH CHAPTER

IME(I) CHANDIGARH CHAPTER TECHNICAL VISIT TO CHEEMA BOILERS

The Chandigarh Chapter organised a Technical visit to Cheema Boilers situated at Kurali about 40 km from Chandigarh on the 10th February 2022. The visit was sponsored by M/S Cheema Boilers.

There were seventeen members who visited the prestigious Boiler manufacturing plant. Being an ex-Marine Engineer himself, Mr. Harjinder Singh Cheema, MD, Cheema Boilers Ltd., spoke about the journey from a six plus acre unit to a 500 crore organisation spread over the world. A video presentation on the innovations and inventions by the Unit was presented by him. He explained about the joint project with IIT Ropar to make a portable human body cremation unit. The unit used less wood than what is normally required and the complete cremation could be done in about 2 hours' time. (https://www.youtube.com/watch?v=c_eYC19jfGw).

He then showed the installation where from bare steel plates and tubes are taken and how the complete boiler is constructed. He explained how the parts are stress relieved, how welded joints are being x-ray tested for faults and how the metal plates are subjected to NDT.

The visit was very informative not only to the presently sailing young engineers but also for seniors.

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I, Dr. Rajoo Balaji hereby declare that the particulars given above are true to the best of my knowledge and belief.

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Sd/-
Dr. Rajoo Balaji
Publisher

SHIPPING MATTERS

CLASS ACTION/INDUSTRY MOVES

Compilation : **Rashmi Tiwari**

NYK TAKES DELIVERY OF SECOND ECO-PCTC

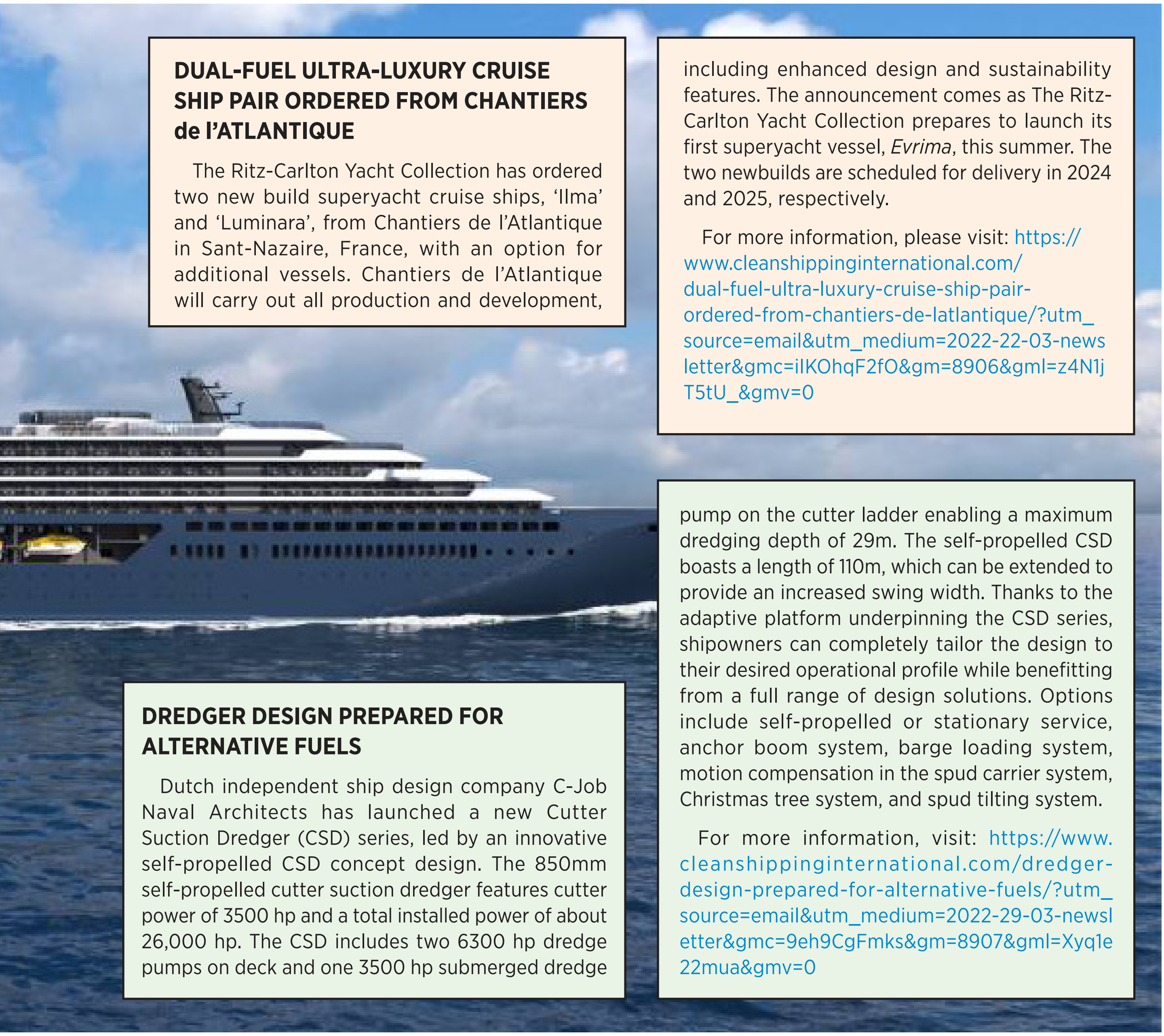
NYK of Japan has taken delivery of 'Plumeria Leader', a pure car and truck carrier (PCTC) capable of navigating oceans with only LNG as the ship's main fuel. The vessel was built at Shin Kurushima Toyohashi Shipbuilding, and is NYK's second LNG-fuelled car carrier following the *Sakura Leader.* By vessel modification and the switch to LNG, Plumeria Leader will make the ship about 40% more energy efficient (by reducing CO_2 emissions per unit of transport) compared to ships using conventional HFO-fired engines. The vessel is expected to reduce SOx emissions by around 99% and NOx by about 86% compared to ships using conventional oil fired engines. This ship will be one of the largest PCTCs, capable of transporting about 7,000 units (standard vehicle equivalent) per voyage, beginning with vehicles produced by the Toyota Motor Corporation.

For more information, visit: https://www.cleanshippinginternational.com/nyk-takes-delivery-of-second-eco-pctc/?utm_source=email&utm_medium=2022-29-03-newsletter&gmc=9eh9CgFmks&gm=8907&gml=q5QZD5G3l1&gmv=0

CLASSNK ISSUES AIP FOR WORLD'S FIRST METHANE OXIDATION CATALYST SYSTEM DEVELOPED BY HITACHI ZOSEN, MOL AND YPT

Leading Classification Society ClassNK granted the Approval in Principle (AiP) for the world's first concept design of the methane oxidation catalyst system*1 jointly developed by Hitachi Zosen Corporation (Hitachi Zosen), Mitsui O.S.K. Lines, Ltd. (MOL) and Yanmar Power Technology Co., Ltd. (YPT). Moreover, MOL, which operates the actual demonstration vessel for the project, and Namura Shipbuilding Co., Ltd. set to build the vessel and conduct design for installing the system on board, have joined to develop specifications of the system together through a risk assessment and other measures.

For more information, please visit: https://www.yanmar.com/global/news/2021/10/27/99066.html



DUAL-FUEL ULTRA-LUXURY CRUISE SHIP PAIR ORDERED FROM CHANTIERS de l'ATLANTIQUE

The Ritz-Carlton Yacht Collection has ordered two new build superyacht cruise ships, 'Ilma' and 'Luminara', from Chantiers de l'Atlantique in Sant-Nazaire, France, with an option for additional vessels. Chantiers de l'Atlantique will carry out all production and development, including enhanced design and sustainability features. The announcement comes as The Ritz-Carlton Yacht Collection prepares to launch its first superyacht vessel, *Evrima*, this summer. The two newbuilds are scheduled for delivery in 2024 and 2025, respectively.

For more information, please visit: https://www.cleanshippinginternational.com/dual-fuel-ultra-luxury-cruise-ship-pair-ordered-from-chantiers-de-latlantique/?utm_source=email&utm_medium=2022-22-03-newsletter&gmc=iIKOhqF2fO&gm=8906&gml=z4N1jT5tU_&gmv=0

DREDGER DESIGN PREPARED FOR ALTERNATIVE FUELS

Dutch independent ship design company C-Job Naval Architects has launched a new Cutter Suction Dredger (CSD) series, led by an innovative self-propelled CSD concept design. The 850mm self-propelled cutter suction dredger features cutter power of 3500 hp and a total installed power of about 26,000 hp. The CSD includes two 6300 hp dredge pumps on deck and one 3500 hp submerged dredge pump on the cutter ladder enabling a maximum dredging depth of 29m. The self-propelled CSD boasts a length of 110m, which can be extended to provide an increased swing width. Thanks to the adaptive platform underpinning the CSD series, shipowners can completely tailor the design to their desired operational profile while benefitting from a full range of design solutions. Options include self-propelled or stationary service, anchor boom system, barge loading system, motion compensation in the spud carrier system, Christmas tree system, and spud tilting system.

For more information, visit: https://www.cleanshippinginternational.com/dredger-design-prepared-for-alternative-fuels/?utm_source=email&utm_medium=2022-29-03-newsletter&gmc=9eh9CgFmks&gm=8907&gml=Xyq1e22mua&gmv=0

ABS SPEAKS TO SOUTHERN EUROPEAN INDUSTRY

ABS recently brought together more than 70 marine and offshore industry leaders from Italy, Switzerland and Monaco at a meeting for charterers, designers and shipbuilders, to inform them about the classification society's latest developments in sustainability, digital solutions, safety and digital innovation. The meeting heard about the safety performance of ABS; how its Port State Control performance and fleet safety performance underline its focus on safety and its mission. Those present were briefed on the latest developments in the dynamic regulatory environment and given a detailed breakdown of the industry's sustainability challenges and ABS' services for the industry.

For more information, please visit: https://www.cleanshippinginternational.com/abs-speaks-to-southern-european-industry/?utm_source=email&utm_medium=2022-22-03-newsletter&gmc=iIKOhqF2fO&gm=8906&gml=IANBqCd8Qn&gmv=0

FLOATING BORDER OUTPOSTS BUILT FOR BORDER SECURITY FORCE BEING CLASSED BY THE INDIAN REGISTER OF SHIPPING

Indian Register of Shipping is classing a series of nine Floating Border Outposts (FBOPs), constructed by Cochin Shipyard Limited for the Border Security Force, Ministry of Home Affairs. Six vessels have been delivered so far and are being deployed in the Sundarbans in West Bengal. The next three vessels will be based in creeks of Kutch (Gujarat). Each FBOP carries four "Daughter Boats" on board for patrolling, capable of attaining a speed of 29 knots. IRS has played a dual role in this project; as Classification Society for classing the vessel and also to ensure that the specific requirements of BSF are met. IRS has been involved in the project as early as tendering stage, taking an active role in finalising the technical specifications and subsequently evaluating the technical bids of the shipyards.

For more information, please visit: https://www.irclass.org/media-and-publications/news/floating-border-outposts-built-for-border-security-force-being-classed-by-the-indian-register-of-shipping/

ABS PROVIDES GHG ACCOUNTING SOLUTION

ABS has launched Greenhouse Gas (GHG) Inventory and Carbon Accounting, adding to its suite of marine and offshore sustainability services, pairing Marine and Offshore Insight with Carbon Economics. GHG Inventory and Carbon Accounting enables organisations to quantify their GHG emissions to understand their climate impact and set goals to limit emissions as well as define their footprint and contributions in Scope 1, 2 and 3 accounting categories. ABS provides GHG Inventory development in conformance with the ISO 14060 collection of standards, which are applicable to a variety of individual units or projects and can be applied organisation-wide. ABS GHG Inventory enables monitoring and control of energy consumption and GHG emissions from project inception all the way through to construction, production and decommissioning of all assets.

For more information, please visit: https://www.cleanshippinginternational.com/abs-provides-ghg-accounting-solution/?utm_source=email&utm_medium=2022-08-03-newsletter&gmc=YD3B2WJIsL&gm=8907&gml=SIA4_COLuq&gmv=0

MARLINK HELPS MSC BOXHIPS TOWARDS DIGITALISATION

Smart network company Marlink is partnering with MSC, the largest container shipping line, to support the shipping company's ambitious digitalisation goals, using Marlink's hybrid network solutions and advanced, secure IT management. Marlink deploys a fully managed hybrid network solution, bundling its VSAT connectivity with L-band backup and global 4G connectivity on 127 vessels, providing MSC with seamless, secure connectivity to run its critical business and crew applications. This hybrid network solution is fully secured by Marlink's Cyber Detection Service which scans real-time outbound and inbound network traffic for targeted cyber threats and takes immediate countermeasures to remediate incidents. In this way the shipping giant can keep its remote vessels securely connected.

For more information, please visit: https://www.cleanshippinginternational.com/marlink-helps-msc-boxhips-towards-digitalisation/?utm_source=email&utm_medium=2022-15-03-newsletter&gmc=ui_UUZUKQ8&gm=8906&gml=poNpf4vQbV&gmv=0

INDIAN REGISTER OF SHIPPING WINS THE NATIONAL BEST EMPLOYER BRANDS AWARD

Leading classification society, the Indian Register of Shipping (IRS) was awarded the prestigious 'National Best Employer Brands 2021 Award' by the World HRD Congress in a glittering ceremony held at Taj Lands End, Mumbai on 23 March 2022. The National Best Employer Brand Awards features top organisations across India who have showcased exemplary human resources practices and have put employee wellbeing and an employee-first philosophy at the core of their business - especially during the pandemic period.

For more information, visit: https://www.irclass.org/media-and-publications/news/indian-register-of-shipping-wins-the-national-best-employer-brands-award/

CLASSNK GRANTS HIGHEST INNOVATION ENDORSEMENT PROVIDER CERTIFICATION TO NYK- FIRST "CLASS S PROVIDER CERTIFICATION" FOR ORGANIZATION SUSTAINABLY IMPLEMENTING INNOVATION

Leading Classification Society ClassNK granted the first of its highest Class S Innovation Endorsement Provider Certification for organizations to Marine Group of Nippon Yusen Kaisha (NYK). ClassNK offers its third-party Innovation Endorsement "Provider Certification", which supports innovative initiatives, to companies and organizations. As companies pursue ESG-oriented management and SDGs, ClassNK conducts the third-party certification on the initiatives to transform their own business methods and organizations in order to establish sustainable and competitive business. There are three categories of certification available to companies according to their innovation activity stage.

For more information, visit: https://www.classnk.or.jp/hp/en/hp_news.aspx?id=7644&type=press_release&layout=5

CLASSNK ISSUES APPROVAL IN PRINCIPLE (AIP) FOR GTT'S DESIGN OF LNG FUEL TANK WITH 2 BAR GAUGE DESIGN PRESSURE

Leading Classification Society ClassNK has issued an Approval in Principle (AiP) to GTT's technical solution fitted with Mark III membrane tank. The design developed by GTT is an upgrade of the Mark III system with a design pressure up to 2 bar gauge (barg) for LNG fuel applications. The company describes that the 2 barg upgrade is particularly useful for PCTCs and cruise ships, and offers improved pressure holding capabilities and operational flexibility in particular during bunkering operations. ClassNK carried out the verification according to its Rule Part GF incorporating IGF Code, especially on maximum tank dimensions, tank structural reinforcements, tank operating pressure during in service operations as well as aspects related to potential emergency situations. Upon satisfactory completion of the review, ClassNK has issued the AiP accordingly.

For more information, visit: https://www.hellenicshippingnews.com/classnk-issues-approval-in-principle-aip-for-gtts-design-of-lng-fuel-tank-with-2-bar-gauge-design-pressure/

RINA AND FINCANTIERI PARTNER IN DECARBONISATION R&D

Italian classification society and consultancy RINA and Fincantieri, designer and builder of high value-added ships and supplier of complex technological systems in various sectors, have signed a memorandum of understanding to develop synergies in the field of decarbonisation, with a focus on alternative fuels, carbon capture and renewable energies in the shipping sector. The agreement sees the involvement of the two companies in initiatives related to technology scouting, the analysis, study and simulation of new fuels and energy vectors – in particular hydrogen and ammonia – and carbon capture. The collaboration will include Approval in Principle (AiP) activities, a risk-based approach to classification that allows new designs and concepts to be validated on the basis of safety equivalence, and the qualification of innovative projects and technologies.

For more information, visit: https://www.cleanshippinginternational.com/rina-and-fincantieri-partner-in-decarbonisation-rd/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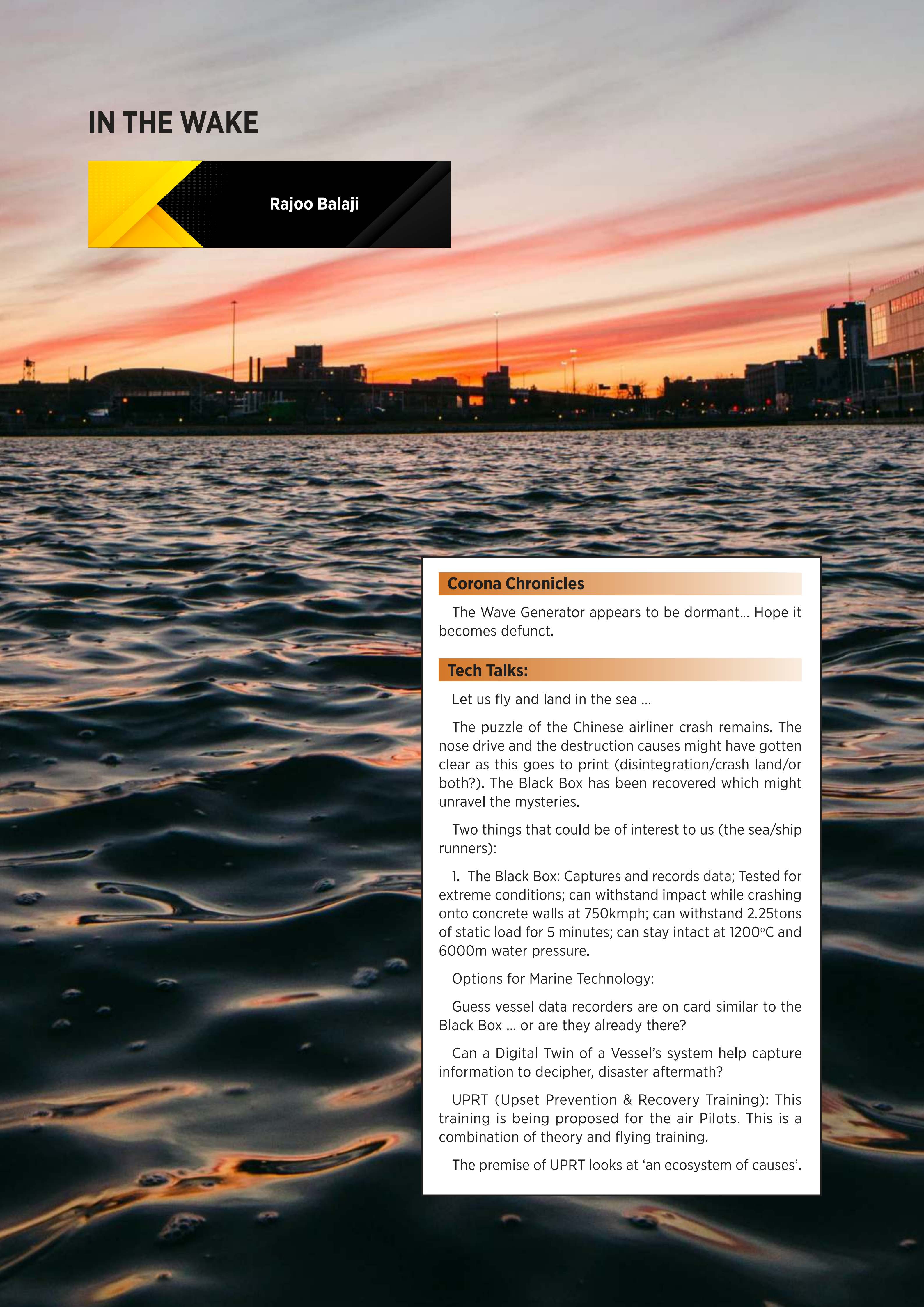
IN THE WAKE

Rajoo Balaji



Corona Chronicles

The Wave Generator appears to be dormant... Hope it becomes defunct.

Tech Talks:

Let us fly and land in the sea ...

The puzzle of the Chinese airliner crash remains. The nose drive and the destruction causes might have gotten clear as this goes to print (disintegration/crash land/or both?). The Black Box has been recovered which might unravel the mysteries.

Two things that could be of interest to us (the sea/ship runners):

1. The Black Box: Captures and records data; Tested for extreme conditions; can withstand impact while crashing onto concrete walls at 750kmph; can withstand 2.25tons of static load for 5 minutes; can stay intact at 1200°C and 6000m water pressure.

Options for Marine Technology:

Guess vessel data recorders are on card similar to the Black Box ... or are they already there?

Can a Digital Twin of a Vessel's system help capture information to decipher, disaster aftermath?

UPRT (Upset Prevention & Recovery Training): This training is being proposed for the air Pilots. This is a combination of theory and flying training.

The premise of UPRT looks at 'an ecosystem of causes'.

What does this ecosystem comprise of?

'environmental, systems, system malfunctions, aerodynamic issues, pilot induced/human factor and/or their combinations of the above'

Just replace, 'aerodynamic' with 'navigation/stability'; and 'pilot' with 'navigator/engineer'. We can then apply this to the ocean going vessels and our ship's professional competencies etc.

The key training objective of UPRT: 'resolve an upset condition, both technically and emotionally'.

Ceteris paribus, the only big difference could be that ships move (very) slowly as compared to aeroplanes. But the UPRT sounds suitable for marine engineers.

Any thoughts?

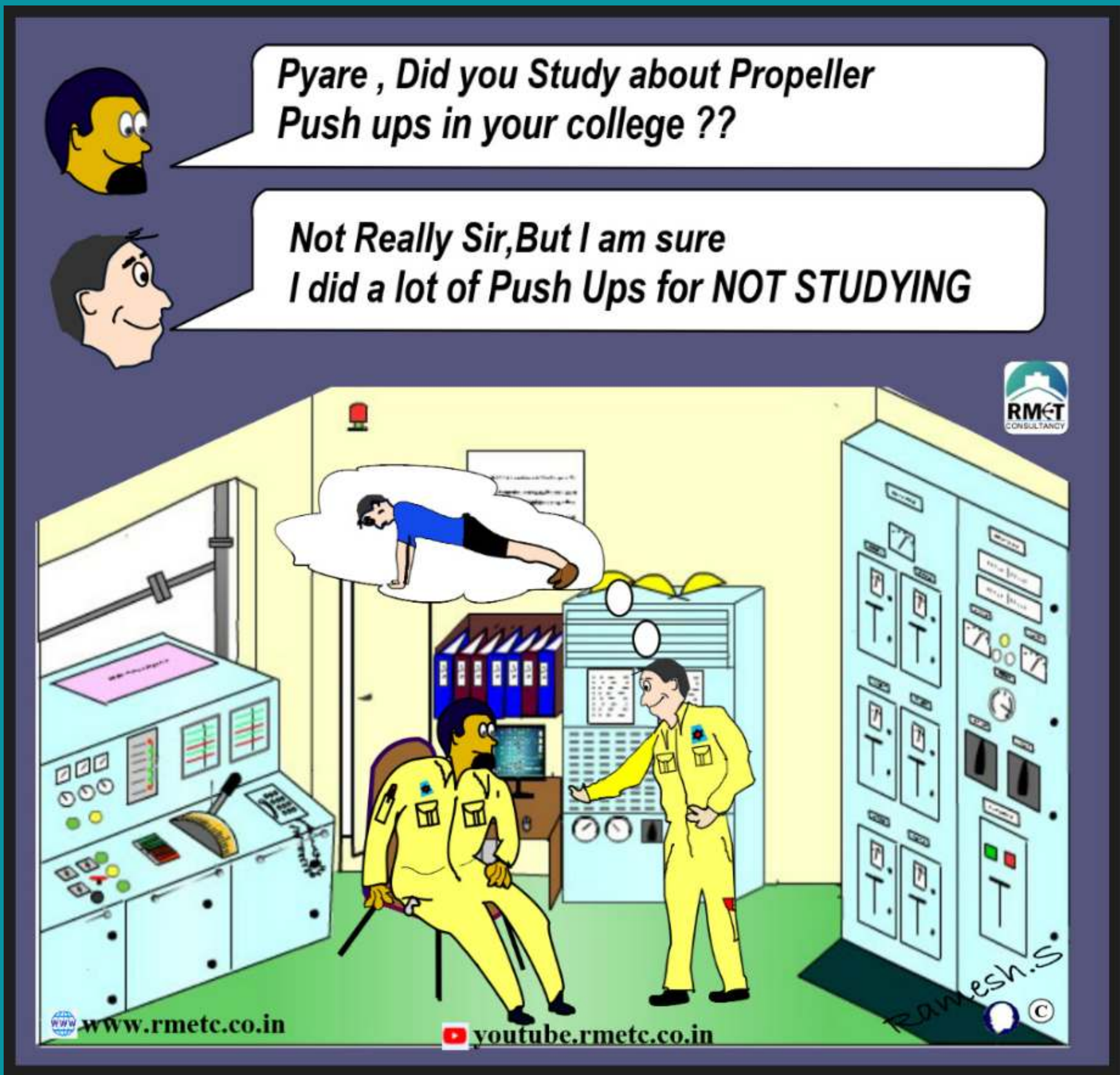
About April

5/4: National Maritime Day

7/4 & 30/4: World Health Day & Ayushman Bharat Diwas

Need we say more...? Let us go back to the start of the column and end with that wish.

THE END VIEW

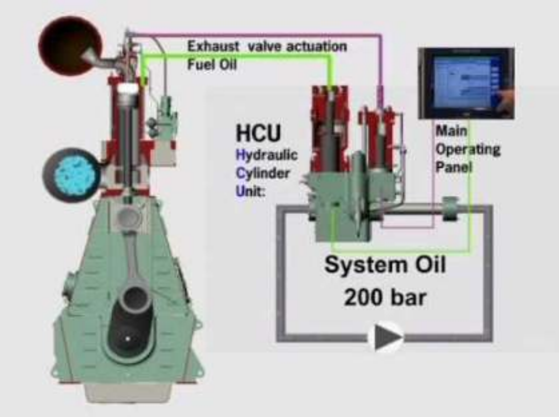


Idea, Words & Drawing: **Ramesh Subramanian**

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 : 19th to 21st **Apr'22**; 17th to 19th **May'22**; 14th to 16th **June'22**; 19th to 21st **July'22**; 16th to 18th **Aug'22**; 20th to 22nd **Sep'22** **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
(Under Category - Value added Courses) *10% discount available for IME(I) members*

FOR MORE INFORMATION : **@IME(I)** - **email:** training@imare.in, Ms. Anukampa
(M). 9819325273, **(T)** 022 27701664 / 27711663 / 2771 1664.
@ MASSA Maritime Academy Chennai - **email:** mmachennai@massa.in.net
Ms. Saraswathi, **(T)** 8807025336 / 7200055336 .

After registration and payment, please email the details of the receipt to: ***training@imare.in***

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