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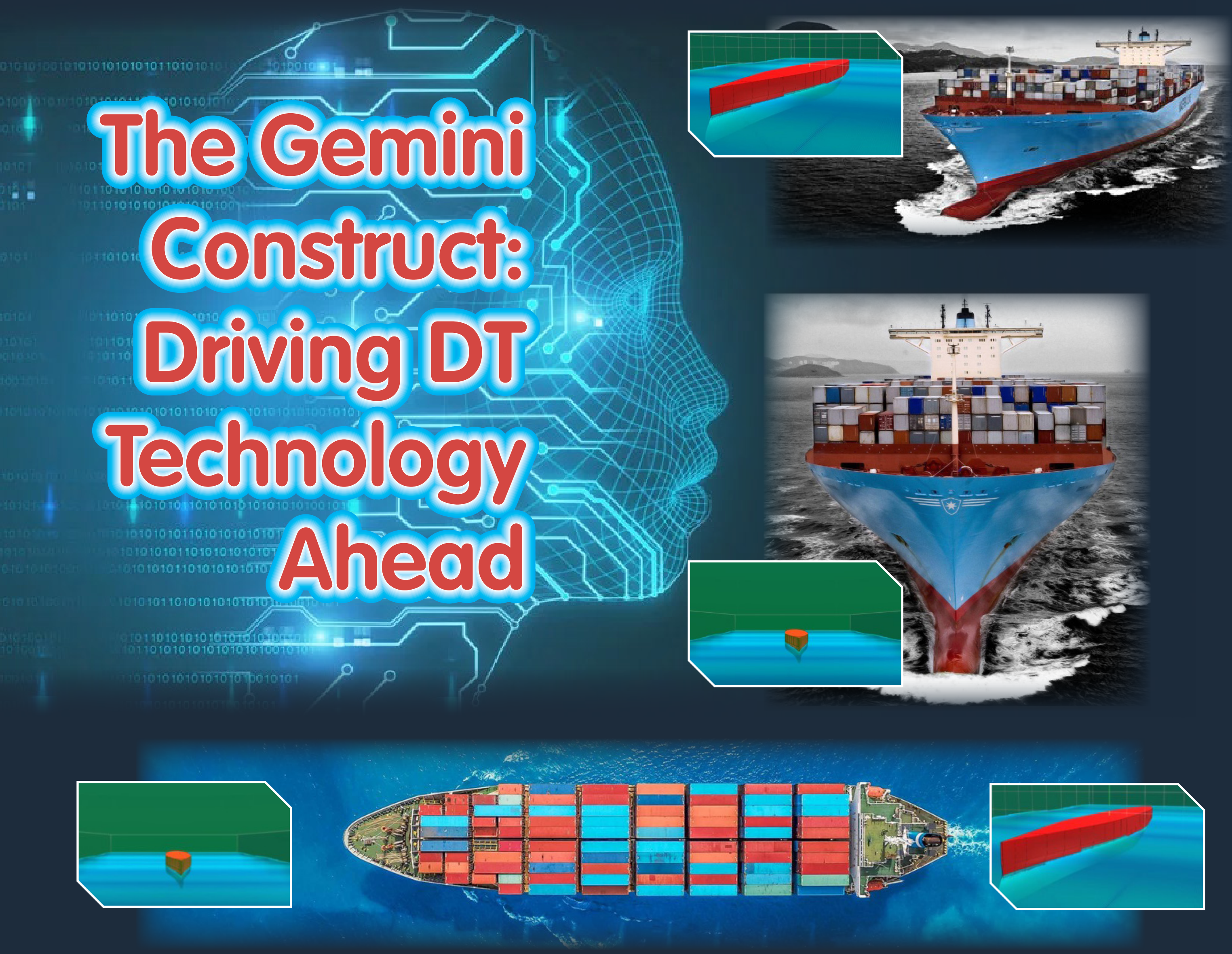

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EDITORIAL

Progress lies not in enhancing what is, but in advancing toward what will be.

- Khalil Gibran

Since the latter half of 2022, the model of international trading in rupee accounts is gaining traction.

While the US Dollar is the major currency of exchange in imports/exports, the acceptance of rupee will ease the load for procuring dollars (for settlements). Presently, about 15-18 countries appear to be in favour (rupee settlements with Russia already started) and the numbers are expected to increase. The Ru-Uk War, the difficulty of many countries to garner US Dollars (getting dearer with Fed interest increases), the geopolitical equations, greater inclination towards trade independence, etc., are driving the proposition.

The trading countries can gain by curtailing conversion losses in capital /current account transactions. Also, the currently depreciated rupee remains attractive for the foreign exporter. The so called 'internationalisation' of the rupee will get justified when transaction scope is enhanced to NRIs (and the residents). Yet much needs to be done. While digitalisation has helped, the procedural issues (Vostro-Nostro accounts, tariff issues etc.) need to be ironed out to make the mechanism work effectively.

The wishful thinking that trade deficit can be brought down will remain so. India, due to its dependence on external energy resources (petroleum), will still need inflows of US Dollars. So, on the policy front, while push for capital inflows and trade liberalisation will be needed for wider acceptance of the rupee, concerted efforts must be made for increasing the non-petroleum energy resources. Being a service sector, Indian shipping will also reap the rewards of rupee's internationalisation.

At sea levels, another wishful thinking we may advance towards: Indian (and foreign) seafarers may use rupee in foreign ports/air ports/trade-centres etc. That would be progress.

In this issue...

We start with Dr. Vedachalam elucidating on the Artificial Intelligence (AI) application supported Digital Twin (DT) for autonomous vessels. Progressing from power management protocol, the discussions pass through path planning and guidance. The signal processing, kinetics and propulsion system response etc., are well sequenced for understanding. The evolution of DT and the AI enabled situation awareness, and the Machine Learning algorithm implementation etc., follow. A short but interesting section is the comparison of DT for manned and unmanned vessels. A feature one cannot miss is the fact that propulsion backbone is becoming electric and the controls, more electronic.

Knowledge points to pursue: DRL controllers, exteroceptive sensors, visual odometry, emergency systems. This is another educative read from Dr. Veda's stock.

Following this is another DT study. The premise is that with the DT in place, data can be used for predictions of vessel seakeeping. Employing a prototype ship design, boundary conditions having been established, a CFD study is discussed. Dr. Sheeja et al., present the study outcomes in a brief manner with few significant, understandable observations. The exercise provides confidence of obtaining reliable outcomes and could be a tiny segment of the scope, which CFD studies could digest. This original work is worth your attention.

We return to the DT and doing-good-digital talks. Maninder Singh meanders through much-discussed merits of digitalisation, AR and VR etc., and presents a few prevalent 'solutions'. 3D capturing of an asset and digital [DI] (the rationale for DI etc.) are highlighted in this easy read.

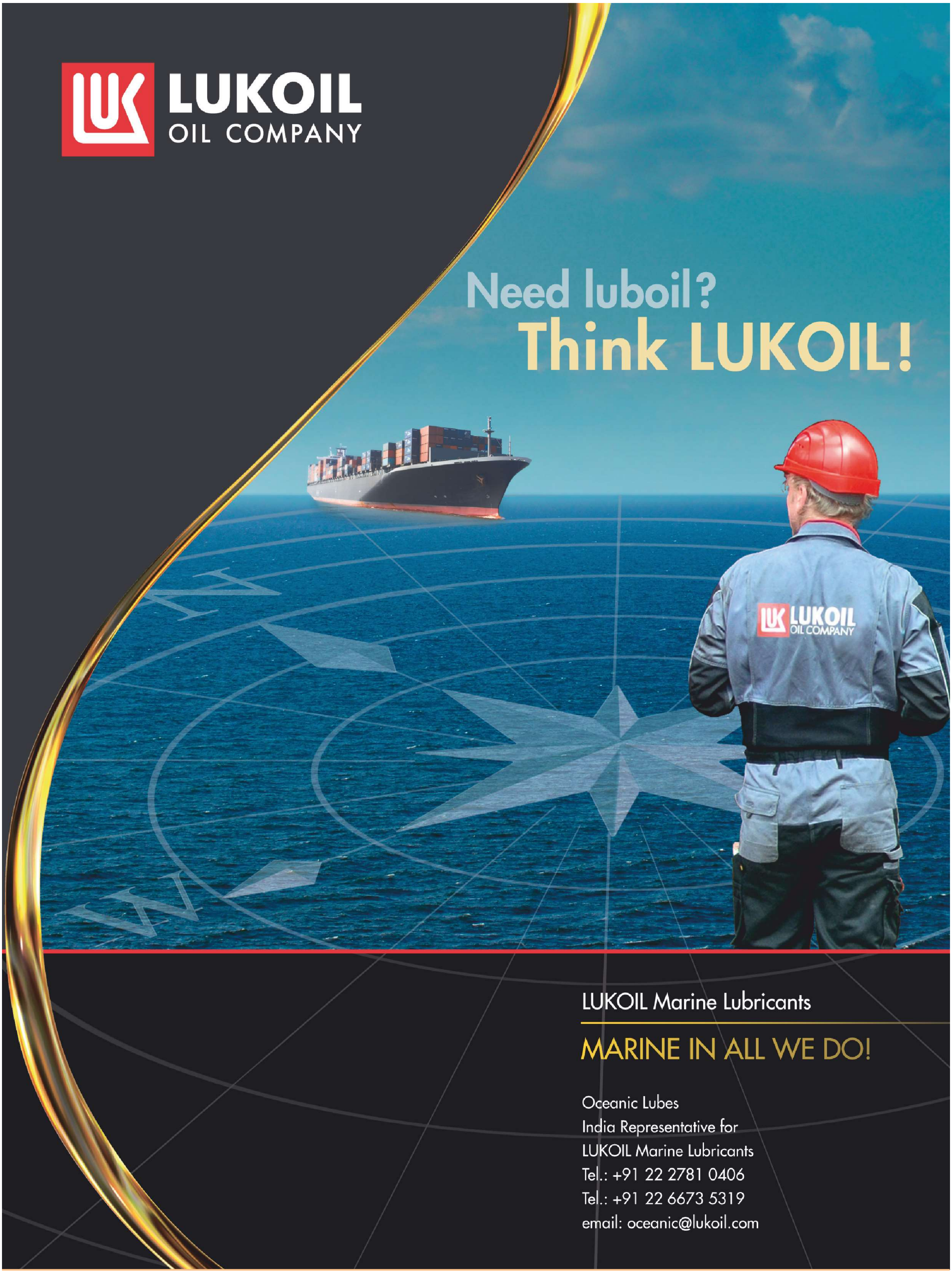
And we continue with Part B of the Subsea Navigation Systems. Dr. Jyothi describes the principles and the functioning of the acoustic positioning systems. The description of the Doppler Log and the progression in to the APoS are smooth. The computation of the slant/bearing angles, and the performance assessments, simulations etc., are explained in an understandable manner. The interesting takeaway is the short discussion on SOFAR (Sound fixing and ranging) channel.

Continuing in the Competency Corner is the electrical troubleshooting talks by Elstan Fernandez.

The MER Archives (MER April 1983) has a very connecting discussion on engine performance assessments with MIP calculator. I would recommend this for you to dig into the IME(I)-iLibrary and the archives and also invite discussion threads from readers on this.

Here is the April 2023 issue for your reading pleasure.

Dr Rajoo Balaji
Honorary Editor
editormer@imare.in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Importance of Artificial Intelligence Enabled Digital Twin for Autonomous Ships

N. Vedachalam

Abstract

Marine Autonomous Surface Ships is gaining increasing attention due to the potential benefits of improving safety and efficiency. However, successful demonstration in harsh marine environments and congested ports are vital for increasing the public confidence and complying with stringent regulatory frameworks. The article describes the technological maturity of the vessel autonomy-enabling systems, importance of machine learning/ artificial intelligence-enabled and situation-aware digital twin in improving the operational safety of autonomous ships by predicting vessel response to system failures and safety-critical events, as well as implementing robust collision avoidance algorithms.

Introduction

The global fleet of more than 94,171 ships comprising of passenger vessels, containers ships, tankers, gas carriers, bulkers, dry and cargo carriers, with a consolidated dead weight tonnage of ~2 Billion Tons contribute to ~90% of the global trade. With the objective of realising safe, climate-resilient, eco-friendly, intelligent and sustained shipping, International Maritime Organisation insists on switching to cleaner fuels, implementing Energy Efficiency Design Index (EEDI) for the newly-built vessels, Ship Energy Efficiency Management Plan (SEEMP) for operating vessels, autonomous operations and silent/quiet configurations (**Figure.1**).

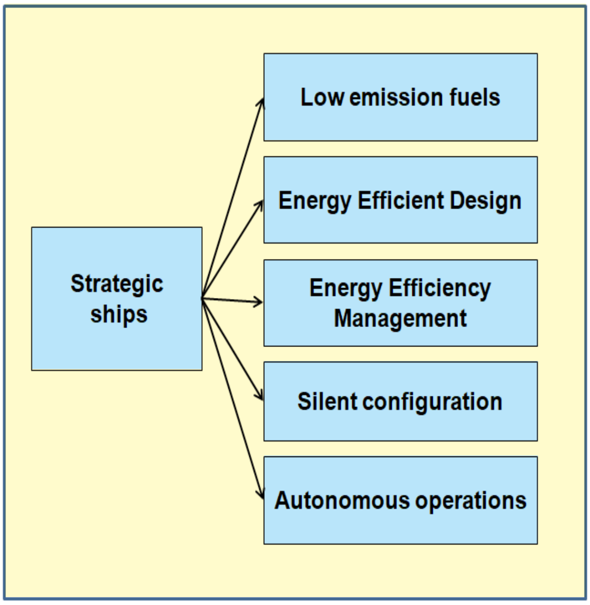

Figure.1. Requirements for strategic ships

Progress in Autonomous Ships

With the increased implementation of vessel automation and digitalisation, technological efforts in realising Marine Autonomous Surface Ships (MASS) are in progress over the past two decades. The European Commission's Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) with 8 research and industry partners in Europe worked in developing technologies for unmanned and autonomous vessels. The EU-funded MONALISA/STM validation project involving a consortium of 7 partners' demonstrated route planning, route sharing and situational awareness sharing between multiple 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 that of a human navigator.

As a part of the Advanced Autonomous Waterborne Applications Initiative (AAWA) project, Rolls-Royce in cooperation with Svitzer demonstrated Sisu, the world's first remotely operated commercial vessel and the world's first fully autonomous ferry Falco with Finferries to develop solutions to optimise the safety and efficiency of MASS. The Maritime Robotics and Rakuten Institute of Technology developed a zero-emission unmanned surface vessel Rakuten for carrying out research of unmanned cargo ships. DNV along with NTNU worked on the development of an unmanned, zero-emission, short sea vessel, ReVolt to solve growing need for cargo transport capacity (**Figure. 2**). Since 2021, the Novel Inland water transport and Maritime transport concepts project (NOVIMAR) involving a consortium of 22 partners are working towards application of MASS in enabling optimal use of the waterborne system of waterways, vessels and ports/ terminals.

> **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 that of a human navigator**

In February 2020, shipping company Bastø Fosen, Kongsberg and the Norwegian Maritime Authority demonstrated the world-first fully autonomous ship carrying passengers and vehicles, by automatically performing all docking and crossing functions to a high and repeatable level of accuracy. During December 2020, MTI Co., Ltd., Japan Marine Science Inc. and Kobe University connected the autopilot of the training ship Fukaemaru with an artificial intelligence manoeuvring support system and demonstrated evasive manoeuvres in the congested waters of Osaka Bay. In addition, 22 companies including Nippon Yusen K.K. are planning for demonstration of autonomy in a coastal contained ship in congested waters.

Norwegian companies including Yara, Kongsberg Maritime, NTNU and DNV are designing an all-electric, autonomous container ship that is expected to operate fully autonomously. 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. Japanese companies Mitsui O.S.K. Lines and Mitsui Engineering & Shipbuilding Co. are working towards the deployment of autonomous ocean transport systems in 2025. In Finland, ABB has demonstrated a remotely operated passenger ferry Suomenlinna.

Understanding the importance of MASS, the International Maritime Organization (IMO) and some flag states have already started to evaluate the scoping exercises and implementing preliminary national regulations. The IMO ensures that the regulatory framework for MASS keeps pace with the 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. The scoping exercise was a starting to address human element, safety, security, liability and compensation for damage, interactions with ports, pilotage, responses to incidents and protection of the marine environment. 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 IMO guidelines, 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) considering the degree of each advanced function, the location where supporting function is provided, and the degree of human involvement.

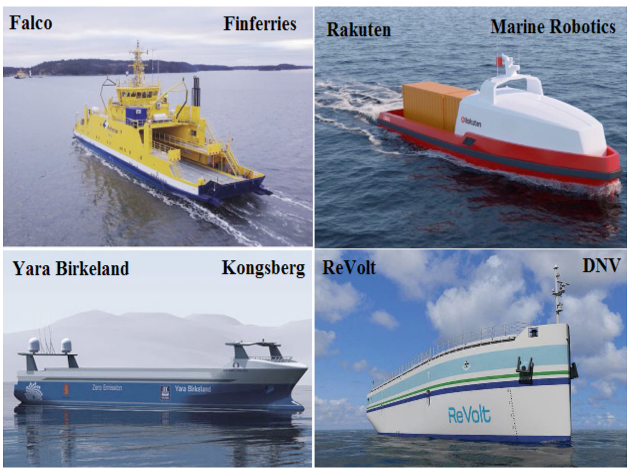

Figure. 2. Significant MASS demonstration projects

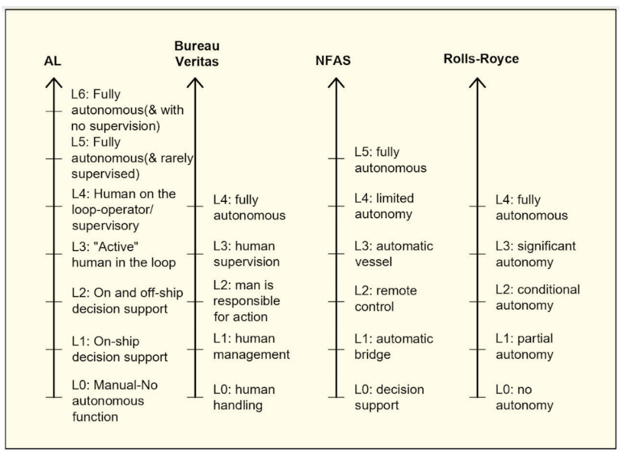

Figure. 3. MASS developments strategies by various agencies

From the ongoing MASS developments and the strategic development plans proposed by multiple agencies and various activities reported related to intelligent autonomy, the global ecosystem favours commercial deployment of MASS by 2025

Various studies compare 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 for use in MASS. From the ongoing MASS developments and the strategic development plans proposed by multiple agencies and various activities reported related to intelligent autonomy, the global ecosystem favours commercial deployment of MASS by 2025.

Technological Maturity of Autonomous Systems

The subsystems involved in vessel autonomous operations and the interface architecture is shown in **Figure. 4.** They include guidance, navigation, control, power generation and propulsion subsystems (GNCPP).

Power Generation and Management System

A typical vessel Power Generation and Management System (PGMS) with fully-redundant diesel power generators and bus coupler arrangement is shown in **Figure.5.** The Power Management System (PMS) receives the total vessel power demand from Computer Control & Sensor System (CCSS) and determines the share of active

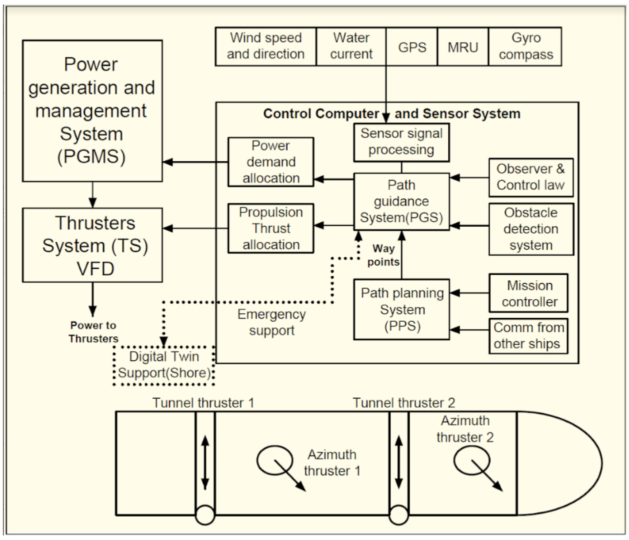

Figure. 4. Architecture of vessel autonomy-enabling systems

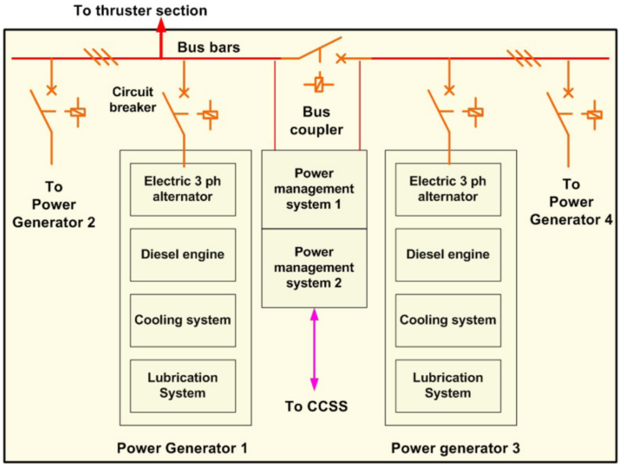

Figure. 5. Architecture of PGMS

and reactive power to be generated by the individual power generators.

The share is allocated based on their capacity and speed-droop characteristics. Based on the allocated targets, electronic speed governor in the respective diesel engine or steam turbine throttles the fuel/steam to deliver the targeted active power (kW) and Automatic Voltage Regulator (AVR) in the alternator to meet the reactive power (kVAR) target.

The PMS which houses required control systems for automatic synchronising of power generators to the bus bars also monitors the health of the alternator, engine, cooling and lubrication systems. The power optimisation algorithm such as particle swarm optimization (PSO) in the PMS ensures optimal loading of diesel generators (Maximum continuous rating -MCR) ensuring highest possible fuel efficiency.

At present vessels feature Integrated Full Electric Propulsion (IFEP) systems that use diesel generators for base load and gas turbines to meet peak loads. The intelligent power optimization algorithm ensures optimal loading of generators ensuring fuel efficiency considering the dynamic non-linear loads arising from a wide variety of load profiles.

The Equivalent Consumption Minimization Strategy (ECMS)-based supervisory control facilitates optimisation of fuel consumption by converting electrical power into the equivalent fuel consumption ensuring

The power optimisation algorithm such as particle swarm optimization (PSO) in the PMS ensures optimal loading of diesel generators (Maximum continuous rating -MCR) ensuring highest possible fuel efficiency

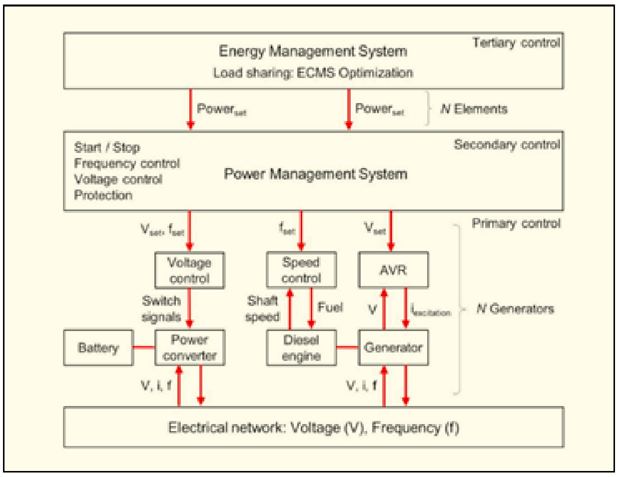

Figure. 6. Architecture of energy management protocol in PGMS

optimal load sharing between power generators and other power sources (renewable and battery storage) (**Figure. 6**). During uncertainties in dynamic response and time-varying weather conditions, modern ECMS uses predictive control methods such as Particle Swarm Optimization (PSO) techniques to mitigate power system instabilities, maintaining energy efficiency and reducing emissions.

Path Planning System

The CCSS comprises of two sections including Path Planning System (PPS) and Path Guidance System (PGS). The PPS comprises of Programmable Automation Controlle (PAC) operating the mission objective-based trajectory planning algorithm (TPA). The TPA determines optimal and safe way points based on the objective anisotropic cost function that minimises travel time, lower energy consumption and increased safety, amidst constraints such as utilising/avoiding the favorable/harsh environmental conditions in the navigating area, the vessel dynamic maneuverability limitations/agility in all the degrees of freedom, presence of dynamic obstacles such as other passing vessels, and the information received from the other ships on or closer to the trajectory being considered. The output of the PPS serves as way point inputs to CCSS-PGS.

Subsequent to Dijkstra shortest path algorithmand fast-marching methods, numerous TPA are operational in various terrestrial vehicles and autonomous underwater vehicles. These TPA fall in four categories, including artificial potential field, geometric model search, random sampling, and intelligent bionic methods that can be adopted for use in MASS after due validation. The TPA classified based on their application in predictable and unpredictable environments.

The TPA also takes inputs from the collision avoidance algorithm. The collision avoidance algorithm receives inputs from the RADAR, LIDAR and on-board cameras. Combined with the positional data from Inertial Measurement Units (IMU), RADAR/LIDAR point clouds are accumulated over time to form detailed 3D representations of static environments, which enables precise mapping of surrounding static and dynamic environments, more critically during autonomous berthing in a congested port. Based on the progressive position of the ship and dynamic position of the obstacle/ other approaching ship, TPA redefines the path so that the vessel maneuvers effectively out of the collision zone.

Path Guidance System

The CCSS_PGS controller receives vessel trajectory definition/ way point inputs from the high level CCSS_ PPS. The PAC in the CCSS-PGS operates the vessel Propulsion Plant Model (PPM) consisting of engine, propeller and vessel maneuvering models with multiple degrees of freedom (DoF). The maneuvering model, based on ship translation dynamics calculates the ship speed by integrating the force balance between the vessel resistance and the thrust forces. The vessel resistance parameters are usually obtained from experimentally-validated hydrodynamic models. The propeller model based on shaft rotation dynamics calculates the shaft speed by integrating the torque balance between the engine and propeller. The output from the propeller and maneuvering model provides input to the engine model for computing the power generation requirements. In addition to the PPM, CCSS-PGS PAC also receives the environmental disturbances from the environmental sensor suite comprising wind speed, wind direction and water current velocity, real-time position from the Global Positioning System (GPS) and/or acoustic base line systems, and vessel attitude from Motion Reference Unit (MRU) (**Figure. 7)**

With the aid of PPM, environmental, attitude and position inputs, the control law/algorithm operating in the CCSS_PGS controller generates a speed control signal for thrusters in all three DOFs. In addition to PD/PID control, the path planning function is supported by kinematic non-linear function that operates based on Lyapunov theory and integrator back-stepping that offers reliable and effective control during environmental disturbances and parametric uncertainties.

The vessel dynamics is described using a multi-DOF maneuvering model represented by highly-coupled and non-linear first-order ordinary differential equations containing kinetic and kinematic parts. The kinematics represents the geometrical evolution of the vessel in Euler angles (including surge, sway and heave in linear orientation, and pitch, roll and heading/yaw in the angular orientation). The kinetics are the forces and moments causing

The recent deep reinforced machine learning (DRL) controllers are developed using algorithms that can learn to execute tasks by reinforcing actions based on performance metrics

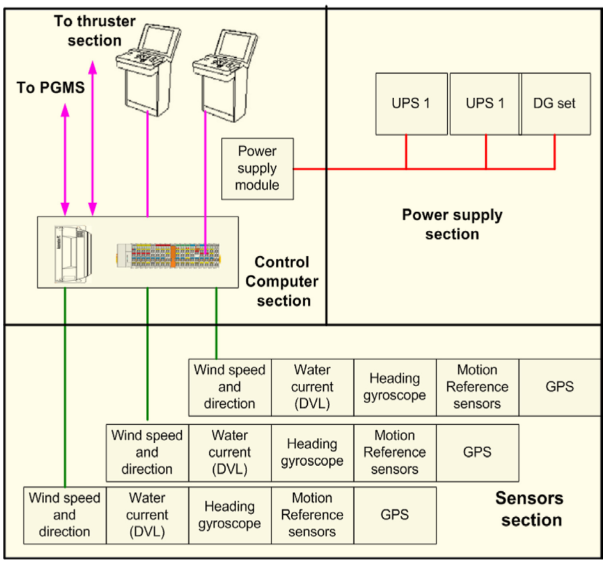

Figure. 7. Sensors and power supply architecture in CCSS

vehicle motion, in which, the linear forces are represented by X, Y and Z, and the angular moments by K, M and N. The kinetics includes mass forces, coriolis forces, damping and restoring forces. Based on the changes in the vessel attitude and position, the controller dispatches the control command to the propulsion system.

The speed signal to the propulsion thrusters shall be proportional to the 3-D position and heading deviation error-vector referenced to the vessel position relative to the desired set point (proportional term), velocity deviation vector(differential term) and to the accumulated position deviation vector (Integral term). In addition to PID, the control functions are based on Proportional-Derivative (PD), sliding mode and fuzzy logic. The recent deep reinforced machine learning (DRL) controllers are developed using algorithms that can learn to execute tasks by reinforcing actions based on performance metrics. The DRL controllers with the reward function offer very impressive results in achieving the objective of optimal path-following. The controller also receives the state estimate inputs from the observer module based on adaptive wave filtering techniques. In case of lost or erratic sensor signals, the Kalman predictor algorithm in the observer module provides dead-reckoning capabilities. The controller also incorporates functions for system status handling, mode transition from auto tomanual and model adaptation. Modern controllers include non-linear output feedback control, nonlinear passive weather optimal,fault tolerant, back-stepping and robust and adaptive fuzzy types that helps to achieve wider technical solutions. Thus, CCSS_PGS controller provides thrust allocation command to propulsion TS and power demand allocation to PGMS through datacommunication bus.

Propulsion System

The vessel propulsion system comprises of redundant Medium Voltage Variable Speed Drive (MV-VFD) driven azimuth and tunnel thrusters. Each thruster train comprises the MV-VFD, 3 phase squirrel cage induction electric motor, speed reduction gear and fixed-pitch propellers. All 2 azimuth and 2 tunnel thrusters are operated by independent trains.The MV-VFD, on receiving the thrust allocation command from the CCSS-PGS, dispatches the respective power to the electric motor (**Figure. 8**). The CCSS_PGS controller functions as a master and PGMS and TS section control systems operate in slave mode. Power regulation by varying the output voltage and frequency isdone in power electronics-based inverter and active front end (AFE) sections of the VFD. The Insulated Gate Bipolar Transistors (IGBTs) are active components in the VFD that carry out power regulation based on Pulse Width Modulation (PWM) techniques. The computations of the firing angles for IGBTs are done by power electronic controller unit and cooling section provides adequate cooling to IGBTs by circulating cooling water through heat sinks.

The technological maturity of the GNCPP system computed based using GRIF reliability modeling and simlation tool (Failure trees and Safety Integrity Level) with field-failure data as inputs (OREDA, IEEE, FIDES etc) indicates that the GNCPP systems have a probability of failure 50.1% in 1 year, which corresponds to an Mean Time To Fail (MTTF) period of 2.1 years **(Figure. 9).** The Probability of Failure on demand (PFD) analysis results also indicate that the healthiness monitoring interval

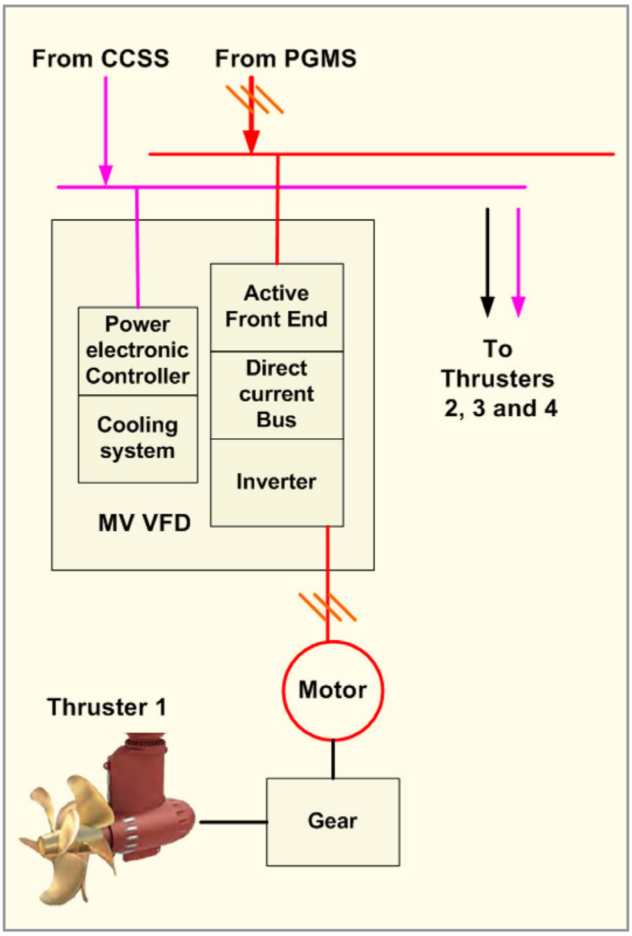

Figure. 8. Architectue of the propulsion thruster section

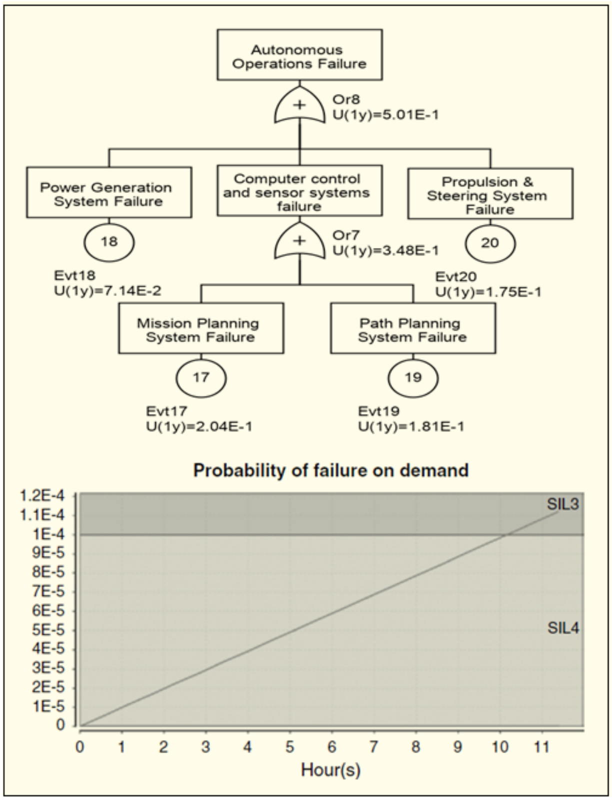

Figure. 9. Technological maturity of autonomy-enabling systems

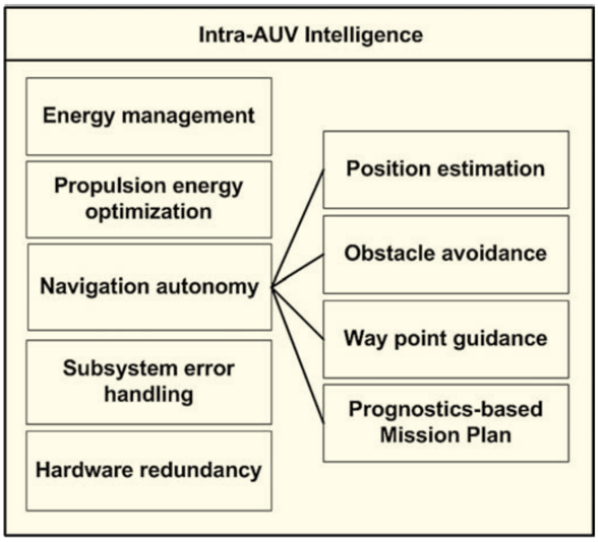

Figure. 10. Importance of autonomy in navigation & error handling

for the GNCPP systems should be 10h to maintain the autonomy-enabling systems in SIL4 category.

Importance of Autonomy in Navigation and Fault Handling

Even though autonomy-enabling technologies are expected to positively impact on the safety, efficiency and sustainability of vessel-based marine operations, actualisation of MASS will pass through the interplay of several technical, social, economic and regulatory factors. More importantly, the link between modern intelligent technology and regulations will be dominant. Computer systems replacing the human operator (partly or fully) should demonstrate total compliance with the existing international regulations, specifically Convention on the International Regulations for preventing collisions at sea (COLREG). This addresses the conflict detection and resolution between vessels. As mapped in **Figure.10**, autonomy in navigation, subsystem fault handling and predicting vessel behaviour during safety-critical situations requires development and implementation of latest situation-aware technologies for ensuring safety at sea.

Computer systems replacing the human operator (partly or fully) should demonstrate total compliance with the existing international regulations, specifically Convention on the International Regulations for preventing collisions at sea (COLREG)

Conflict resolution is the core of collision prevention that determines collision-free solutions for the ship. They include rule-based methods, virtual vector methods, discretisation, 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 ship's states become progressively more important for autonomous execution of safety-critical manoeuvres. Presently, radar systems offer decision support in collision-free navigation. But it is the professional navigator who interprets 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.

Various 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 (**Table.1**). However, hitherto, there is no standardised or internationally agreed validation method for collision avoidance algorithms. Most of the investigated algorithms are not fully COLREG compliant, capable of handling typical encounter situation in high density traffic areas, traffic separation schemes and narrow channels, where majority of the accidents were reported.

Table. 1. COLREG for conflict resolution among MASS

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
Optimization algorithm / bionic algorithm	Model predictive control, Distributed random search, Multi-objective optimization, Particle swarm optimization, Bacterial foraging optimization, Artificial fish swarms, Ant colony optimization, 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

During failures in the MASS-GNCCP systems, as suggested by MUNIN project, the shore-based stations could extend support in ensuring safe operations at sea. However, the shore-based stations require reliable Decision Support Systems (DSS) for supporting the vessel in distress due to unpredictable vessel manuverability arising out of ship system failures, harsh sea conditions and due to the presence of static/dynamic obstacles. This requires shore-based/on-board AI/ML-enabled situation-aware digital-twin as an intelligent decision system for the ship's GNCPP systems.

In the high-tech manufacturing sector DT are used to spot emerging problems and simulate the effect of upgrades and design changes, thereby reducing field-tests

Evolution of Digital Twin

The concept of physical twin was first applied during the failure of the life-support system in NASA's Apollo-13 space program, where engineers on ground needed to be able to rapidly account for changes to their vehicle (322,000kms away) while exposed to the extreme conditions in space, and with lives on-board. Subsequently, with the advancements in digital technologies, the concept of Digital Twins (DT) was described by David Gelernter in 1991 in his book Mirror Worlds. The concept and model of the DT was first publicly introduced in 2002 by Michael Grieves for product lifecycle management, which was subsequently used by John Vickers of NASA in a 2010 roadmap report.

A DT is a dynamic digital representation of an object or system (describing its characteristics and properties as a set of equations) that spans its lifecycle, is updated from real-time data streams (from IOT-based systems), and uses simulation, machine learning, analyse possible outcomes and reasoning to help decision-making.

In view of its distinct advantages, DT is being widely used in product development, maintenance, automotive, medical and for supporting critical manned and unmanned missions. In the product development domain, DT is used to create a concept configurator during development phase and for enabling simultaneous evaluation of customer requirements.

In the high-tech manufacturing sector DT are used to spot emerging problems and simulate the effect of upgrades and design changes, thereby reducing field-tests.

In the maintenance sector DT are used for monitoring, diagnostics and prognostics so as to optimise asset performance and utilisation.

In the automotive domain, DT use live data from multiple sensors to track the energy consumption under different driving regimes and in varying weather conditions. In the aviation sector, AI-based DT is presently used by General Electric, Rolls-Royce and Pratt & Whitney to maintain simulations of individual engines at engineering centres on the ground based on real-time data from their counterparts in the air. Incorporating sensor data from real-world vehicles into these tests helps companies improve the veracity of their simulations and identify blind spots in the virtual test database. Recently engineers at Cranfield University are proposing to expand the idea of digital twinning to produce a "conscious aircraft", which involves creating a DT of an entire plane by integrating its monitoring systems, and interpreting the results using AI.

The typical architecture of an AI-enabled situation-aware DT used for decision support is represented in **Figure.11.** They include numerical models of the subsystems, sensors that create standardised data streams on the operational status of the systems and real-time interface with data repository for enabling machine learning. Influence of potential failures and abnormal environmental conditions could be simulated using the DT for decision-making.

Digital Twin for Manned and Unmanned Ships

The DT is a comprehensive mathematical model / virtual replica of the physical ship, including the ship-specific vessel dynamics, power, propulsion, navigation,

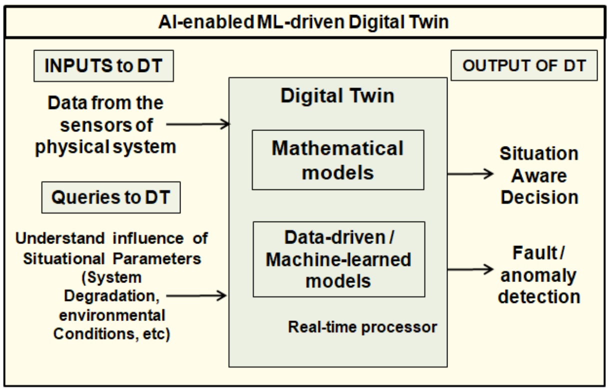

Figure. 11. DT in situation-aware decision-making

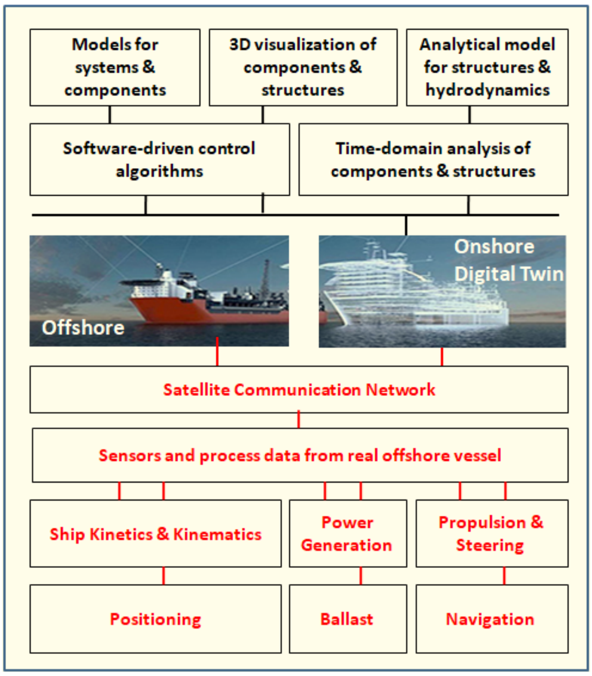

Figure. 13. Confguration of MASS involving shore-based DT

positioning, ballast, dynamic positioning and other automation systems. It co-exists with its physical counterpart and maps the dynamic behaviour in real-time, emulates sea conditions with inputs from environmental, navigation and obstacle monitoring sensors, thus helping the navigating personnel to have early and efficient control over the degraded vessel. The DT shall integrate sensor data from the vessel on-board Integrated Vehicle Health Management (IVHM) system, maintenance history and all available historical and fleet data obtained using data mining and text mining. By combining all of this information, the DT continuously forecasts the health of the vessel or subsystem, remaining useful life and the probability of failures over time.

> **In case of manned ships, DT are operated on-board, while in the case of MASS, DT could be operated at the shore station with the sensor data streamed in real-time through offshore satellite communication networks**

The DT implementable for manned ships and MASS are described in **Figure.12.** In case of manned ships, DT are operated on-board, while in the case of MASS, DT could be operated at the shore station with the sensor data streamed in real-time through offshore satellite communication networks. The configuration of a shore-based MASS DT is depicted in **Figure.13,** in which the data from sensors from the offshore-located real vessel (including ship kinetics, kinematics, power generation, propulsion, steering, positioning, ballast and navigation) are streamed to the shore-based DT through satellite communication networks.

The DT based on the numerical/ ML data-driven models and software-driven control algorithms and subsystems streamed data as inputs, enables time-domain analysis and visualisation of systems and structures, as well as simulate the behaviour of the subsystems/vessel during various subsystem degradation/ failure scenarios. The outputs of the DT serve as important inputs to access/maintain the reliability/ performance and safety of the vessel while in high seas by emulating specific safety-critical scenarios, as well as hard-to-predict operational scenarios.

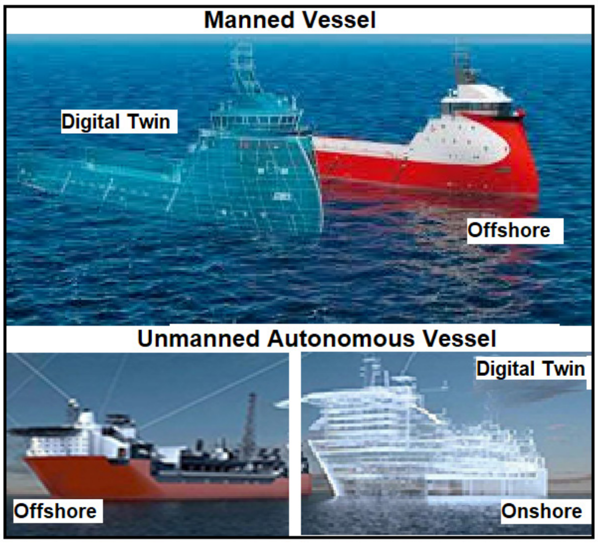

Figure. 12. Digital twin for manned and unmanned ships

Machine Learning Algorithms for MASS Implementation

The evolution of AI/ML algorithms since 1980 categorised into traditional, deep learning and transfer learning is mapped in **Figure. 14.** An AI-enabled machine-learned DT shall support MASS implementation by proving real-time support through –

- Computing the safest (collision-free) vessel trajectory on a finite moving horizon in high density traffic areas.
- Identifying fixed obstacles preventing allision.

- Predicting dynamic obstacle motion considering uncertainties.
- Incorporating non-linear dynamic vehicle behaviour, steering and propulsion system by incorporating:
  - o Environmental forces.
  - o Uncertainties associated with sensors and predictions.
  - o Vessel operational constraints.
  - o Planned trajectories of other vessels in the vicinity, their evasive manoeuvres and unexpected manoeuvres.

Machine Learning (ML) is the creation of sophisticated algorithms that can give the computer the ability to learn and act for the user without being directly programmed to do so

Machine Learning (ML) is the creation of sophisticated algorithms that can give the computer the ability to learn and act for the user without being directly programmed to do so. The classification of ML algorithms is represented in **Figure.15.** ML algorithms are also divided into four categories, including decision matrix algorithms, cluster algorithms, pattern recognition algorithms and regression algorithms.

Supervised ML algorithms use large amounts of labelled data to analyse and learn. These algorithms learn from the training data and are then given test data to see how well it accurately predicts, which is presented through an accuracy percentage in image processing applications. The user then analyses these answers and any errors are corrected and re-learned, helping train the model and increase the accuracy of a given algorithm. Thus supervised algorithms make use of a training dataset to learn and they continue to learn till they get to the level of confidence they aspire for (the minimisation of the probability of error). Supervised algorithms are sub-categorised into regression, classification and anomaly detection or dimension reduction.

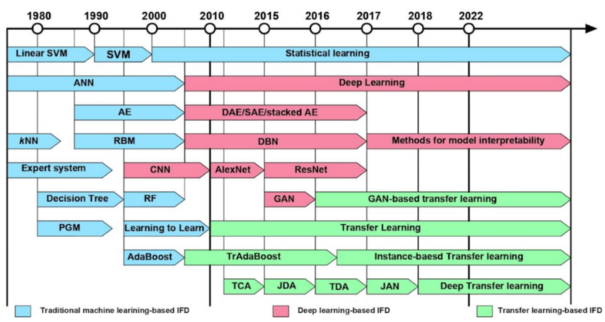

Figure. 14. Trends in AI-ML

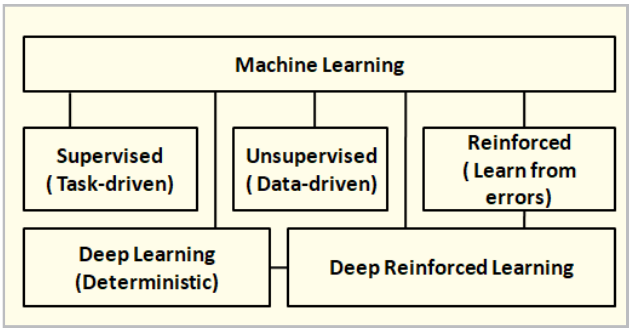

Figure. 15. Classification of ML algorithms

Unsupervised ML does not require expensively marked-up data as is required for supervised ML. Unsupervised ML algorithms learn using its own methods in categorising and highlighting patterns within the available data, instead of relying on user feedback. The algorithm develops a relation in order to detect the patterns or divides the data set into subgroups depending on the level of similarity between them. Thus unsupervised ML algorithms learn to cluster unlabelled data sets together, potentially showing hidden patterns that were not explicitly identifiable. Unsupervised ML algorithms can be largely sub-categorised into association rule learning and clustering.

Deep-learning algorithms are based on the structure and function of the human brain. They learn unstructured and unlabelled data using complex neural networks with autonomous input feature extraction, as opposed to manual extraction. Their three-layered neural network consists of input, hidden, and output layers. When the input data is applied to the input layer, output data in the output layer is obtained. The hidden layer is responsible for performing all the calculations and 'hidden' tasks. Recent deep-learning algorithms include Convolution Neural Networks (CNN), Long short term memory networks (LSTM), Recurrent Neural Networks (RNN), Generative Adversarial Networks (GAN), etc. The CNN based deep-learning is through a family of multi-layered deep-learning algorithms, in which discrete features can be detected. CNN algorithms define a series of mathematical convolutions to generate the output from the input, allowing all instances of a feature falling within a data set/ image to be located based on a predefined set of features.

Deep Reinforcement Learning (DRL) algorithms are another set of ML algorithms which fall between unsupervised and supervised learning, in which an agent learns a policy to optimally react to its environment through trial and error, given only a scalar reward signal as feedback (**Figure.16**). It is used in enabling autonomous driving (trajectory optimization, motion planning, dynamic pathing, controller optimization, and scenario-based learning policies), industry automation (training robots to perform tasks), natural language processing, health care, optimising large-scale production systems, gaming and marketing. Russel and Norvig define an agent as anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators. This framework is advantageous in control problems where hand-crafting

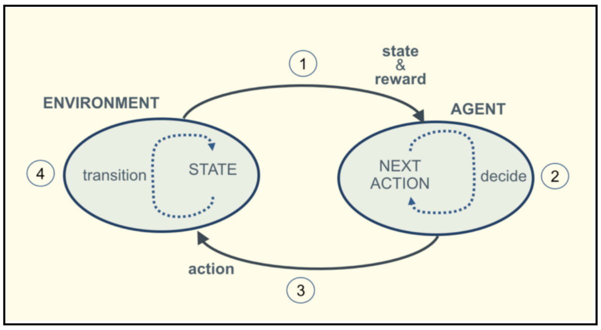

Figure. 16. Principle of reinforced machine learning

a control law is intractable or if a dynamics model is unobtainable, which is a case for MASS behaviour during subsystem degradations.

As described in **Figure. 16**, DRL consists of time-delayed and sparse labels, which are future rewards. The agent learns to behave in environment depending on these rewards. The learner and the decision maker are called the agent. The agent interacts at a sequence of discrete time steps with its environment. At each step the agent receives some representation of the environment's state, and on that basis selects an action. One step later, as a consequence of its action, the agent receives a numerical award, and moves to the new state. The agent thus seeks to maximise the received awards over time. Thus the goal of DRL is to understand the limitations and merits of an algorithm and to develop efficient ML process. Recent DRL algorithms include off-policy, on-policy, deep deterministic policy gradient (DDPG), twin delayed DDPG, Soft Actor-Critic and proximal policy optimization. Based on the scalability, learning speed and/or convergence performance in complex domains, they are further classified into reward shaping, multi-agent RL (MARL), multi-objective RL (MORL), State representative learning (SRL), and learning from demonstrations.

Implementing AI for MASS DT by Machine Learning

Realising situation-aware DT for MASS-GNCPP systems (**Figure. 4**) requires implementation of AI through rigorous DRL process, so that it becomes capable of reliably operating/guiding the MASS equivalent to an experienced engineer/pilot/navigator during safety-critical situations, unpredictable operational scenarios and vessel degradations. Safety-critical situations include path/trajectory planning to avoid collisions in areas with vessel traffic and while navigating in high seas, following traffic policies for conflict resolution with the approaching vessel described by COLREG rules (**Table. 2**), mauverability support in first-time-access locations (without the aid of local port pilot), unpredictable environments, during subsystem degradations/failures and in rough environmental conditions. Hence enabling AI to the ship DT through DRL process helps in realizing "situation-awareness". The process of implementing AI to the autonomy-enabling systems forming part of the DT based on Percption-Planning-Action methodology is detailed in **Figure. 17.**

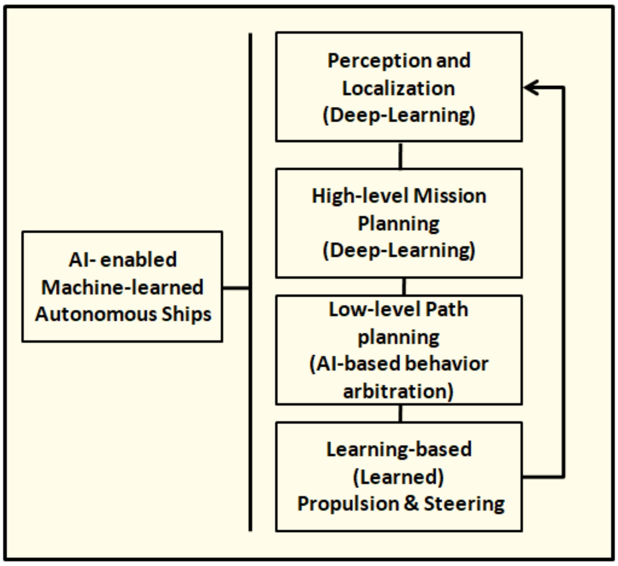

Figure. 17. Implementation of AI to MASS-DT using DRL

Table. 2. COLREG for conflict resolution among MASS

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

Vision

DRL is a promising solution in realising AI-enabled DT for steering/COLREG through predictive perception (based on visual odometry), path planning (by classifying different objects), motion planning and driving the low-level propulsion controller. Perception and localisation helps the vessel to see the world around itself, as well as recognise, and classify the objects that are within the field of vision, with the aid of RADAR, LIDAR and cameras. Localization algorithms calculate the position and orientation of the vessel as it navigates (visual odometry).

Visual odometry works by matching key points in consecutive video frames. With each frame, the key points are used as the input to a mapping algorithm. The mapping algorithm, such as Simultaneous localization and mapping (SLAM), computes the position and orientation of each object nearby with respect to the previous frame and helps to classify objects around.

Neural networks, such as PoseNet and VLocNet++, are some of the frameworks that use point data to estimate the 3D position and orientation based on scenario classification through data fusion from different ship-board internal and external sensors (**Figure. 18**). These estimated 3D positions and orientations can be used to derive scene semantics. The integrated analysis of low-level image features, together with high-level semantic and 3D object models, will enable robust scene understanding in complex and ambiguous environments. The role of DRL is to interpret complex vision tasks, localise itself in the environment, enhance perception, and actuate kinematic maneuvers in MASS, thus ensuring operational safety. DRL used for decision-making is based on Markov decision process and Bayesian optimization. They can be used to predict the future behavior of moving objects and to find the safe/optimistic route. Decision making is a heiarchial process involving path/route planning, beahviour arbitration (uncertainty in the behavior of other approching ships is solved by using probabilistic planning algorithms), motion planning and vehicle control.

Propulsion and steering

Larger ships have limits in manoeuvrability, especially in channels or crowded port, hence the likelihood of accidents caused by collision and contact is high. Therefore, manoeuvrability is one of the important functions that need DRL in order to ensure passenger and cargo safety, as well as sea keeping performance. The International Towing Tank Conference (ITTC) has proposed the standard for ship manoeuvres for sea trials such turning circle, zig-zag manoeuvre, pull-out manoeuvre, spiral manoeuvre, reverse spiral manoeuvre and stopping trial. **Figure. 19** shows the coordinate systems for investigating the manoeuvrability, indicating earth-fixed and body-fixed coordinate system that moves together with the ship. The heading angle (ψ) is the angle between the direction of x_0 axis and x axis. In the earth-fixed coordinate system, the ship centre of gravity is assigned as the position of ship and the heading angle (ψ) is determined by the orientation of ship.

Predicting the mauverability of a vessel using a DT and DRL could be done using a numerical model with inputs including rudder angle, speed/thrust of the main

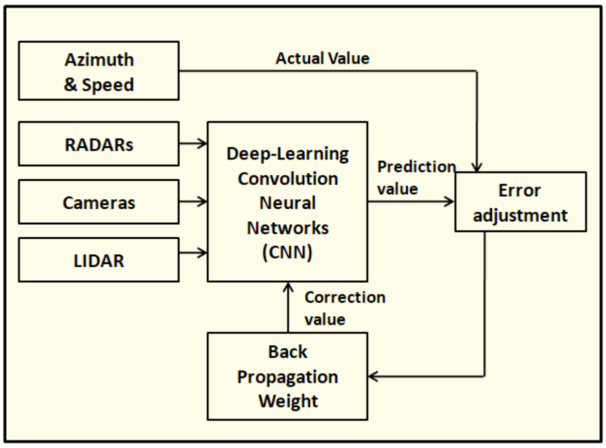

Figure. 18. Application of CNN in DRL for vision supported steering

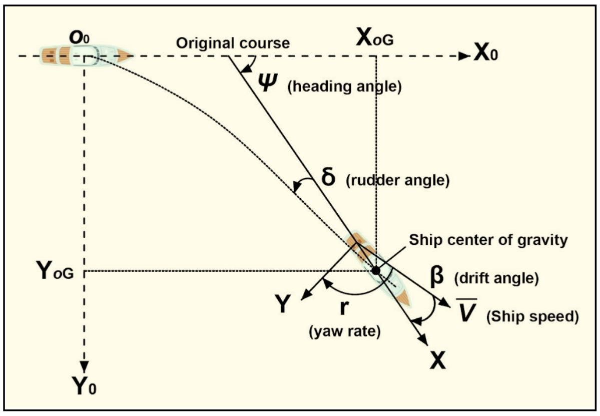

Figure. 19. Coordinate system for representing ship manoeuvrability

and azimuth propeller and the sea state (equation 1), in which M and L are the mass and length of the ship, Y is the hydrodynamic force acting based on the sea state, M is the moment, Xg is the centre of gravity, Yv1 is the y-component of hydrodynamic force and Nv1 is the virtual moment of the inertia coefficient.

$$R = \frac{Y'_v(N'_r - m'x'_G) - N'_v(Y'_r - m')}{(Y'_v N'_\delta - N'_v Y'_\delta)} \frac{1}{\delta} L$$

The hydrodynamic derivatives are developed using Clarke approach. The mass and the centre of gravity are derived based on Schneekluth's method. The acceptance criteria of manoeuvring follow the regulation of IMO Resolution MSC 137 (76) which states that the tactical turning diameter should be less than five times ship length. The manuverability of the vessel (turning radius) for various rudder angles/azimuth thrust are described in **(Figure. 20)** is a key input for implementing COLREG algorithms. Through DRL, the DT shall learn from the results of the numerical studies carried out on the vessel under normal and degraded conditions, data logged in the sea under various operational and environmental

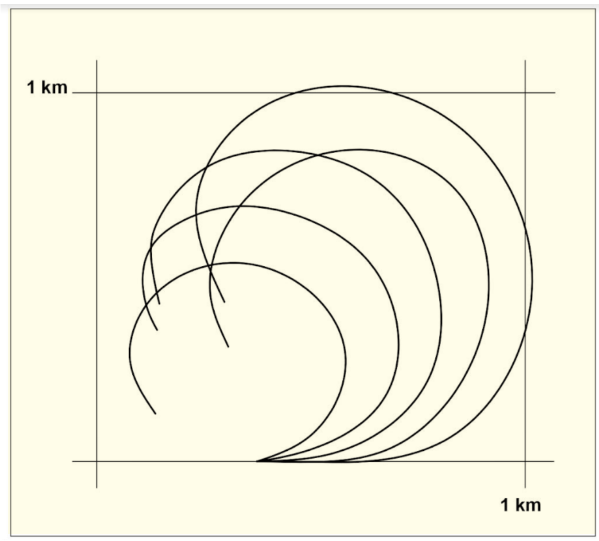

Figure. 20. Manuverability under various rudder angles/azimuth thrust

scenarios. The learned DT shall thus support MASS-GNCPP in ensuring reliable performance during safety-critical situations arising out of vessel degraded operations, implementing COLREG (**Figure. 21**) through reliable conflict detection and resolution, berthing in first-time-access locations (where a port's local pilot support is essential), unpredictable operational scenarios and in rough sea conditions.

Intelligent Fault Diagnosis

Intelligent Fault Diagnosis (IFD) is the key for enabling autonomy of MASS. Failures/faults are likely to occur in electric motors, diesel engines, alternators, bearings, gear boxes, etc. In electric propulsion motors, stator winding inter-turn faults are identified from the negative sequence currents, negative sequence impedance and electromagnetic torque harmonics. Motor rotor failures are caused due to magnetic stresses caused by the electromagnetic forces/unbalanced magnetic pull, dynamic stresses due to shaft torques, abrasion of the rotor material and mechanical stresses due to the loose laminations. In medium voltage motors, a broken rotor bar or a loose connection between one of the rotor cage bars and an end-ring prevents the rotor current from flowing through the broken rotor bar or into the end ring. This leads to unbalanced rotor flux that can be detected from the harmonics induced in the stator current. From the stator current harmonic analysis (**Figure. 22b**), when the sideband becomes larger than about 0.5% (-45 dB) of the power frequency current, then the rotor bars are likely to be broken.

Management of power quality in large ships requires monitoring voltage variations, frequency variations, voltage asymmetry, harmonic distortions, transient pulse disturbances and improper distribution of active and reactive power between generating sets operating in parallel, and maintain these system parameters within limits so as to ensure quality of the power system. Marine power generating sets are "weak" power sources (with 15-20 % impedance) compared to "stiff" sources (4-6 % impedance) more common in industrial applications. High capacity variable frequency converters (propeller drives) when operated in high-impedance ship mains generate harmonic and inter-harmonic distortions causing disturbances in power system. Distortions > 20% are observed on board ships many times. **Figure. 22 (b)** shows the notching caused by commutation over-voltage in MV power converter, which has resulted in voltage-THD of ~14%.

IFD constructs diagnosis models that are able to automatically bridge the relationship between the collected data and the health states of machines. Various stages involved in IFD include sensor data collection, feature extraction, identifying sensitive features and health state recognition (**Figure. 22**) The fault features are extracted from the logged data, subsequently the sensitive features are selected to train diagnosis models to establish the relationship between selected features and machine health. This process forms the basis of application of AI to fault diagnosis. Deep learning-based diagnosis models automatically learn features from the input monitoring data and simultaneously recognise the health status of the machine according to the learned features.

Emergency Support Systems

According to the International Maritime Organization (IMO) - Safety of Life at Sea - SOLAS 74 convention, in the event of ship mains failure, the emergency diesel generators (EDG) are used for powering the vessel's critical loads including emergency lighting, navigation and communication equipment, steering gear, fire and sprinkler pumps, bilge pump, water-tight doors and lifts. According to the SOLAS 19 regulations, EDG sets EDG should take the required load as quickly as is safe and practicable, and within a maximum period of 45s, and cater continuous power (18h for cargo and 36h for passenger vessels). During emergency, EDG may have to cater an additional load or for an increased duration based on the nature of emergency. The DT which is connected to the EDG measurement network shall help to predict the endurance of the EDG for various load conditions (**Figure.23**), which serves as a decision support system for rationing the power for extended durations during a crisis. Similar methodology could be adopted for estimating the navigational performance of MASS during various sea states and vessel conditions including normal and degraded modes.

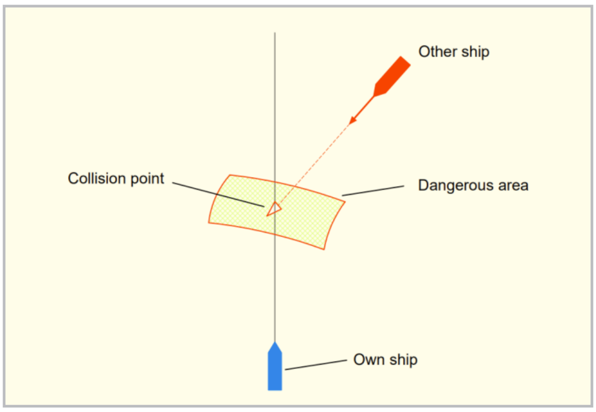

Figure. 21. Identification of unsafe zone for collision avoidance

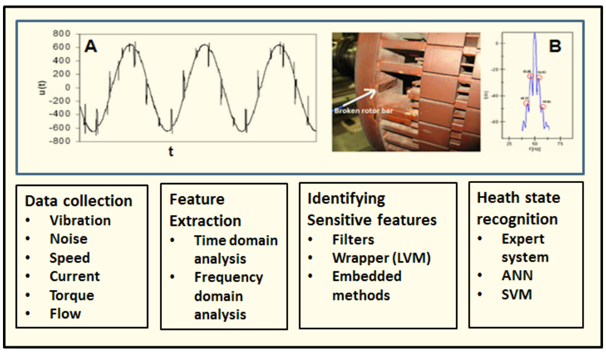

Figure. 22. IFD in power quality and electric motors

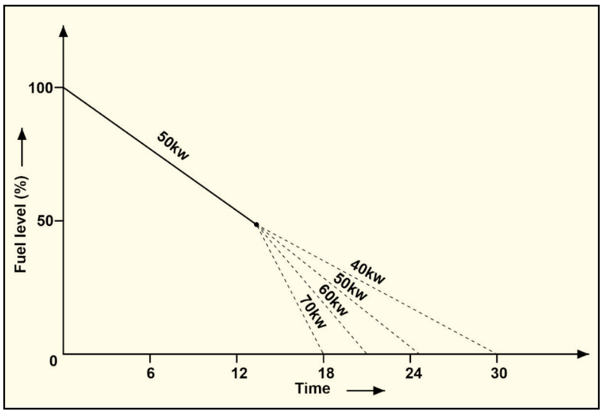

Figure. 23. DT as a DSS for rationing emergency support systems

Conclusion

Advanced sensor technology, vessel digitalisation, data analysis, autonomous path planning and efficient collision avoidance algorithms based on situational awareness and communication bandwidth to the shore are the essential requirements for safe deployment of marine autonomous surface ships. The maturing digital twin concept could be of immense use in predicting the ship response to safety-critical events in real-time and uncover previously unknown issues before they become critical by comparing predicted and actual ship responses. The importance and increasing interest in the use of digital twin is evident from DNV's in-principle approval for the innovative Hyundai Intelligent Digital Twin Ship. Digital twin enabled with deep reinforced machine learning algorithms with real-time inputs from proprioceptive sensors defining the condition of on-board equipment critical to navigation and corresponding estimated navigational capability based on exteroceptive sensors measuring the met-ocean conditions helps to develop rugged collision avoidance mechanisms mandated by COLREG. Further, AI/ML-enabled digital twin are capable of mitigating damage or degradation by activating self-healing mechanisms or by recommending changes in vessel or subsystem operational profile to decrease loadings, thereby increasing both the life span and reduce the probability of failure, thus ensuring the safety of the ship in high and rough seas.

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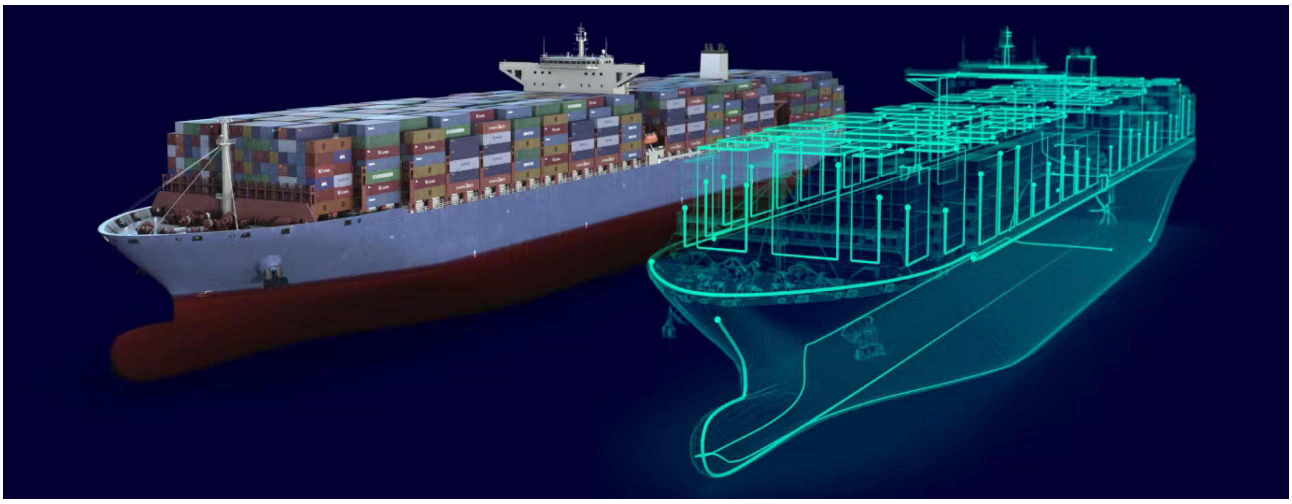
Digital Twins: A CFD Model for Vessel Motion Data Analysis



Sheeja Janardhanan, Rajoo Balaji, Piyush Raj, Anantha Krishnan A.

Abstract:

Computational Fluid Dynamics (CFD) applications have matured over the past two decades in providing vessel situational predictions at sea with reasonable degree of accuracies. This work focuses on predicting vessel motion at sea under the influence of waves using a CFD method. The analysis is one of the many sub-processes integrable in the scheme of generating digital twins. To illustrate, the ship's hull in motion is considered. Realistic wave conditions are simulated and the response of the vessel in six degrees of freedom (6 DOF) has been studied using a time marching approach. The motion response in the form of Response Amplitude Operators (RAO) gives strong implications on the sea-keeping characteristics of the vessel. A prognosis or a prediction is identifiable from the exercise as a forecasting approach depending upon the real time inputs and a compared-verified decision is possible for decision making. Future study will include collating real data from vessels and verification of some of the above propositions

Keywords: Ship's motions, simulation, wave effects, forecasting

Introduction

Digital twinning of physical systems is getting serious attention in maritime domain. With a paradigm shift in analysing data on a real time basis, port and vessel operations are expected to gain in efficiencies, including tangible reductions in emissions etc. Tools such as Software in Loop (SiL), Hardware in Loop (HiL), co-simulations etc., are being used for testing, dynamic barrier management etc. Solutions are extended to training platforms also. With sensor driven data, virtual replicas of a dynamic system at a location away from the real theatre are being envisaged under the twinning concept. Its end use ranges from simple home appliances to high fidelity designs in the defence sector. Though such a concept has been in use in automobile and military sectors, its adaptation by the maritime sector is recent and may still be termed as "works in progress". Building on real time data, such analytical systems will mature well for decision making and also for forecasting. Considering ocean going ships, this gives an immediate access to real time visualisation to monitor the system/machinery condition and status. This paper analyses a vessel's motion in the seaways. A dynamic system representation (extracted from the twin) a fluid dynamic application is carried out.

Background

A modern digital system will be based on electronic and particularly computerised technology. When such a system replicates a physical asset, it becomes a twin. In this era of digitalisation, maritime industry is witnessing the sunrise of digital twinning. At least three representative definitions for a Digital Twin (DT) are locatable, one based on ISO, one as an academic representation and one from an enterprise perspective (Wu et al., 2021). A simpler description would be that a DT arrangement typically includes a digital representation of any physical asset. **Systems such as automobiles, ships, wind turbines, container warehouses, power grids etc., can also be twinned well, representing their physical realism.**

While the discussion on DT have existed for some time, more recent concepts can be attributed to NASA and the aerospace industry (Boschert and Rosen, 2016). Case reports cite simulation of a mission in the DT to study faults and the effect of changes.

Similar scope exists along with other merits which help in decision making.

Fonseca and Casper (2021) place the DT ship implementations under two broad applications – which may be used for further classifying the literature:

- Decision support for ship operations
- System integration testing and for training

> A modern digital system will be based on electronic and particularly computerised technology. When such a system replicates a physical asset, it becomes a twin

Under the first, few ship-related studies mentioned are a simulation study on speed loss by biofouling (Coraddu et al., 2019), structural fatigue estimation (Schirmann et al., 2019) and autonomous vessels (Danielsen-Haces, 2018). Considering the second application, a simulation model on a pipe laying vessel (Tofte et al., 2019) and system integration testing of a naval ship's power systems (Dufour et al., 2018) may be cited as support. DNV records running a virtual engine room, factoring engine parameters and cost data for valuable solutions (DNV, 2017). An extended version of the DT is also being envisaged to be used as a forecasting tool for condition monitoring and calibration of propulsion systems based on ship's data (Bekker, 2018). A wide range of activities can be envisaged under the DT construct.

Methodology

The present work focuses on the prediction of vessel (ship) seakeeping using DT. The scope of this paper is confined only to the simulation of ship motion in waves using a numerical technique called **smoothed particle hydrodynamics** (SPH). SPH offers convenience in computation and the merits are enumerated as follows (Liu and Liu 2006):

(a) Implements Lagrangian approach and the distinct mesh free feature of the SPH method allows a straightforward handling of very large deformations, since the connectivity between particles are generated as part of the computation and can change with time.

(b) Facilitates easier conservation of mass as every particle represents mass.

(c) Faster computation of pressure from weighted contributions of neighbouring particles rather than by solving linear systems of equations.

(d) Ease of representation for free-surface in a multiphase flow by exploiting the density difference between the fluids.

Governing Equations in SPH:

The Navier-Stokes equation of flow is given by Eq. (1)

$$\frac{dV}{dt} = \frac{-1}{\rho}\nabla p + \frac{\mu}{\rho}\nabla.\nabla V + \frac{1}{\rho}F_{ext} + g \qquad (1)$$

Where

V is the velocity field in m/s

ρ is the fluid density in kg/m^3

p is the fluid pressure in Pa

μ is the dynamic viscosity of fluid in N-s/m^2

F_{ext} is the external force in N

g is the acceleration due to gravity in m/s^2

Each term in Eq. (1) represents acceleration. The discretisation term for each term is given by Eq. (2) through to Eq. (4).

The pressure term is

$$\langle\frac{-1}{\rho}\nabla p\rangle_i = \sum_j P_{ij}\nabla W\,(r_{ij}) \qquad (2)$$

Where $$P_{ij} = -\frac{m_j}{P_j}\left[\frac{p_i}{\rho_i{}^2} + \frac{p_j}{\rho_j{}^2}\right] \qquad (3)$$

W is known as the weighting or Kernel function.

The viscosity term is

$$\langle\frac{-\mu}{\rho}\nabla.\nabla V\rangle_i = \sum_j V_{ij}\nabla^2 W\,(r_{ij}) \qquad (4)$$

Where $$V_{ij} = -\mu\frac{m_j}{P_j}\left[\frac{V_i}{\rho_i{}^2} + \frac{V_j}{\rho_j{}^2}\right] \qquad (5)$$

Hence the total acceleration of ith particle is given by

$$\frac{dV_i}{dt} = a^{pressure} + a^{viscosity} + a^{external} + a^{gravity} \qquad (6)$$

It computes numerical acceleration of the boundary particles solving the particle interactions with fluid neighbouring particles.

We assume the same mass for all particles, $m_i = m$. The mass m is calculated by

$$m = \frac{\rho.v}{N} \qquad (7)$$

Where v is the total volume of the computational domain and N is the total number of fluid particles. Fluid dynamics computation of forces and pressure are carried out from here.

Numerical Set-up

The computational domain with a container ship S175 is shown in **Figure. 1.** Principal particulars of S175 are shown in **Table 1.**

The boundary extends are $2L_{pp}$ in front of the ship hull, $3.5L_{pp}$ behind the ship and along the transverse direction the boundaries are $1.5L_{pp}$ away from the ship hull. The bottom boundary is chosen to suit deep water conditions such that water depth to draft ratio d/T=0.6. A numerical problem holds its proximity to the actual physical one based on the appropriateness of the boundary conditions. The conditions existing at various boundaries in the present simulations are given in **Table 2**.

While the SPH method was used to compute the vessel motions in waves, the turbulence model used here is Large Eddy Simulation (LES). Since the main focus of the present study is heaving motions, the natural frequency of the bare hull (is computed using Eq. (7).

$$\omega_n = \sqrt{\frac{g.A_{wp}}{(\rho\nabla + A_{33})}} \quad (7)$$

Where A_{33} is the added mass of the hull in heave.

The natural frequency of the bare hull, taking added mass in heave 90% of the hull mass is found to be 1.0 rad/sec. The waves with an amplitude 2.0 m, an encounter frequency equal to the natural frequency and length same as L_{pp} have been induced at 0^0, $90^0$and 180^0 in order to digitally mimic the following, beam and head seas respectively.

Results and Discussions

The distribution of particles in the simulated wave is shown in **Figure. 2** and contours of free surface elevation of the three sea types are shown in **Figure. 3** respectively.

At the 0th sec of simulation, the wave crests are represented by red colour while green colour represents the wave crests.

Time histories of linear and angular displacements of the vessels in the three sea types are shown in **Figures. (4) through (6)**.

As the frequency of encounter is same, the natural frequency of the vessel in 'heave' condition, a resonance is observed in the heave motions. Pitch motion and surge motions are coupled motions with heave and they have also significantly higher amplitudes as shown in **Figure 4 through 6**. The RAOs of heave and pitch motions in various sea are shown in **Table 3**.

The results presented above lead to interesting observations. Since the heave motions are coupled to pitch, under resonance conditions of heave, significant pitching is also observed in all seaways. However, in beam sea, the sway motions are significant giving rise equally significant pitch coupled

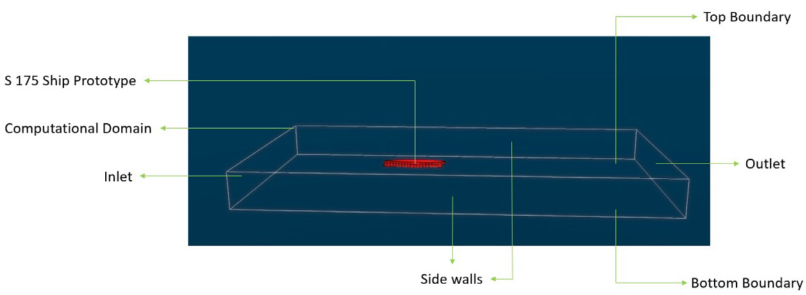


Figure. 1. Ship prototype in the computational domain

Table 1. Principal particulars of the ship

Principal Particulars	Dimensions
Length between perpendiculars (L_{pp})	175 m
Beam (B)	25 m
Draft (T)	8.5 m
Depth (D)	11.0 m
Displacement ()	21,222 m^3
Block Coefficient (C_B)	0.588
Water plane area coefficient (C_{wp})	0.85

Table 2. Boundary Conditions

Boundary	Condition
inlet	Inlet velocity with waves
outlet	Pressure outlet
top	Flow with free shear
bottom	No-slip
ship	No-slip
side walls	Symmetry

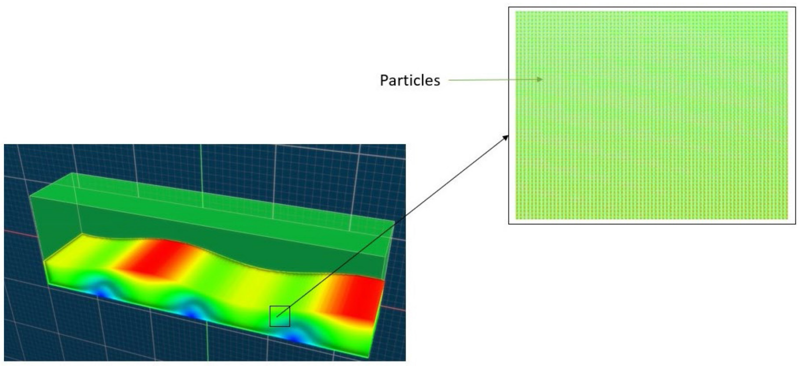


Figure. 2 Particle distribution in the simulated wave

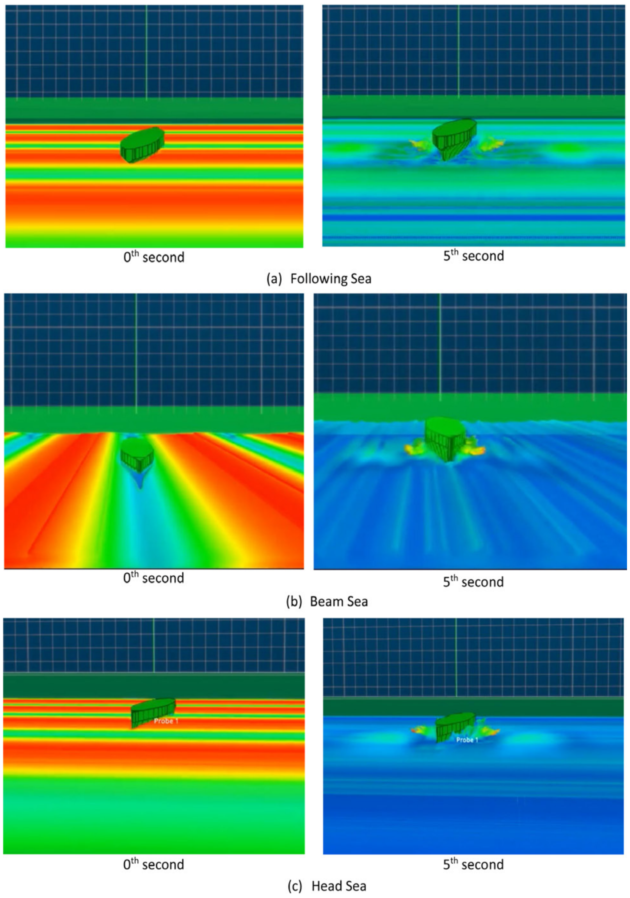


Figure. 3 Free-surface elevation at different sea states

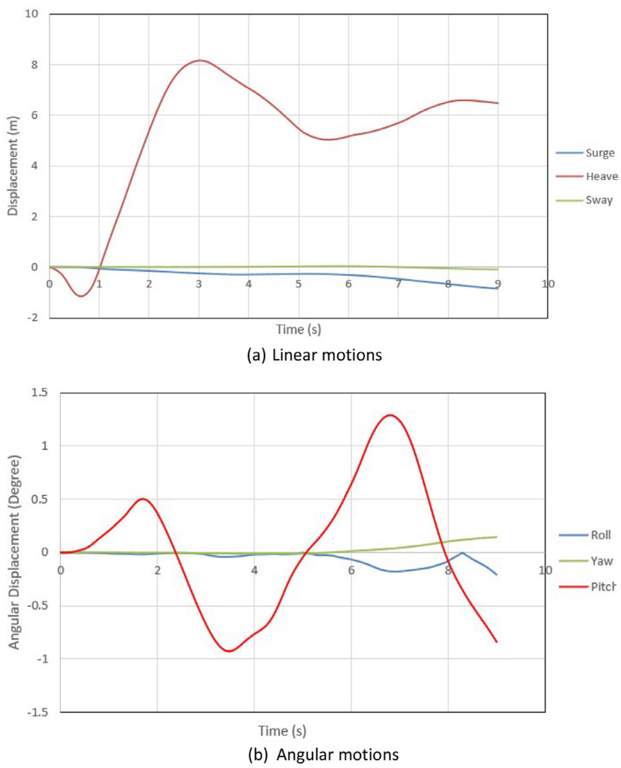


Figure. 4 Motion response of S175 in the following seaway

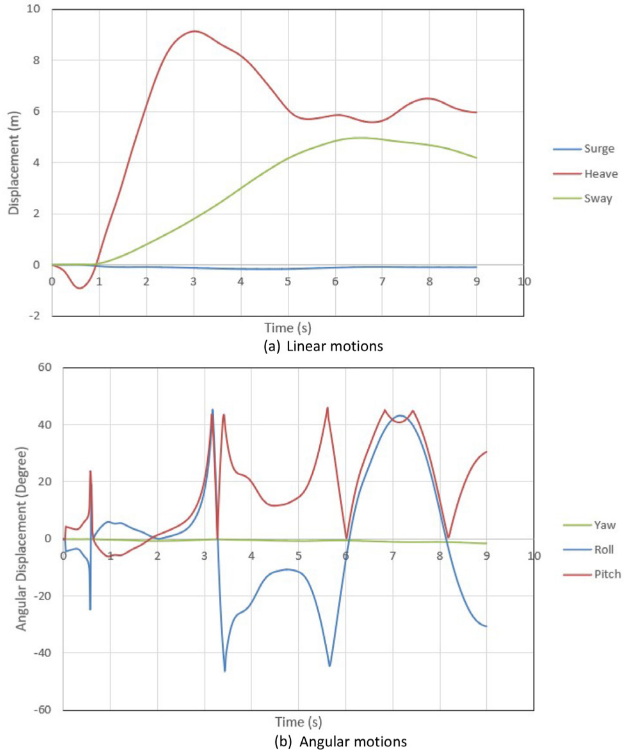


Figure. 5 Motion response of S175 in the beam seaway

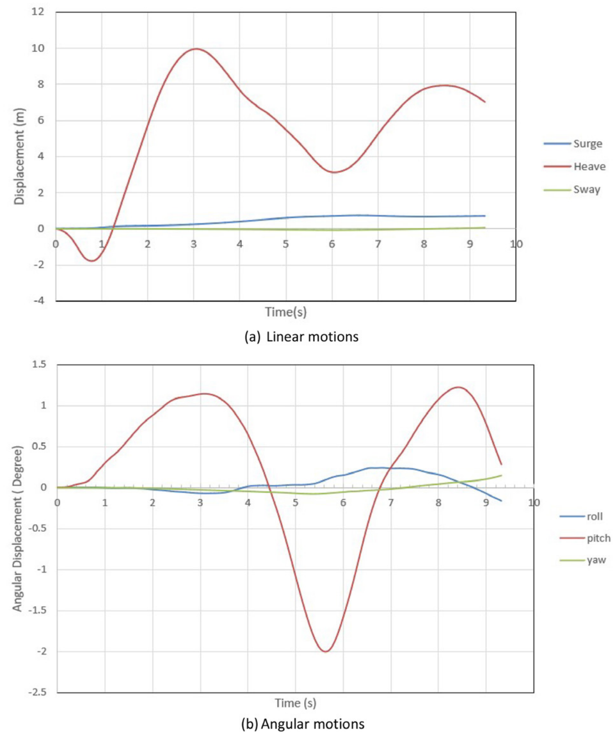


Figure. 6 Motion response of S175 in the head seaway

Table 3. RAO in heave and pitch

Sea	Heave RAO (m/m)	Pitch RAO (deg/m)
Following	4.1	0.65
Beam	4.5	24
Head	5.0	0.7

motions. In the beam sea, the sway and pitch RAOs are reported as 2.25 m/m and 24 degrees/m respectively.

Conclusions

The present CFD simulations based on SPH were carried out to accomplish a part of digital twinning of vessel motions in a seaway have yielded reliable motion prediction metrics under resonance conditions. It provides the naval architect with insights, anticipation and inputs for design and also to incorporate modifications if need be. This can be one of the modules in the entire digital twinning of a vessel-from conception to operation. When several such modules are integrated it will indeed prove to be a tool for:

- visualising vessel design, construction and operation
- providing end-to-end vessel related data to all stake holders
- enhancing the performance and efficiency of the vessels and the entire fleet

Future Work

The work can be extended to study the effect of mooring lines on heave and pitch motions of the vessel as a part of sea-keeping analysis. The work can also be used for the manoeuvrability predictions of the vessel with environmental loads such as waves. DT has a major role to play wherever there is an element of decision making involved subsequent to digital simulations. With the advances in 3D simulation and 3D printing, defence, transportation (inclusive of shipping) and manufacturing sectors are expected to make the best use of DT in the coming decade.

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How Can Technology Close The Gap Between Ship At Sea To Shore?

Maninder Singh

ABSTRACT:

In this paper, we talk about the technology available in today's market and the various digitalisation tools which bring ship closer to shore in the most efficient and effective ways. Although on broader aspect technology is the answer to almost all pain points in shipping industry but here, we describe how the most common challenges faced by shipping can be tackled with the right digitalisation tools.

INTRODUCTION

Earlier industrial revolutions have taken a new phase every 100 years, but industrial revolution 4.0 has picked up fast in around less than 50 years **(Figure. 1).** Today technology talks about innovation in production and industrial process on another hand it enables autonomous decision-making, enhancing asset management and monitoring by enabling connected networks and making asset and data easily available to stake holders. Shipping Companies are therefore exploring ways to leverage new technologies to improve the efficiency and productivity of their investments.

Exploring new technologies becomes important as failure to do so will cause shipping organisations to fall behind as operations will not be digitised enough to match their competitors.

WHY 4.0?

4.0 talks about various technologies which have been developed today and to name a few they are Autonomous Robots, Simulations, System Integration, Internet of Things (IoT), Cyber Security, Cloud Computing, Additive Manufacturing, Augmented Reality (AR), Virtual Reality(AR), Big Data (**Figure. 2**).

All these tools focus mainly on greater productivity, better resource management and more efficient decision-making based on real-time and accessible information

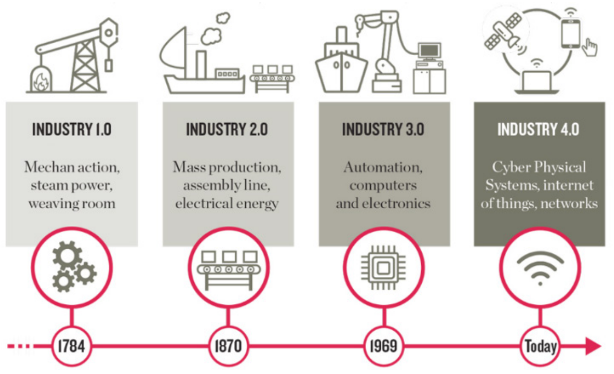

Figure. 1

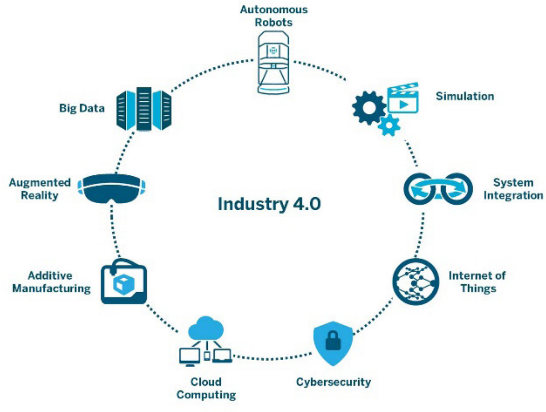

Figure. 2

MARITIME 4.0

Shipping Companies are exploring ways to leverage new technologies to improve the efficiency and productivity of their investments (**Figure. 3**). Some of these technologies are already in the implementation phase. With established IoT providers many ships' data are now well connected to shore. Other technologies (AV, Smart Port, new fuels, etc.) are also coming up.

One of the major GOALs of maritime 4.0 is:

- to develop innovative digitally connected vessels
- to bring ships closer to the stakeholders for better and faster decisions

WHY SMART SHIPPING?

Although innovation in shipping is driven by compliance, we see that industry's focus will also remain on Operational Expenses (OPEX) reductions and increasing efficiencies in operations. This requires industry to think and go smart. Investment in the right digitalisation tool could result in significant operational cost reduction, safer ships, and cleaner environment. Autonomous technology is anticipated to lessen the scope for human error from operations on the vessels, thereby reducing the risk of accidents.

Autonomous technology is anticipated to lessen the scope for human error from operations on the vessels, thereby reducing the risk of accidents

For example, (**Figure. 4**), for Fuel and Energy management performance insight, voyage planning or route planning, trim optimisation are various ways it can be dealt with. For maintenance and repair condition monitoring can be one tool. Since data analytics is becoming prominent nowadays, makers and manufacturers are fast moving from planned maintenance module to predictive maintenance module for better lifecycle of equipment and assets. Thus, digital transformation leads to significant cost savings.

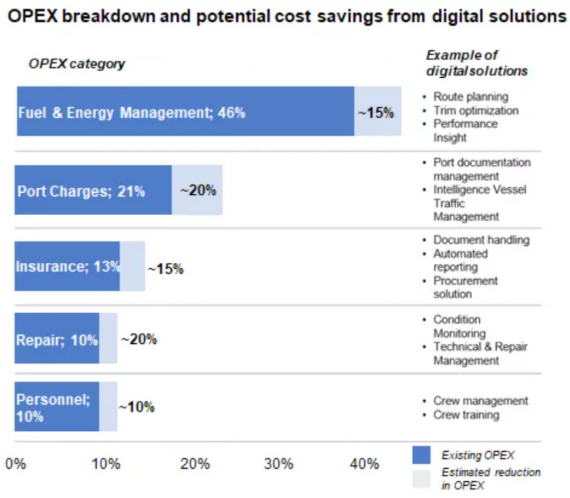

Figure. 4

Ship owners are increasingly using digital 3D models of their ships and real-time information about ship condition to improve maintenance and efficiency, and lower costs.

CHALLENGES FACED TODAY

Ships being far at sea pose inherent daily operational challenges such as crew familiarisation, cargo planning, technical review, training, repair and retrofit planning, etc. Traditionally the crew familiarisation is done using generic presentation and photos, cargo planning is done using 2D drawings of ship structure and photos/ snaps, technical review is again done through printouts of reports, historical data, photos and drawings, crew going on board vessel are trained through animation videos and presentations, repair and retrofit planning is carried our using photos or 2D drawings. Also, with the latest technological developments in the shipping industry, which involves high capital investments, the

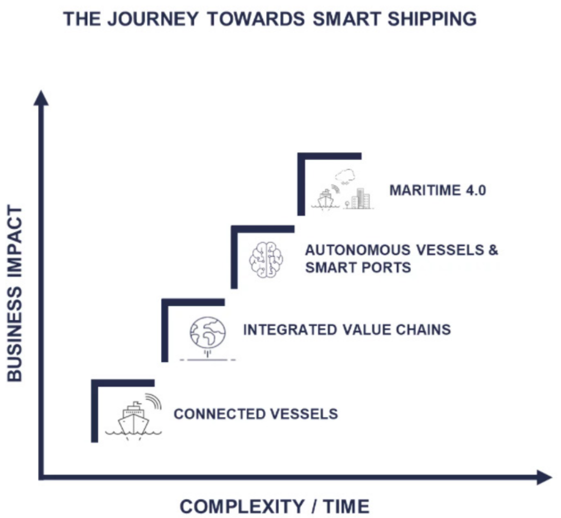

Figure. 3

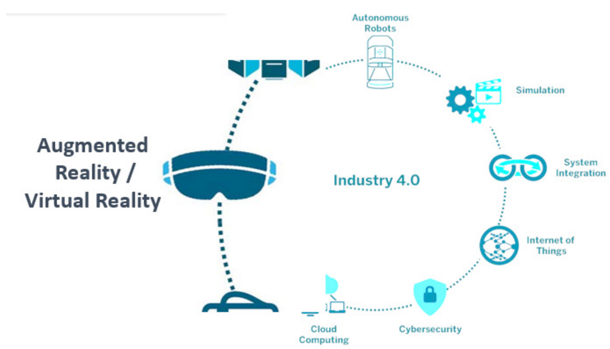

Figure. 5

risk of error margin goes high. It has been observed that 95-96% of incidents/accidents in shipping are due to human error, 3-4% machinery failure and remaining 1% is act of God. This adheres for shipping industry to go find different ways which can make it to revolutionise to Smart Shipping.

SOLUTION

One solution to above mentioned challenges from today's technology is AR/VR (Augmented Reality and Virtual Reality) (**Figure. 6**). In simple terms Augmented reality (AR) augments our surroundings by adding digital elements to a live view, often by using the camera on a smartphone while Virtual reality (VR) is a completely immersive experience that replaces a real-life environment with a simulated one.

The rapid expansion of technologies like VR, AR, and MR (Mixed Reality) is opening new opportunities in the shipping industry. These ground-breaking technologies are set to revolutionise industry while paving the path for its digitalisation journey. Vedam aims to utilise these innovations to accelerate and simplify processes to Showcase complex operational procedures in a visually engaging format.

Solution No. 1 – Photo Realistic Digital Twin (PDTWIN)

One way to achieve digital transformation for ships is by using Photo Realistic Digital twin (PDTwin) which is a 3D captured image of asset, with specific information of components/functions which is maintained throughout life cycle and easily accessible instantly at any time, any place with correct user credentials.

This tool enables to tag all machineries, add technical specifications, add different layers of information like user manuals, maintenance manuals, instructional videos and any other required documents as required. (**Figures. 8,9,10,11,12**).

Even historical data like past maintenance reports, historical analysis, past breakdowns, and action taken can be added to it for complete information and knowledge. Some of the key features included in this tool is Floor plan viewer where it enables easy movements to the user throughout the vessel/asset. Also, such twins can be viewed in any simple VR headsets such as mobile VR headset in which the twin link is opened on browser in the mobile and one can have immersive and interactive experience as if the user is present in that real environment. This tool can also be integrated with IoT data or live data for machinery, or any component required easily, which then in turn updates the same in PDTwin.

Figure. 6

Figure. 7

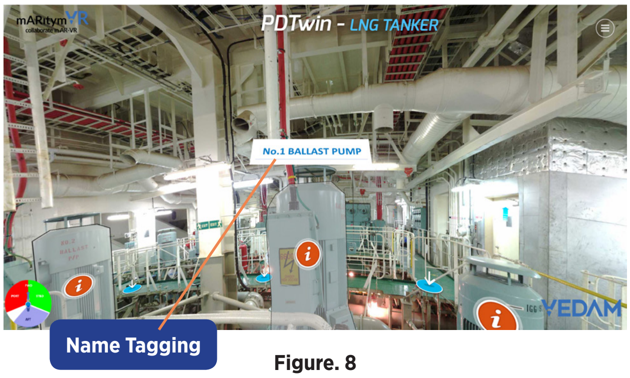

Figure. 8

Figure. 9

Figure. 10

USE CASES

This tool mainly acts as a centralised virtual data bank of asset/ship which then helps to conduct the following in most efficient manner.

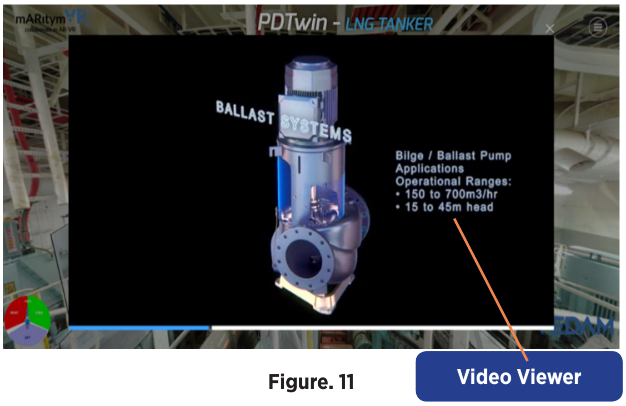

Figure. 11

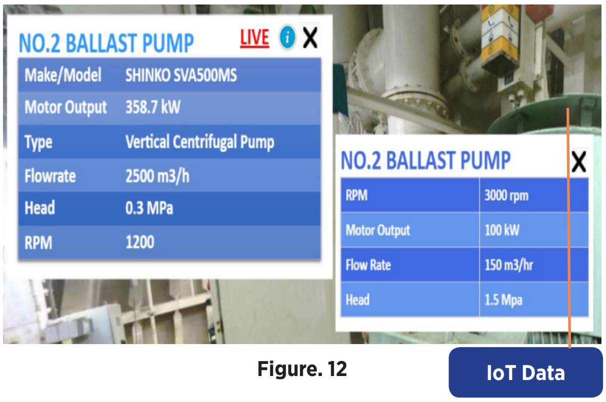

Figure. 12

- Design Review
- Preliminary technical reviews
- Operational review
- Conduct safety training
- Enabling immersive and ship specific familiarisation.

This not only makes decision making easier but also brings office personnel closer to ship thus identifying the problem and saving time.

Solution No.2 – Digital Inspection

CHALLENGES and SOLUTIONS DURING INSPECTION OF SHIPS

1. Inspection Methods – Pen/Paper based, Excel sheets.

Inspections are still carried out today in traditional methods by using printed inspection checklist or survey checklist and then complete the same and add in excel sheet leading to duplication of work and added efforts.

Solution: The solution to this can be if inspections/ survey are made in digital format it leads to better control and efficient efforts of the surveyor/inspector.

2. Limited Remote Support – Means to contact shore for support.

During an ongoing inspection or survey the means to connect to shore experts are limited. Due to this it becomes difficult to assess a situation where a person needs external or additional assistance to ascertain and complete the tasks/jobs by surveyor/inspectors.

Solution: One such solution to tackle above can be use of WhatsApp call, Zoom, MS teams, etc.

3. Scattered Data and No Reporting: Photos/Evidence/ Proofs

Over the years it has become increasingly important to provide evidence and proof to justify a survey or inspection carried out by the concerned person. To mitigate this same was tackled in form of photographic, videographic and documentary proof. These data captured during inspections/survey are in scattered form and to collate all this and make a standard report takes long time investment and extra efforts

Solution: This data captured as proof or evidence should centralised, stored digitally with date, time and geo tags and generate report automatically

4. Logistics and Travel: Travel to vessel

For any inspection or survey the concerned person must travel to the vessel physically to complete the assigned task. But this comes up with its own challenges as the vessel should be available at convenient port, time for travel in involved, lodging, boarding and other expense make up most of the times for a one-day task

Solution: To minimise these overhead expenses travel has to be reduced and means to carry out inspections remotely should be provided.

One such method to mitigate all the above challenges under one umbrella is Digital Inspection, which in short is a smart way to review ships and conduct surveys and inspections. It includes digitalised checklist, Date/Time and Geo tagged photos and videos, Automated report generation and remote call facility.

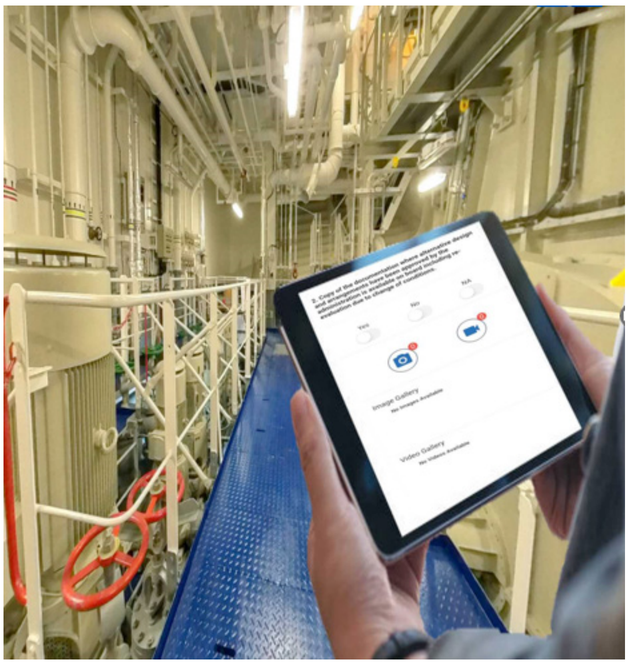

Figure. 13

WHY DIGITAL INSPECTION??

Firstly, it solves all the challenges we face while carrying out any inspection today, moreover it gives more transparent and tamper method to capture photos and videos which cannot be altered. Secondly it covers both features of inspections i.e., onsite inspection where a surveyor or inspector physically visits the vessel **(Figure. 14)** to complete the tasks and other is remote inspection **(Figure. 15)** where the person can complete the survey remotely sitting in office or wherever by being connected to an on board person through the app.

The features for both modes of inspection are more or less same giving seamless and user friendly experience while using such technologies.

USE CASES

This tool is mainly used to carry out inspections or surveys not only across marine industry but also by various other domain. To name a few:

- Class Surveys
- SIRE 2.0 Preparatory Survey
- Right Ship Preparatory Survey
- Superintendent Surveys

ON-SITE INSPECTION

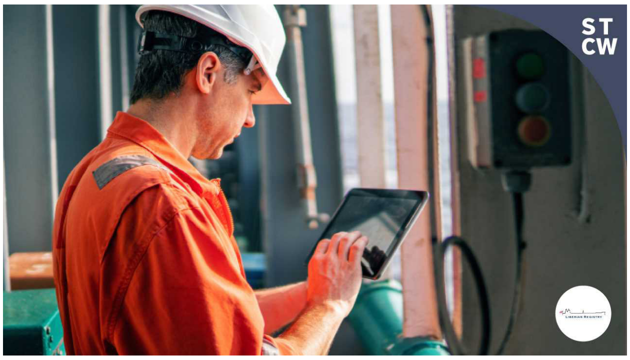

Figure. 14

REMOTE INSPECTION

Figure. 15

- 3rd Party Inspections/Surveys
- Flag Surveys
- OEM based Surveys.
- Bunker Surveys
- PSC Surveys

CONCLUSION

To summarise the availability of such technology, maintaining such digital representations of ships would not only add value to above mentioned needs but also to Sales and Purchase activity of vessels/ships. This in turn allows customers to have insights into their investments.

Looking at the near future roadmap, one of the industry's immediate focuses will be on the application of machine learning analytics which will let us start to break down failure periodicity. This will open doors to advances in predictive maintenance.

Many manufacturers now intend to focus on developing these digitalised solutions around predictive services. This development will help OEM's have insights on engine performance monitoring and operational optimisation.

In the long term for another scenario, the introduction of digital technology solutions will contribute to reforms to current periodic surveys and maintenance cycles, which are based on traditional five-year cycles.

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Figure. 3 - Source: https://home.kpmg/gr/en/home/insights/2021/02/digital-transformation-shipping-industry-papageorgiou.html

Figure. 4 - Source: https://home.kpmg/gr/en/home/insights/2021/02/digital-transformation-shipping-industry-papageorgiou.html

Figure. 14 – Source: https://safetyculture.com//checklist//port-state-control-psc-inspection/

Figure. 15 – Source: https://www.dnv.com/news/dnv-gl-rolls-out-remote-surveys-for-all-vessels-142769

About the author

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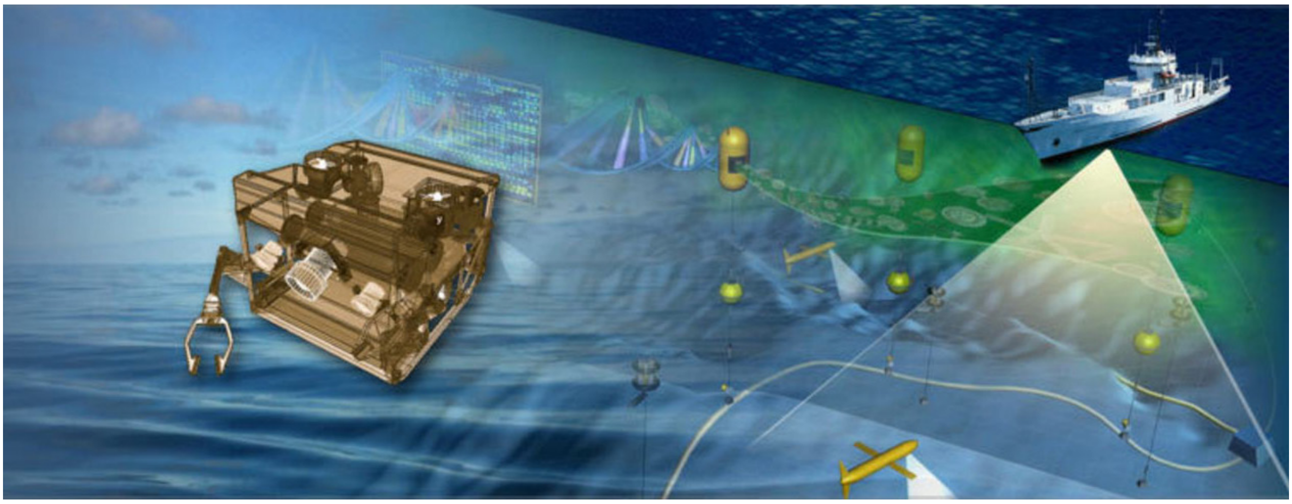
[This paper was presented at INMARCO (November, 2022)]

Assessment of Maturity of Subsea Navigation & Positioning Systems –Part B

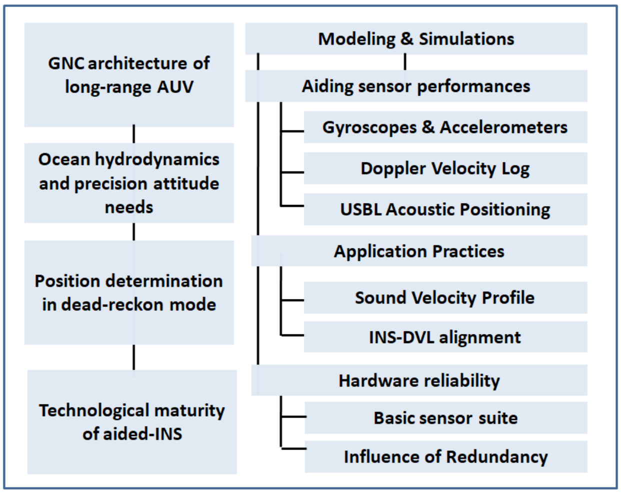


V B N Jyothi, R Ramesh, N.Vedachalam

Abstract

Effective manoeuvrability, precise navigation and position determination are the key requirements for effective operations of deep-water and long-endurance autonomous under water vehicles (AUV). The article is published in three parts. The first part detailed the kinetics and kinematics involved in AUV attitude control when operated in hydrodynamic environments, principles of underwater real-time position determination based on dead-reckoning technique and the technological maturity of the state-of-the-art Inertial Navigation System.

This (second) part describes the maturity of acoustic sensors/systems, principle of acoustic positioning systems and their performance in various water depths and sea states using acoustic channel propagation modelling and simulation software - Bellhop.



Index terms:AUV, Bellhop, Control, Guidance, Navigation.

The next (last) part shall describe the importance of aiding sensor performances and best field application practices in achieving the desired position accuracies. Modelling and simulation case studies presented for seven important scenarios shall help in understanding the intricacies in subsea guidance and navigation system design, identification of mission-specific sensor suite for achieving the desired performance and reliability.

Technological maturity of A-INS

Understanding acoustic aiding sensors performance

Doppler Velocity Log

The Doppler Velocity Log (DVL) is an aiding sensor for the INS which provides direct vehicle velocity measurements in three linear degrees of freedom (DoF). The most primitive method to measure the ship speed was based on throwing a wooden log overboard and measuring the time it takes for the log to pass between two marked points on the deck. It is the reason why modern navigation solutions often use the word “log”. During 1903 and 1950, Ekman water current meter and electromagnetic based current meter were invented, followed by Doppler shift based current meter in 1972.

The DVL measures the 3-axis velocity relative to the sea bottom by sending acoustic waves from the four angled transducers and measures the frequency shift (Doppler Effect) (**Figure 1a**) from back-scattered sound from the sea bed or sea suspended particles (**Figure 1b**). Conventional DVL has four transducers elements that are fixed in a Janus array configuration with four beams (**Figure 1b**) oriented in a circle, separated by 90° azimuth and elevated from vertical (20º-30º) by a common angle referred to as the Janus angle, named after the Roman God who looks both forward and backward. By combining the measurements of all four transducers and the time between each acoustic pulse, the speed and direction of AUV movement in 3 linear DoF is estimated.

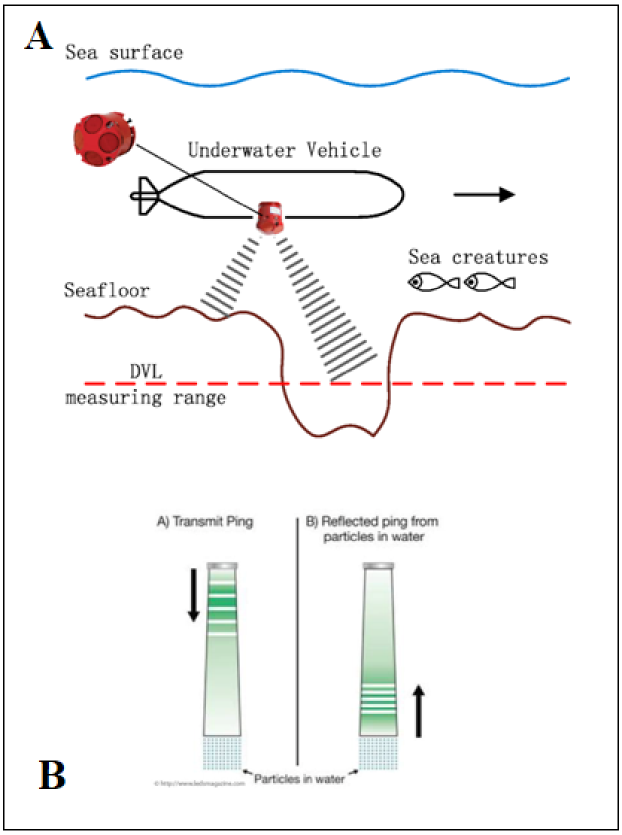


Figure 1. DVL operating on-board AUV

From the measured 3-DoF velocities, a 3-D velocity vector is obtained by transforming the measured radial beam velocities to an orthogonal coordinate system. The Doppler shift is measured in each beam by digitizing the received waveform, correcting for speed of sound and frequency-drift errors, computing the Doppler shift and combining velocities in the beam pairs to generate fore–aft and starboard–port velocity components. The DVL operates in two modes, bottom lock mode (typically < 200 m) and water lock mode (based on the reflections from suspended particulate matter).

The bottom track mode measures speed against a stationary (with reference to sea floor) reference and water track measures speed against a moving surface. The recent DVL with state-of-the-art technology has an accuracy of ±0.1 cm/s and velocity resolution of 0.01mm/s in the bottom track mode (range of 0.3-200m), and an accuracy of ±0.3 cm/s velocity resolution in the water tracking mode. The upcoming DVL technology is the Correlation Velocity Log (CVL) that operates at lower source frequencies with better accuracies and achieves higher range. The maximum operating range of a DVL/CVL is limited by the minimum required signal-to-noise (S/N) ratio at which detection algorithms can operate [1].

The error model of DVL is explained in below equation.

$$V_o = (1+S_f)\, V_i + b(t)$$

where Vi is the velocity input data from the DVL sensor, 'SC' is the sea current, 'Vo' is the velocity output from the model, 'S_f' is scale factor, and 'b(t)'is the white Gaussian noise, which can be standard deviation based on the manufacturer of the sensor.

Depth sensor

For estimating the AUV position in 3-D co-ordinates (NED), depth sensor is an important aid that provides the depth data as Z-axis for the AUV. The depth sensor uses hydrostatic pressure measurements to calculate the depth. Recent depth sensors use vibrating quartz crystal technology that is highly stable and has measurement sensitivity better than 2×10^{-7}, which translates to <1 mm in 6000m water column [2].

The sensor measures the pressure based on equation,

$$P_o = P_{meas} + b_p + \delta_p$$

Where, the output pressure is sum of the measured pressure, sensor bias and measurement noise. The pressure measurement is converted to depth measurement

$$P_{DS} - P_{atm} = \rho\, g\, d_{DS}^{N}$$

where is the local atmospheric pressure measure during the initialisation. g is the acceleration due to gravity, is the density of water and the measured depth is d_{DS}^{N}.

Acoustic Positioning System (APoS)

The DVL-aided INS experiences position drift over time. To overcome this, APoS is used a direct position aiding input to the A-INS. The APoS is used for computing the position of the AUV with reference to the deployment ship or fixed subsea locations where transponders are deployed. The distance between the ship-mounted transceiver (with multiple transducer element arrays, usually >3 and up to 250) and the AUV-mounted transponder is called the slant range. The phase difference with the time of arrival between individual transducer elements is used to determine the bearing angle (**Figure 2**).

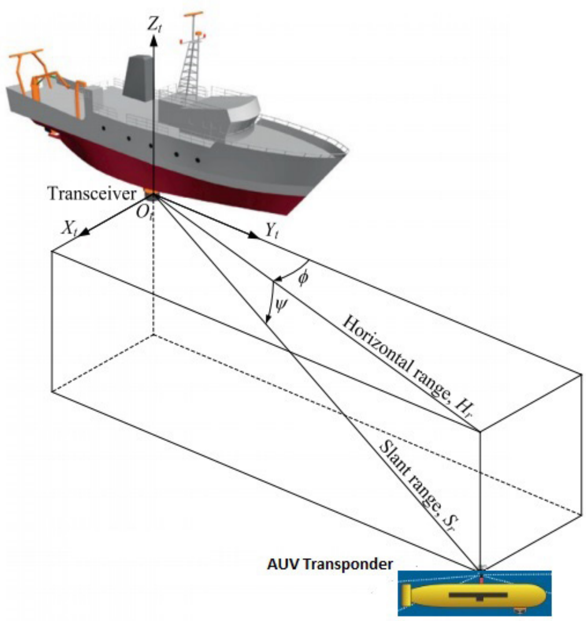


Figure 2. Depiction of range and bearing

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Computation of slant range

The slant range is computed using the time-of-flight t. If 't' is the time taken for the sound to travel (with the velocity of v m/s) from ship to the AUV-mounted transceiver and back (excluding instrumentation delays) the slant range 'R' between the ship and AUV is given by,

$$R = \frac{ct}{2}$$

Computation of bearing angle

The bearing angle is calculated based on the time difference of arrival (TDOA) between the hydrophones separated by distance d (**Figure 3**), in which d is the distance between the transducers, x is the extra distance travelled by the wave front to reach transducer a after reaching transducer b; Sin Φ = (x/d).

If ΔT is the time taken for the wave front to cover the distance of x and cis the velocity of sound then,

$$x = \Delta T * c$$

$$\text{Sin } \Phi = \Delta T * (c / d)$$

Let Φ be the phase difference between wave front at b and a. A phase difference of 2 radians corresponds to a time difference λ/c, where λ is the wavelength. Hence phase difference of corresponds to a time difference of distance of

$$\Delta T = * ((1/2) *) * (\lambda / c)$$

Based on the computed range, bearing (ϕ) and elevation angle (ψ) parameters shown in the **Figure 2**, the position of the AUV with respect to the deployment ship is calculated using below equation.

$$\Phi = \sin^{-1}\left(\alpha * \left(\frac{\lambda}{2}\right) \pi * d\right)$$

$$P_t = \begin{bmatrix} Sr\text{Cos}\psi\text{Sin}\varphi \\ Sr\text{Cos}\psi\text{Cos}\varphi \\ -Sr\ \text{Sin}\psi \end{bmatrix}$$

Depending on the distance (baseline) between the transducers, APoS are classified into Ultra-short baseline (USBL), Super Short Base Line (SSBL) and Long Base Line (LBL) systems (**Table 1, Figure 4**)[3]. The matured APoS Ultra Short base line (USBL) system (having maximum of 255 transducer elements) having an operating range of 10km and operating at 10-15kHz frequencies has a positioning accuracy of ~0.2% of the slant range with 50% Circular Error Probability (CEP50). The location-specific Sound Velocity Profile (SVP) obtained by casting before mission is an essential input to APoS for achieving the desired positioning accuracy [4].

These acoustic sensors data will be provided as inputs to the INS for estimating the velocity and position accurately. The 3-D position data from the A-INS will be fed to the Guidance and Control of AUV for precise attitude control using thrusters and control surfaces.

Table. 1. Classification of APoS based on baseline length

Type of APoS	Base length
USBL	Few cm
SSBL	20-50m
LBL	>100m

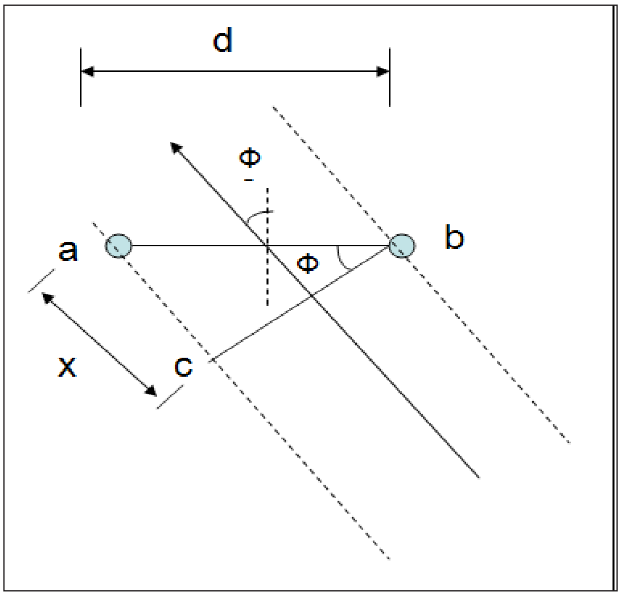

Figure 3. Principle of bearing angle calculation

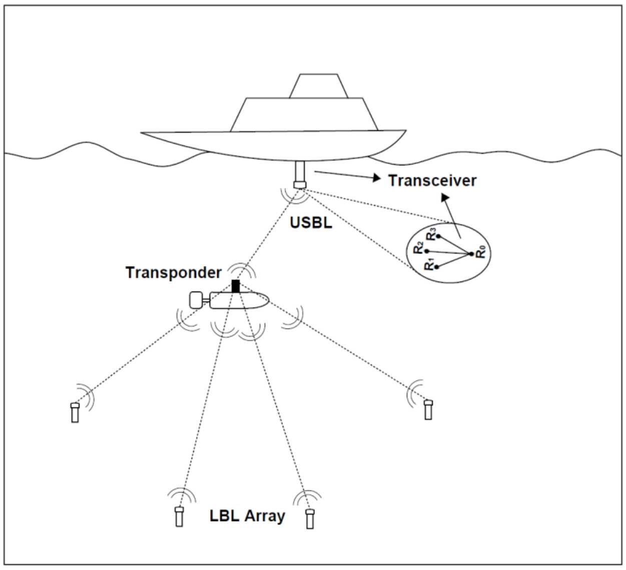

Figure 4. Principle of USBL and LBL

Case A: Performance assessment of APoS in various water depths and sea states using Bellhop software

Even though acoustic signals have good underwater propagation characteristics, it has limitations in the operating range. The effective range of the APoS depends on a number of factors including the time and depth-dependent refractive properties of the ocean sound channel, operating frequency, distance between the source (acoustic transmitter) and receiver, transmitter power,

receiver sensitivity, transducer beam pattern, ocean state and the presence of acoustic shadow zones [5].

Considering all these factors, the performance is analyzed by modeling the underwater propagation channel using ray tracing numerical modeling and simulation software. The software is used mainly to compute the Transmission Loss (TL) using the Eigen rays from source to receiver along the propagation channel and impulse response in the defined ocean environment. The TL in the ocean medium is defined as the accumulated decrease in acoustic signal intensity where an acoustic pressure wave propagates outwards from a source. The magnitude of TL can be estimated by adding the effects of geometrical spreading, absorption and scattering. Spreading loss refers to the energy distributed over an increasingly larger area due to the regular weakening of a sound signal as it spreads outwards from the source.

Absorption is a process that involves the conversion of acoustic energy into heat due to the internal friction at a molecular scale within the fluid. At certain frequencies, absorption increases due to ionic relaxation of certain dissolved salts. Scattering occurs when sound waves are redirected when they interact with a body and bubbles. TL also increases with distance and frequency [6]

TL is decibels (dB) is calculated using the following empirical relationship:

$$\mathrm{TL} = \mathrm{A}\log r + \frac{\alpha r}{1000}$$

where 'α' is the absorption coefficient in db/km, 'r' is the range in m, 'A' equals 10 for shallow waters and 20 for deep waters.

When compared with the single-path acoustic wave propagation model, realistic multipath model results in a higher TL because more acoustic energy is lost due to reflections. The six basic propagation paths between a source and a receiver include surface reflection, surface duct, bottom bounce, convergence zone, deep sound channel and reliable acoustic path.

Various numerical modeling and simulation software such as Bellhop, Kraken, Scooter are available for computing the effective range of APoS. For modeling and simulating the performance of APoS, Bellhop, a beam tracing model for predicting acoustic pressure fields in ocean environment is used [7]. The algorithm is based on Gaussian and hat shaped beams, with both geometric and physics based spreading laws. Bellhop accepts the position (water depth) of directional acoustic sources (transmitter) and receiver, source beam pattern, geo-acoustic properties of the bounding media including altimetry, bathymetry and the location-specific sound velocity profile (SVP) as inputs. The outputs include TL with distance, Eigen rays, signal arrivals and received in time-series [8].

Using the open-source Python v.3.3.6.10, Bellhop propagation modeling and simulations are carried out for assessing the TL with distance and the Eigen rays are plotted when the source (AUV-mounted APoS transponder) is at 500m water depth (**Figure 6**) with input parameters shown in **Table 2.**

The Eigen rays plot is used for representing the rays that connect the source and receiver with given sea bed properties. In addition to the hat-shaped default beam there are Cerveny, Popov, Psencik beams that produce additional rays that pass at greater distances from the receiver [9]. **Figure 6** shows the Eigen array plot when the transmitter is located at 500m water depth.

The pressure field is calculated with the scaling 20log P to determine the TL in dB. Operating frequency is a very important parameter, since the beam interference pattern is directly related to the wavelength and it also affects the attenuation. **Figure 7** shows the Bellhop TL with distance

Table. 2. Input parameters for Bellhop 500m depth model

Parameter	Value
Operating frequency	25 kHz
SVP	As indicated in Fig.5[10]
AUV Transponder depth	500m
Sea floor properties	Flat bathymetry, absorption coefficient 0.1 dB/wavelength

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simulation plot when the source is located at 500m water depth, in which the TL between ship and AUV is 100 dB.

Modeling and simulations are carried out using Bellhop to determine the TL for deep-ocean scenario with inputs shown in **Table 3** with deep water SVP. **Figure 8** shows the Bellhop TL with distance simulation plot up to 10 km when the source (AUV mounted transponder) is located at 5500m water depth.

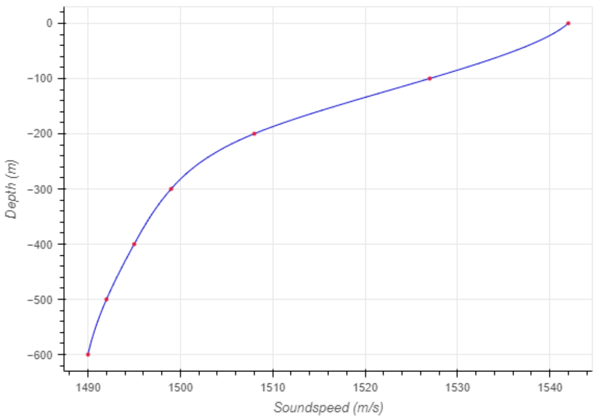

Figure 5. SVP inputs for performance modeling in Bellhop (500m)

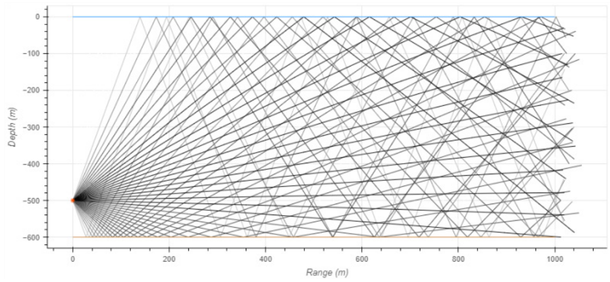

Figure 6. Eigen ray plot when source is at 500m water depth

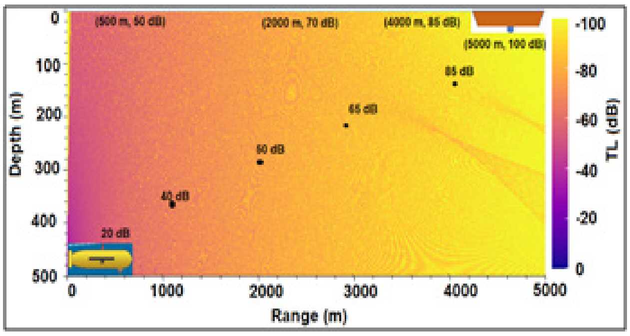

Figure 7. Bellhop TL plot in 500m water depth

Table. 3. Input parameters for Bellhop 5500m depth model	
Parameter	**Value**
Frequency	10 kHz
SVP	As indicated in Figure 8[10]
AUV Transponder depth	5500m
Sea floor properties	Flat bathymetry, absorption coefficient 0.1 dB/wavelength

For the inputs summarized in **Table 3, Figure 9** shows the Bellhop simulations for TL up to a distance of 10km when the source is located at 5500m water depth and the ship-mounted receiver is at 10m water depth.

The TL results obtained using Bellhop software when the source and receiver are located at water depths ranging from 500 to 10000m (in the case of LBL) are summarized in **Figure 10**. The plotted TL values shall be used as inputs to determine the acoustic wireless communication system parameters like data rate, signal-

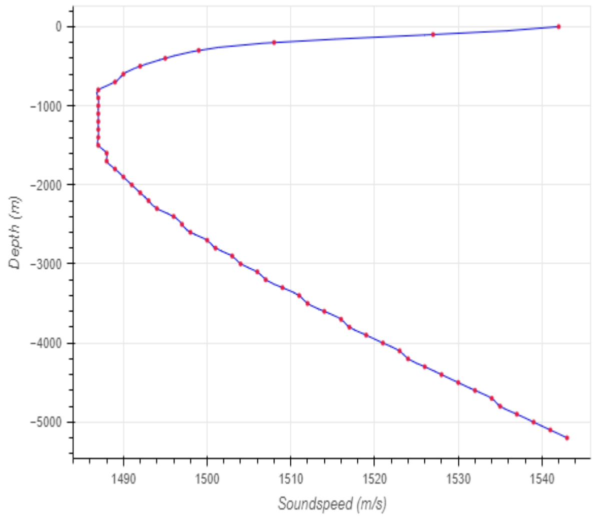

Figure 8. SVP inputs for performance modeling Bellhop (5500m)

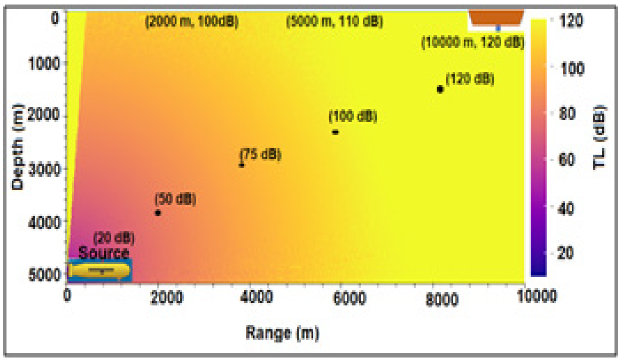

Figure 9. Bellhop TL plot in 5500m water depth

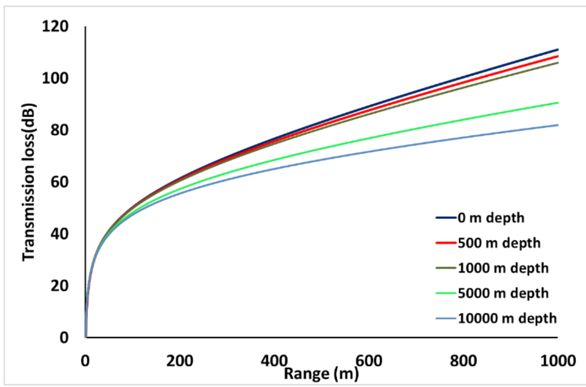

Figure 10. Plot of the TL in various water depths for horizontal propagation (LBL case)

IME (I) GOVERNING COUNCIL, BRANCH AND CHAPTER COMMITTEE ELECTIONS 2023-25

With elections for The Institute of Marine Engineers (India) approaching, we would wish to notify all Corporate Members of the following procedures:

SCHEDULE

- Notice of the entire process of election shall be intimated through electronic media ONLY.
- Soft copy of the Nomination forms will be sent through mass e-Mail and can also be downloaded from the IME(I) website and returned to the Election Officer.
- Soft copy of the Nomination papers for Council elections will be mailed by **15th May 2023** to the Members email id which is registered in the records of the IME(I).
- Nomination papers for the Council are to be received in the Institute's office by **15th June 2023** to the email id: ***electionofficer@imare.in***
- Last date for withdrawing nomination is **30th June 2023**.
- The scrutiny of nomination papers for the Council to be completed by the Election Committee by the **5th July 2023**.
- Election Officer after scrutiny will publish the CVs of the eligible candidates on IME(I) website.
- The election window for eVoting will remain open from **15th July to 1st September 2023**.

E-VOTING

As a corporate member you can exercise your franchise at the forthcoming elections at IME(I), using the standard Ballot **through e-Voting ONLY**.

Two options would be available for both the elections i.e. for Head Office (HO) as well as the Branch Level (if the election takes place for the Branch level). Overseas Members will get Option only for elections at HO level.

Members will get the e-Voting Link **ONLY on** their e-Mail registered in the records of IME(I) as on **15th May 2023**. Members may update their e-Mail ID / contact details by writing to the HGS at ***membership@imare.in*** latest by **15th May 2023**.

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- The use of your personal mail would ensure that you do not miss any important communication relative to the election process.

Election officer

electionofficer@imare.in

noise ratio (S/N) with different ranges and depths using active/passive SONAR equations.

The effective range of APoS in an ocean environment is based on the sonar equation which defines the receiver detection threshold[6].

$$SL - TL - NL + DI > DT$$

where DT is the receiver detection threshold, SL is the source level, TL is the transmission loss, NL is the ambient noise level and DI is the directivity index.

Thus, the APoS design with a specific DI has to be application specific, with an appropriate trade-off between SL, TL, NL and DT. The source level (SL) should be adequate to meet the TL over the required range (which is determined using Bellhop simulations) and capable of providing adequate acoustic signal strength to the receiver (>DT) by overcoming the ambient NL in the location, that varies during various sea states and anthropogenic activities (**Figure 11**). The ocean ambient noise includes turbulence, wind, shipping, waves, rain, and mammals over a range of frequencies. **Table. 3** summarizes the sea state and the corresponding ambient noise level at 25 kHz frequency.

The effective range of APoS with AUV-mounted transponder having a SL of 192dB (300W) and ship USBL receiver sensitivity of 20 dB when operated at different sea states are computed and summarized in **Table. 4.** It can be seen that the maximum operating range under sea state 4 is 10 km. When the sea state is 6, effective range reduces to 6 km. Thus, the system design has to consider a proper trade-off between AUV transponder power, ship receiver sensitivity, range requirements and the sea state in which the AUV is required to operate.

Influence of SOFAR channel

The SOFAR channel is the most remarkable feature of the oceans which was discovered at the end of World War 2 independently in the US and USSR. The channel which is typically 1-2 km thick is created by the minimum in the sound speed, typically at 1 km in water depth that is associated with a balance between the effects of temperature and hydrostatic pressure. **The channel forms a waveguide that is capable of guiding acoustic energy halfway around the planet**.

During 1960, it was proven that low frequency sound travels in this channel for very long distances, with an attenuation of ~0.5x 10^{-3} dB/km. In the popular Heard Island feasibility test conducted later, a detonation of 150kg of TNT in the channel off-Perth was recorded on hydrophones that were located at the SOFAR axis off-Bermuda at a distance of ~ 20000 kms[11].

Simulations are carried out using Bellhop software to understand the effective range between the AUV located in 1000m water depth (inside the SOFAR channel) and the ship-based transceiver (**Figure 13**). It can be seen that (compared to the results shown in **Figures 7** and **9**), the channel acts as a waveguide and involves high TL between AUV and ship. This reduces the performance of the APoS when the AUV operates in the thermocline region.

Hydro-acoustic communication

The first acoustic analog modulation based (8-11kHz) single side band submarine communication system was developed in US by the end of Second World War. In the early 80's, the underwater communication systems based on digital signal processing (DSP) and Frequency Shift Keying (FSK) principles was developed by WHOI and MIT. FSK relies on simple energy detection

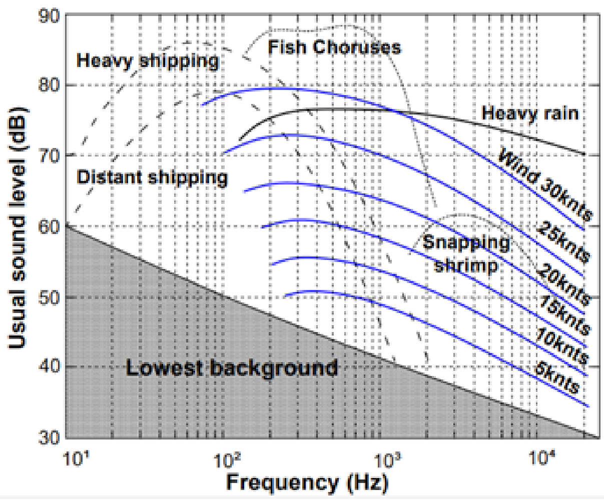

Figure 11. Ambient noise in the ocean under various conditions

Table 3. Sea state and 25 kHz frequency ambient noise

Sea state (Beaufort scale)	Wind speed (Knots)	Sea state	NL (dB) @ 10 kHz
4	11-16	Slight-Moderate	50
5	17-21	Moderate	58
6	22-27	Rough	62
7	28-33	Rough-Very rough	70
8	34-40	Very rough- High	80

Table 4. Effective range of APoS under various sea states

Sea state	Source power level of AUV transponder	Ship receiver detection threshold	Effective range
4	192dB @ 300W	20 dB	10 km
5			8 km
6			6 km
7			4 km
8			3.5 km

(non-coherent detection), and thus offered robustness to channel impairments, its bandwidth utilisation is not efficient.

During 90's phase shift keying (PSK) and quadrature amplitude modulation (QAM) were used as they offered more bits/sec per Hz of occupied bandwidth, but required a receiver that can track the channel and compensate for the time-varying multipath and phase distortion (coherent detection). Recent acoustic telemetry modems with hemispherical beam patterns and optimized for vertical and slant channels operating in 4-14 kHz range offer adaptive communication data rates of ~6 kbps up to 12km (**Figure. 14**).

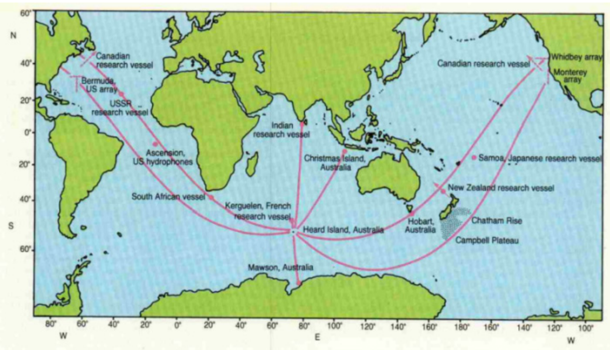

Figure 12. Description of the Heard Island experiment [11]

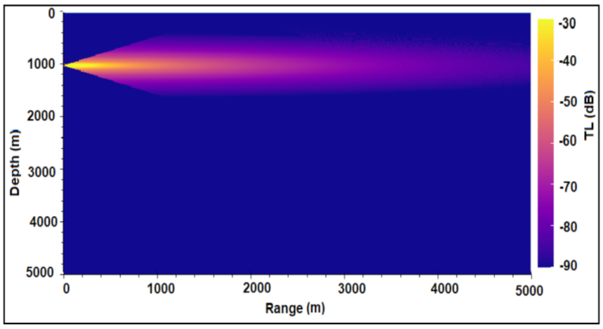

Figure 13. Sound propagation through low-loss SOFAR channel

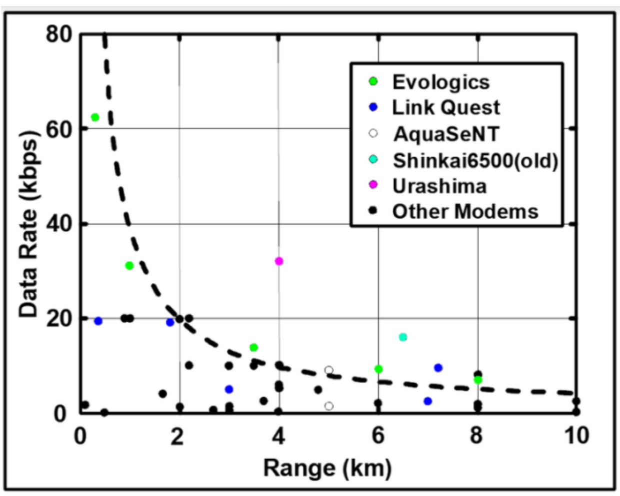

Figure 14. Hydro-acoustic communication system performance [12]

Forthcoming Part C of the article...

Shall include modelling and simulation cases using Bellhop software and MATLAB to understand the importance of sensor characteristics in achieving the desired Aided-Inertial Navigation System performances and best field application practices in achieving desired position accuracies. Modelling and simulation case studies shall be presented for the following. The next part also features a hardware reliability analysis on the A-INS subsystems using probabilistic reliability modelling and simulations software TOTAL-GRIF by which the Mean Time to Fail (MTTF) period for various configurations are identified.

Case	Description
B	Importance of aiding sensor performance (with INS and DVL) and without APoS in AUV Nav & Pos
C	Position error when descend/ascend of AUV without APoS from 6000m water depth in spiralling mode in the presence of ambient water currents
D	Influence of AUV mounted gyroscope-DVL misalignment
E	Positioning error without sound velocity profile inputs to APoS
F	Relative position error of the AUV without ship attitude real-time correction
G	Position error with APoS aid with varying transceiver beam angle coverage

ABBREVIATIONS

A-INS	Aided Inertial Navigation System
APoS	Acoustic Positioning System
AUV	Autonomous Underwater Vehicle
CVL	Correlation Velocity Log
CEP	Circular Error Probability
dB	Decibels
DI	Directivity Index
DoF	Degrees of Freedom
DSP	Digital Signal processing
DT	Detection Threshold
DVL	Doppler Velocity Log
FSK	Frequency Shift Keying
GRIF	Graphical Representation of Fiability
INS	Inertial Navigation System
LBL	Long Baseline Line
MATLAB	Matrix Laboratory
MTTF	Mean Time To Fail
MIT	Massachusetts Institute of Technology

NED	North East Depth
NL	Noise Level
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
SL	Source Level
SOFAR	Sound fixing and ranging channel
SONAR	Sound Navigation and Ranging
SSBL	Super short baseline
SVP	Sound Velocity Profile
TL	Transmission Loss
TNT	Tri-nitro Toluene
USBL	Ultrashort baseline
WHOI	Woods hole Oceanographic Institution

ACKNOWLEDGEMENTS

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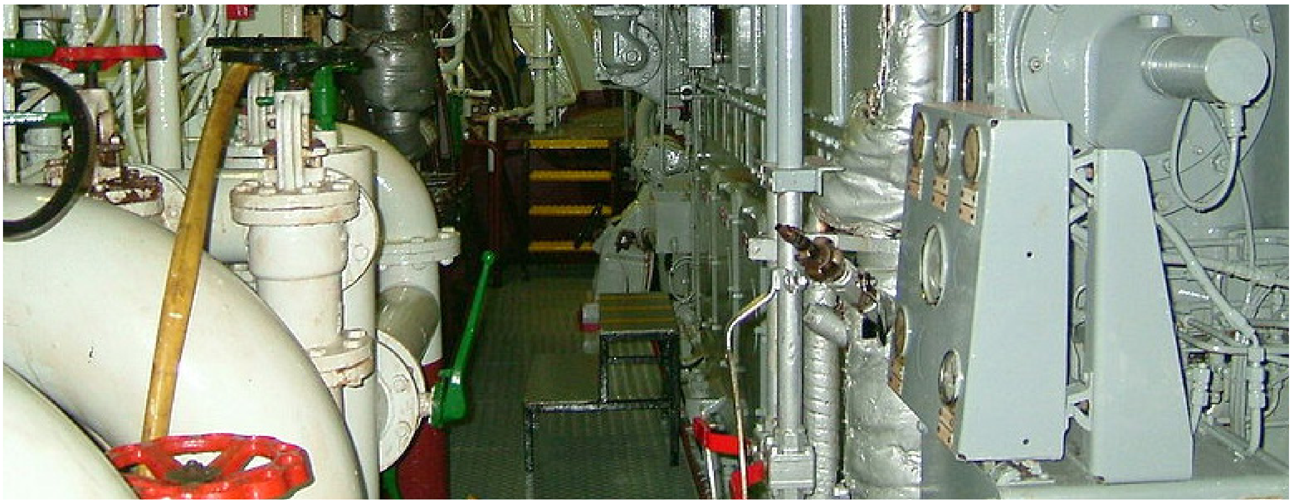
Troubleshooting Marine Electrical Equipment – Part 1B - The First Crucial Steps



Elstan A. Fernandez

5 The Alternative (Logical) Approach to Troubleshooting

It is a proven process that is highly effective and reliable in helping to solve electrical problems. This approach differs from other troubleshooting procedures in that it is more of a *thinking process* that is used to analyse a circuit's behaviour and determine what is responsible for the faulty operation. This approach is general in nature allowing it to be used on any type of electrical circuit. In fact, the principles covered in this approach can be applied to many other types of problem-solving scenarios; not just electrical circuits.

This approach to troubleshooting comprises the following:

5.1 Prepare for the Task

Before you begin to troubleshoot any piece of equipment, you must be familiar with safety rules and procedures for working on electrical equipment. These rules and procedures govern the methods you can use to troubleshoot electrical equipment (including your lockout/tag-out procedures, testing procedures etc.) and must be followed while troubleshooting.

Always inform the senior person in-charge and the person in-charge for the machinery under normal operating conditions that you are there to work on the equipment.

Isolate the equipment by using lock out tag out (LOTO) procedures and equipment in order to prevent someone from turning the power supply 'ON' while the work is being carried out.

A very important point to remember here is that you may have multiple supplies in the panel. One for the main power circuit, and another for the control circuit. Please make sure you follow the correct testing procedure and as per the circuit diagram before touching anything. Your measuring instrument is the most important item in your toolkit, use it!

Next, you need to gather information regarding the equipment itself and the ensuing problem. Be sure you understand how the equipment is designed to operate. Take feedback from the operator of the machinery. He can tell you exactly what happened when the machine stopped, explain the normal behavior of the machine. You can also gain information from him about what generally goes wrong or frequently occurring faults. They tend to watch the behavior of the machine when it's working normally. Although they might not understand the work fully but the little information you will get from them will be helpful at times in fault rectification. Failing that, you will have to proceed in a more structured approach to troubleshoot the circuit. It is much easier to analyse faulty operation when you know the procedure.

Operation or equipment manuals and drawings are also great sources of information and are helpful when available. If there are equipment history records, you should review them to see if there are any recurring problems. It would also help to have any documentation describing the problem i.e., a work order, failure report, or even your notes taken from a discussion with the user.

5.2 Observe and Identify Symptoms

Most faults provide obvious clues to their cause. With careful observation and a little bit of reasoning, most faults can be traced to the actual component with very

the malfunctioning equipment. Often when equipment malfunctions, certain parts of the equipment will work properly while others will not. The key is to use your observations to rule out parts of the equipment or circuitry that are operating properly and not contributing to the cause of the malfunction.

You should continue to do this until you are left with only the part(s) that if faulty, could cause the symptoms that the equipment is experiencing.

To help you define the problem area you should have a schematic diagram of the circuit in addition to your noted observations. Starting with the whole circuit as the problem area, take each noted observation and ask yourself, "what does this tell me about the circuit operation?" If an observation indicates that a section of the circuit appears to be operating properly, you can then eliminate it from the problem area. Is there anything which is being missed out in the sequence of starting the equipment i.e., is there an oil pump or a priming pump that needs to be started before the machine can be started?

Check for any other interlocks which might have operated. Once you are sure of this, proceed to isolate all power from both the control and power (motor) circuits. Please, *Never Work on A Live Circuit* on board!

As you eliminate each part of the circuit from the problem area, make sure to identify them on your schematic diagram (with a pencil). This will help you keep track of all your information.

little testing. When observing malfunctioning equipment, look for visual signs of mechanical damage such as indications of impact, chafed wires, loose components or parts lying in the bottom of a cabinet.

Look for signs of overheating, especially on wiring, relay coils and printed circuit boards. Don't forget to use your other senses when inspecting equipment.

The smell of burnt insulation is something you won't miss. Listening to the sound of the equipment operating may give you a clue to where the problem is located. Checking the temperature of components can also help one to find problems but be careful while doing this, some components may be alive or hot enough to burn you.

Pay particular attention to areas that were identified either by past history or by the person that reported the problem. A note of caution here! Do not let these mislead you, past problems are just past problems, they are not necessarily *the* problem you are looking for now. Also, do not take reported problems as a fact; always check for yourself as far as possible. The person reporting the problem may not have described it properly or may have made his own incorrect and exaggerated assumptions.

Ensure all the safety switches that will shut the machine down are shown as per circuit diagram normally close or normally open (i.e., NC or NO), the point here to be checked is that most of the time the safety devices in an Electrical circuit like the over load relay, emergency stop button, pressure switches will be generally in a closed position for the circuit to operate.

You can check the safety relay or the overload relay which has indication lights on it to indicate ready state or fault state. If there is no fault, proceed to the next step. However, if you have a fault indication you are almost there. Check each safety switch for operation and repair the faulty unit. Please never bypass a safety switch!

5.3 Define the Problem Area by Analysing the Symptoms

It is at this stage that you apply logic and reasoning to your observations to determine the problem area of the malfunctioning equipment.

5.4 Identify Possible Causes / List the Probable Faulty Functions

Once the problem areas have been defined, it is necessary to identify all the possible causes of the malfunction. This typically involves every component in the problem area(s).

It is necessary to list (*write down*) every fault which could cause the problem no matter how remote the possibility of it occurring. Use your initial observations to help you do this. During the next step you will eliminate those which are not likely to happen.

Here is an example of a fault in a very basic Direct-on-Line circuit:

A majority of faults in this particular basic circuit will be caused by the thermal overload tripping. If you now look at the overload, you will note that a normally closed contact is used in the control circuit. To go the next step, we will see a normally open contact for a "Tripped" indication lamp (normally an amber lamp for this purpose but that is not a fixed rule). What will happen now is that, should the motor exceed the set point of the thermal overload, the overload normally opened contacts will open and trip and the motor while the contacts in the control circuit will also open to disable the same and indication lamp would be turned on by the closing of the normally opened contact. That gives you a clear indication that you have an overcurrent fault as you walk up to the panel. In addition, a green lamp parallel to the circuit of the contactor coil or also, which is energised by an auxiliary contact of the main contactor would not be glowing now.

5.5 Determine the Most Probable Causes / Localise the Faulty Functions

Once the list of possible causes has been made, it is then necessary to prioritise each item as to the probability of it being the cause of the malfunction. The following are some rules of thumb when prioritising possible causes. Although it could be possible for two components to fail at the same time, it is not very likely. Start by looking for one faulty component as the root cause.

The following list shows the order in which you should check components based on the probability of them being defective:

First look for components which burn out or have a tendency to wear out, i.e. mechanical switches, fuses, relay contacts, or light bulbs. (Remember, that in the case of fuses, they burn out for a reason. You should find out why before replacing them.)

The next most likely causes of failure are coils, motors, transformers and other devices with windings. These usually generate heat and, with time, can malfunction.

Connections should be your third choice, especially screw type or bolted type. Over time, these can loosen and cause a high resistance. In some cases, this resistance will cause overheating and eventually will burn open. Connections on equipment that is subject to vibration are especially prone to coming loose.

Finally, you should look for is defective wiring. Pay particular attention to areas where the wire insulation could be damaged causing short circuits. Don't rule out incorrect wiring, *especially on a new piece of equipment*.

5.6 Test and Repair

Testing electrical equipment can be quite hazardous. The electrical energy contained in many circuits can be enough to injure or kill. Make sure you follow all safety precautions, rules and procedures while troubleshooting. Once you have determined the most probable cause, you must either prove it to be the problem or rule it out. This can sometimes be done by careful inspection. However, in many cases the fault will be such that you cannot identify the problem component by observation and analysis alone. In these circumstances, test instruments can be used to help narrow the problem area and identify the problem component. There are many types of test instruments used for troubleshooting. Some are specialised instruments designed to measure various behaviours of specific equipment, while others like multimeters are more general in nature and can be used on most electrical equipment. A typical multimeter can measure AC and DC Voltages, Resistance and Current.

A very important rule when taking meter readings is to predict what the meter will read before taking the reading. Use the circuit diagram to determine what the meter will read if the circuit is operating normally. If the reading is anything other than your predicted value, you know that this part of the circuit is being affected by the fault.

Depending on the circuit and type of fault, the problem area as defined by your observations, can include a large area of the circuit creating a very large list of possible and probable causes. Under such circumstances, you could use a "divide and eliminate" testing approach to eliminate parts of the circuit from the problem area. The results of each test provide information to help you minimise the problem area until the defective component is identified.

Once you have determined the cause of the faulty operation:

- Repair the Fault
- Test continuity after repair to make sure
- Close / replace all covers and / or guarding you may have removed
- Inform the relevant manager you are going to restore power to test the machine
- Ensure it is safe to do so and restore the power to all circuits
- Get the operator to start the machine and check it is operating correctly

After replacing the component, you must test all features of the circuit to be sure you have replaced the proper component and that there are no other faults in the circuit.

5.7 Follow-up / Carry-out Failure Analysis

Although this is not an official step of the troubleshooting process it nevertheless should be done once the equipment has been repaired and put back in service. You should try to determine the reason for the malfunction.

Did the component fail due to age?

Did the environment the equipment operates in cause excessive corrosion?

Are there wear points that caused the wiring to short out?

Did it fail due to improper use?

Is there a design flaw that causes the same component to fail repeatedly?

Through this process further failures can be minimised. Many organisations have their own follow-up documentation and processes. Make sure you check your organisation's procedures.

6 Standard / Fundamental Faults

The following is a concise list of typical faults that are the most common causes of a circuit ceasing to operate correctly.

6.1 Loss of Supply

This is caused by loose connections, a tripped circuit breaker or a blown fuse. In the case of a battery powered unit, it can also be due to the battery being discharged.

6.2 Earth Fault

An earth fault occurs when the insulation resistance between live parts and surrounding non-current carrying metalwork falls below a value as is laid down by the relevant regulations (ABS, Lloyds, I.E.E.E., etc.). This fault is explained in a separate chapter.

6.3 Dead Short

Phase to Neutral / Phase to Phase – has the main fuse at origin blown

6.4 Defective Components

Switches – relays – contactors, etc, not functioning correctly (brings about the decision as to replace or repair)

6.5 Breakdown of Control Circuits

Internal Wiring / PCBs and Electronics

6.6 Reversed Polarity

At the supply origin – at a single outlet (Phase Neutral reversed or neutral earth reversed) or at a single fitting (Phase – Neutral) – Live Test Vs Dead Test.

6.7 Initial Faults on newly Installed Work

Reversed Polarity

Wrong protection discrimination

Loose terminals.

About the author

Elstan A. Fernandez is having 43 years in the Maritime and Energy Industries; Author / Co-author of 80 Books. Chartered Engr, FIE, MIET (UK), MLE[SM] Harvard Square (USA); Joint Inventor with a Patent for Supervised BNWAS; Promising Indian of the Year in 2017.

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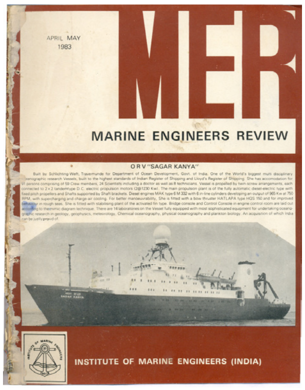
GOING ASTERN INTO MER ARCHIVES



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

The cover carries the picture of the ocean research vessel (ORV). Since then many research vessels have served and some have been scrapped (now we have multi-disciplinary, ice class ORV also).

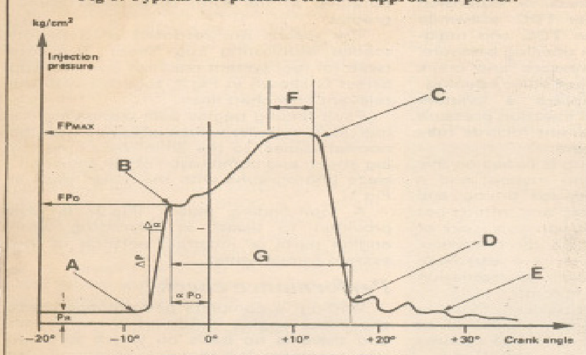
The next is an article I would recommend to all those reading this. The article (Performance Monitoring based on an MIP calculator) has some very good takeaways for the practicing marine engineer and connects very well. There are much sophisticated and precise instruments in use nowadays, but this discussion would underline the significance and understanding.

The next article is a more absorbing discussion about the function of LO in controlling corrosion. To whet your appetite, few figures have been extracted and inserted. Do check out these at: IME(I)-iLibrary;

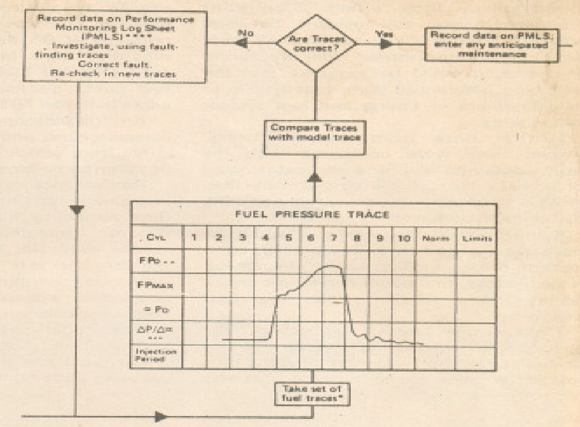
https://i-library.imare.in.

There are more maintenance talks on cleaning the engine while in operation and fuel consumption/ assessment. The article discussing engine-driven pump from the perspective of reducing sea loads is another interesting one. And there is one article introducing the B&W LMC engines. Do check out the POSTBAG extracts, particularly the letters on wind power driven ship and the uptake fires.

Fig 1: Typical fuel pressure trace at approx full power.



A – Pump spill closes; 8° approx BTDC
B – Fuel valve opens; 4° approx BTDC
C – Spill opens; 12° approx ATDC
D – Fuel valve closes; 16° approx ATDC
E – Reflected pressure wave due to fuel valve closing
F – Partial equilibrium
G – Injection period; 20° approx
P_R – Residual fuel pressure
$\Delta P/\angle\alpha$ – Rate of fuel pressure rise before fuel valve opens; 2·5 approx
FP_O – Fuel valve opening pressure; 350 kg/cm²
P_O – Angle at which fuel valve opens relative to TDC; 4° approx BTDC
FP_{MAX} – Maximum fuel pump discharge pressure; 650 kg/cm²



*While taking traces, the fuel system should be suitably 'locked' to remove governor influence and so achieve steady running conditions.
**The dynamic opening pressure of a fuel valve in service will be nearly 100 kg/cm² higher than the static opening pressure on the test bench—this is due to inertia in the moving parts of the fuel valve.
***ΔP/Δ∝ rate of injection-pressure rise and injection period will have to be measured by scale drawing from a polaroid picture of trace.
****Where faults are corrected immediately, two PMLS will be required—one showing the 'before-correction' data, the second showing the 'after-correction' data.

Fig 2: Pre-performance check.

FAULTS	INDICATION: $\frac{\Delta P}{\Delta\alpha}$ LOW	FPo LOW	FPo HIGH	PMAX HIGH	PMAX LOW	∝ Po EARLY	∝ Po LATE	Injection period LONG	Injection period SHORT	Reflected pressure wave DAMPED
Worn fuel pump internals										
Leaking valve on fuel pump										
Fuel valve spring set too HIGH										
Fuel valve spring set too LOW or broken										
Fuel valve nozzle worn excessively or damaged										
Fuel pump index setting too HIGH										
Fuel pump index setting too LOW										
Choked fuel valve nozzle										
Fuel pump timing too ADVANCED (LEAD)										
Fuel pump timing too RETARDED (LEAD)										
Fuel viscosity too HIGH										
Fuel viscosity too LOW										

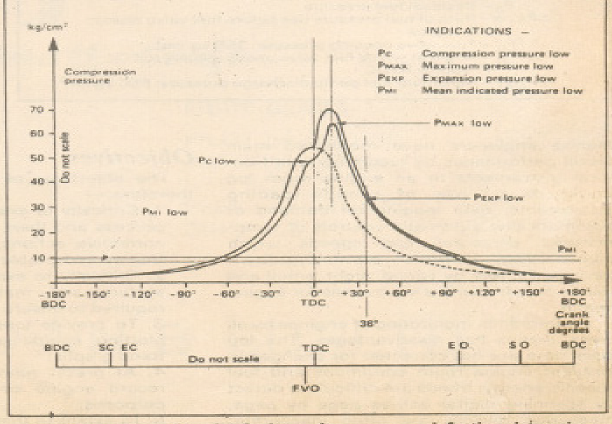


Fig 4: Pressure profiles for faults such as worn or defective piston rings, burnt crown or worn liner.

◄ **Fig 3: Pre-performance test fault-finding table.**

Fig 1: The influence on the dew point of sulphuric acid of fuel sulphur content and combustion pressure.

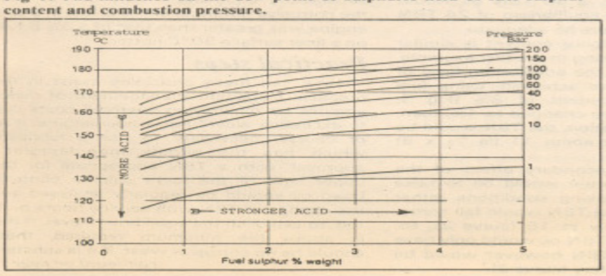


Fig 2: The influence of oil consumption on equilibrium TBN.

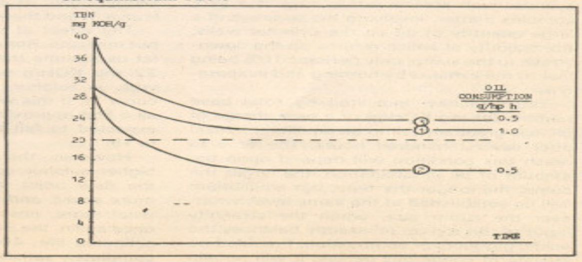


Fig 3: The influence of fuel sulphur content on equilibrium TBN.

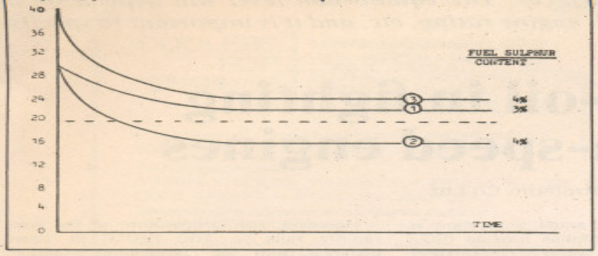
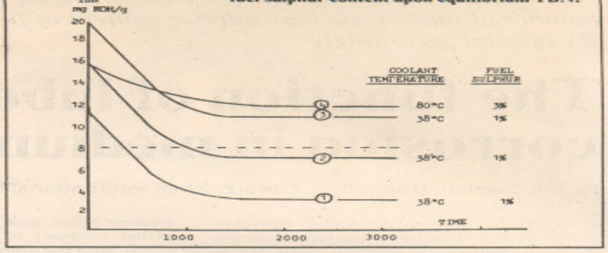


Fig 4: Example of the combined influence of coolant temperature and fuel sulphur content upon equilibrium TBN.



POSTBAG

Fuel systems

Sir,
I was interested to read your 'Opinion' (MER January), indicating the lack of comprehensive guidelines concerning fuel systems, fuel compatibility and performance, etc. particularly with reference to the involvement of classification societies.

You may be interested to learn that we have obtained a contract from Lloyd's to undertake exactly this work. We hope to be able to 'finger print' the performance of a total range of fuels and also to correlate this with actual performance in a range of diesel engines, with particular emphasis on performance reliability. Furthermore, we have ongoing programmes investigating alternative fuels and simulating fuel/engine systems.

I think it fair to suggest that perhaps insufficient is being done in this area in the UK, but thought you would like to know that, within our own resources, we are at least attempting a solution to what has become a significant problem.

R V Thompson
University of Newcastle upon Tyne

Marine turbines

Sir,
Words of appreciation are due, on behalf of marine engineers everywhere, to Professor Ingvar Jung, for his part history of the marine turbine. This most excellent work, made especially interesting by the knowledge that Professor Jung has himself 'kept watch', was recently published in English by the Trustees of the National Maritime Museum and made available through the Institute.* The work covers developments up to 1927 and must surely be the most definitive book of its kind yet set down. The second part is, I am sure, eagerly awaited.

Controversy, however, never lurks far beneath the surface in the field of science and engineering, particularly when referring to the 'inventor' or to the 'first' in a particular field. The steam turbine is no exception in this respect and I would like to take issue with a minor matter recorded in Table 1 of the book, which I believe creates a slightly biased impression.

Setting aside for the moment the early reaction turbine of a certain Mr Hero and the impulse turbine of Branca, serious but unsuccessful steam turbine development work is reported to have been first carried out between 1843 and 1848 by Pilbow and by Robert Wilson. De Laval's reaction turbine of 1883 was, I believe, on the Hero principle, and therefore hardly a successful commercial engine. Also, the performance of the impulse turbine, although built from 1883, was generally regarded as inadequate, prior to a sound understanding of the steam nozzle.

Parsons, who paid tribute to the ingenuity of de Laval on several occasions, attributed the correct understanding of the convergent–divergent nozzle to John Perry in 1887. By this date Parsons had, through the firm of Clark Chapman and Parsons Ltd, manufactured and installed several hundred turbo-dynamo sets aboard ship. These were in the power range 1–75 kW and included, incidentally, a 12 kW set installed in the ill-fated HMS *Victoria*.

This rather suggests that Parsons was the first commercially successful designer of the steam turbine. From an historical viewpoint, however, the famous Mr Hero must take the accolade of having been the 'first'.

E F Kirton
Sunderland

*See MER Nov 82 p 44/45

Windpower

Sir,
I noted with interest in the MER of January 83 that you carried an article on the wind powered motor vessel *Mini Lace*, developed by the Wind Ship Company, and fitted by the Greek owners Hellenic Shipping Enterprises Ltd.

With the help of the Wolfson Unit at Southampton University and Rotormarine Ltd. I developed the *Tradewind* rigs Mk I with rotatable mast and full rigging, using as a prototype a 23 ft motorsailer for short-handed yachts, and Mk II with a fixed mast, with sails rolling inside the mast and with full or topmast rigging only, both with twin booms.

Such a sail rig, with 5 similar sails on two masts and with an area of 1490 m² could be applied to a vessel like *Mini Lace* (of 3000 dwt and only 278 m² of sail). With sails folded together the *Tradewind* rig can point as well as any schooner to 35 deg or less. With adverse winds and in commercial use, the fuel saving would not be so great, but the sail area is still 3 times that close hauled. Once fully rolled, the head resistance in winds dead ahead is minimal, unlike the clumsy 'sails' of *Shin Aitoku Maru* when furled.

I would be happy to provide full details to any UK coastal shipowner who may be willing to have such a sail rig manufactured and run trials. It is possible that a grant of half the experimental cost may be available from the Dept of Industry, Ship & Marine Technology Requirements Board.

Capt W A Stewart
1 Hamilton Hse,
64 Canon St, Winchester

The Editor welcomes correspondence, but reserves the right to edit and shorten letters.

Fires in uptakes

Sir,
From Mr Tye's letter in February Postbag, it seems that the water-tube exhaust-gas boiler was either empty, or not being force-circulated from the oil-fired donkey boiler, while the main engine was being operated at power for some time before the fire became evident. If so, while not being a cause, it had the potential to make a major contribution to the initiation and/or spread of the fire.

Shipboard and laboratory research work, carried out 1967–1970, indicated that if the waste heat recovery unit was to be left empty or without circulation when the main engine was being operated, it was necessary to waterwash the gas side of the WHR unit's tubes before the main engine was started.

Among the interesting findings of the research were that, for the WHR unit for a 7500 bhp engine, combustion deposits, 1/16 in thick over the heating surface, could total 1200–1500 lb. The deposits contained up to 96% combustibles, some of which could be ignited at temperatures as low as 340°C, which was close to exhaust gas inlet temperatures under normal full-load engine operation.

Carbonaceous deposits on exhaust valve cages were predominant due to unburnt fuel which, under certain conditions, could break off in a glowing condition and act as the source of ignition for surface deposits in the WHR unit. Tenable theories were also put forward for the initial extent, spread and intensity of fires.

There is some difference in recommended procedures for dealing with fires in oil-fired economisers/air heaters and those in WHR units. Further information on prevention, causes, detection and fighting of fires in WHR units is given on pages 31, 32 and 34 of Volume 2 Part 18 of 'Marine Engineering Practice' which was published in 1981 by the Institute.

A Norris
Hurstpierpoint, Sussex

Blending

Sir,
I should like to clarify two points regarding the article in January MER (p 17) on the WIMCO blender.

The Bank Line vessel *Roachbank* is fitted with our fuel oil bus-rail module. It is this vessel which has been in service for over a year with the attributed £69 000 fuel cost savings and excellent service results. The first of our fuel oil blenders has recently been fitted to *Dacebank*.

However, it is expected that the savings made on the latter vessel will be about the same figure.

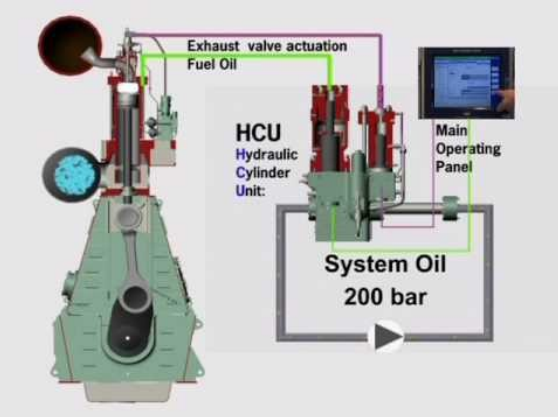
J K Atkinson
WIMCO Technical Services,
Tyne & Wear

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

MASSA Maritime Academy, Chennai

The Institute of Marine Engineers (India)

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



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

Course Aims and Objectives:

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

Coverage / Program Focus:

This course deals with the following training areas:

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

Entry Requirement / Target Group:

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

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

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

REGISTRATION & PAYMENT : Rs. 15,000/- /- per participant – inclusive of taxes.
For IME(I) Members 13,500/- per participant - inclusive of taxes.
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