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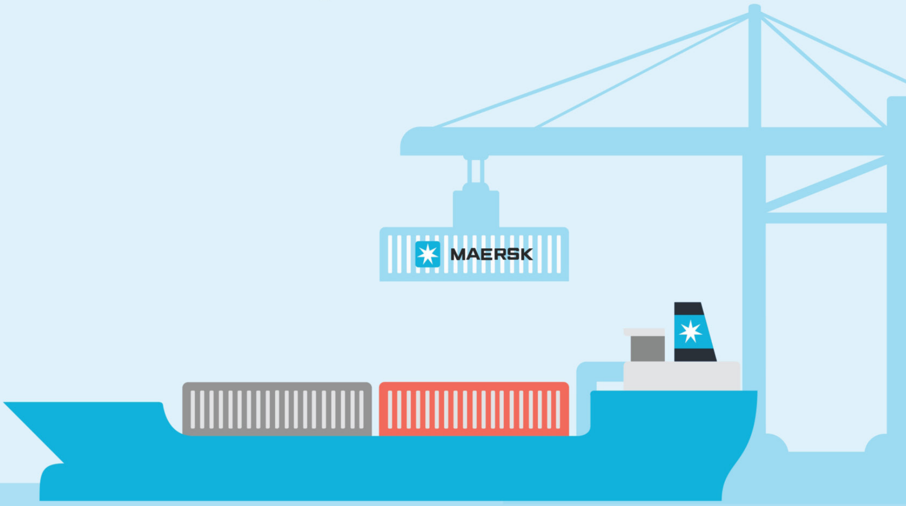

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EDITORIAL

The young have aspirations that never come to pass, the old have reminiscences of what never happened.

- Saki

22-16-23 is certainly a fit figure, though we might wish that the top could have been heavier, while we bring the memories from the Birmingham Common Wealth Games. The teams showed their mettle in wrestling, weightlifting, badminton and table tennis but the heart-warming honours are from the athletics – out of the 8 medals, two podium finishes were for a single event of triple jump. Be it the Asian Games, the CWG or the Olympics, the Indian signatures in the track & field have found little or no space. However, there is a change in the air. These achievements inform the discourses that staying invested in a range of sports and games will pay dividends and cricket can be left to take care of itself.

Another narrative which ran parallel to the CWG was the Chess Olympiad in the southern shores of Mamallapuram, Chennai. The score here reads 2G-1S-2B. The Bronzes are from team events (India 1 Women; India 2 Men). It was clearly the young India adding colour to the black & white squares. Incidentally, India has 73 registered Grand Masters (GM) and this is expected to increase as the new scores are announced and remarkably, the average age of the Indian GM cohort (for 2022) is around 18 years. (As I finish this penning, Praggnanandhaa had completed a hat-trick with Carlsen).

These intriguing times promise to reward the aspirations of the world's young. And those of the global generations, which have transitioned into this Century, may rejoice rather than reminisce and be reassured.

In this issue...

Drones are here to stay... We could be having many sailing marine engineers who have now seen the drones being employed for surveys and inspections. Days may not be far when ships will carry drones for regular inspections and maintenance. The understanding of the technology and the merits are definite inclusions in upskilling menu of the marine engineers.

Here we start with a lift and look at the coast with drone technology. A team from NIOT had done few coastal studies and this original work is being shared. In the first part (Part 1), we have the descriptions of the drones. The flow is simple and easily educative about the components of the drone, materials and the features. The functions of propelling and communication systems are sure to kindle our interest. The Authors end the part directing the drone application for monitoring the water quality. The study and descriptions will follow.

The drone design was derived from the bird... so would Dr. Veda say and pitch for the bio inspiration rationale.

In this Part B, Dr. Veda expounds the approaches to the hydrodynamic design of an Autonomous Underwater Vehicle (AUV) with basic equations and factors. The familiarity to ship's motions and vessel dynamics are easily recognisable. He then ties up the bio-inspiration highlighting the studies on flying birds and swimming fish. An intriguing takeaway is that less-heavy swimmers and fliers being equally efficient and large animals may not be mechanically more efficient.

The rationale for the air lubrication innovation, the development of robot-fish with actuators (supported by electric motors), locomotion improvements, rigid links of articulated robots and developments towards continuum robots are other discussions that arrest our attention. There is good food for the engineering mind here.

In Competency talks, Jagabandu Mazumdar explains PID controls. Briefly dwelling on the basics, he explains the procedure for tuning. This should be interesting to the practicing marine engineers.

Sanjiv Wazir continues Lube Matters with synthetic lubricants.

From the archives, we dig out the September 1982 issue of the MER and share a few glimpses. Under Heritage Hourglass, Jahnavi presents some Indian insignia of yore with marine connections.

And, adding strength to the publication side, the Institute has put forth plans for a newsletter. Amongst other plans to mature MER as a preferred technical journal of repute, this would be one. Seeking your attention and support for such initiatives, here is the September issue for your sighting.

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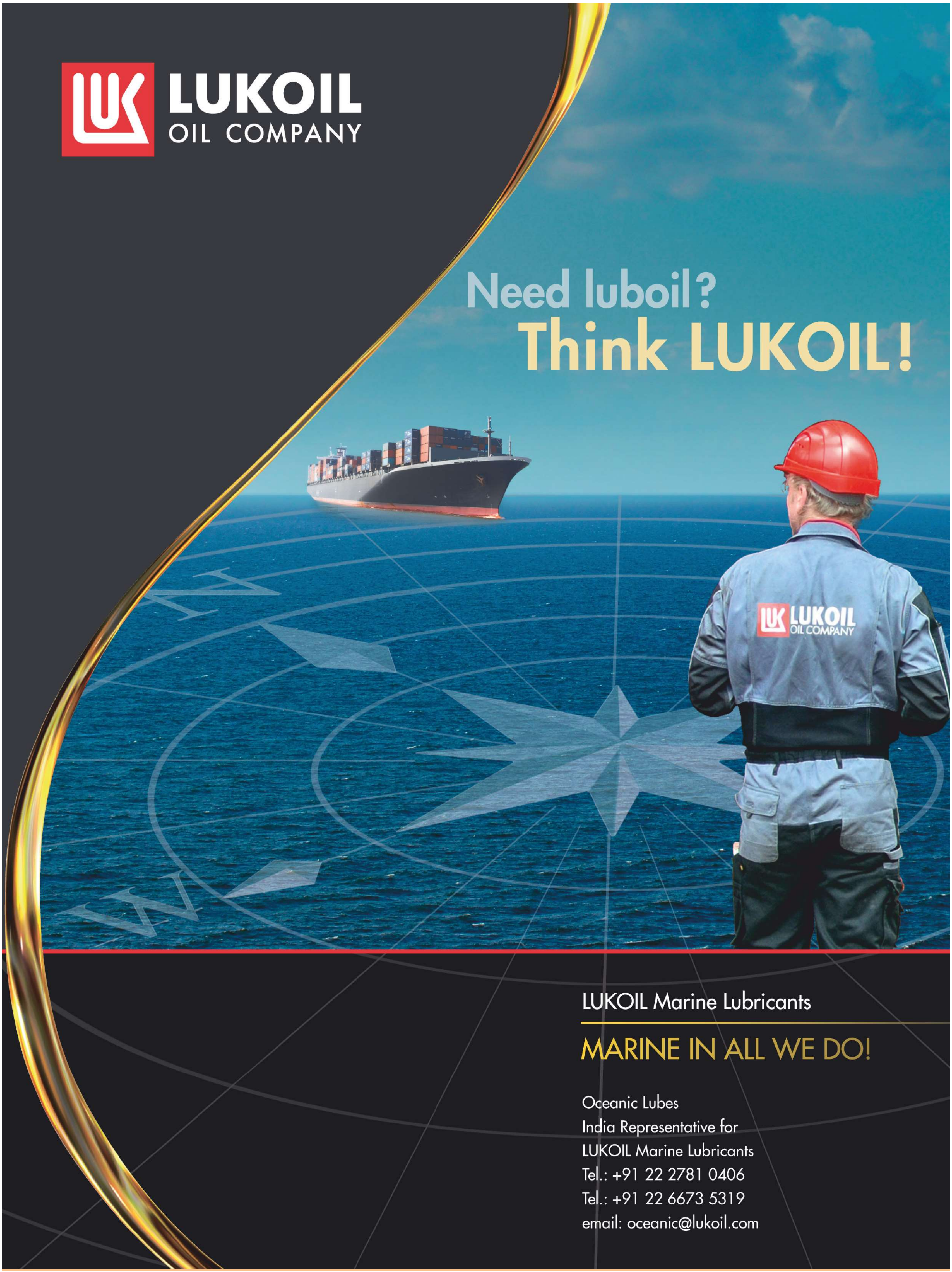
Cover Photo: **Drones by the coast, ready to coast** *(Beach Topography Mapping)*
Location: **Beaches behind IMU Chennai Campus** *(Bay of Bengal)*

Photo Credits: **NIOT Drone Mapping Team**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ADAPTING THE DRONE TECHNOLOGY FOR MARINE APPLICATIONS – A HIGH RESOLUTION WATER QUALITY MEASUREMENT SYSTEM USING DRONE (PART 1)

R.Srinivasan, V.Gowthaman, Tata Sudhakar, G.A. Ramadass

Abstract

Drone based water quality measurement system (WQMS) includes an Unmanned Aerial Vehicle (UAV) instrumented with series of high resolution water quality measuring sensors such as fast responding micro thermistor probes (MTP) to measure the sea water temperature, conductivity, pH, Turbidity, Dissolved Oxygen, partial CO_2 and Micro plastic sensors. Compared to conventional water quality monitoring systems like coastal moored buoys, data collections by water sampler and vessel on move, drone based observation method is easy to operate and collect ocean parameters covering large area in shorter time. Due to industrialisation and increase of manufacturing companies, the coastal waters are polluted with the utility of excessive chemicals, usage of more pesticides in agriculture fields, un- processed water from thermal power plants and anthropogenic activities. This leads to the depletion of marine organism, thermal properties of coastal waters, migration of marine habitats and also effects to shallow water eco system. Every coast cannot be deployed or equipped with buoy based observation system to measure and monitor such water quality parameters. It includes higher cost and not a favourable condition for humans to collect real time data at shallow water surf zones. To cater the coastal monitoring requirement and cost effective manner with larger foot print, the modern technology on drone is highly necessary. This article explains about the various design considerations of the drone based high resolution WQMS for observing the shallow coastal regions of ocean up to the mixed layer depth of 50 m. This article explains about the design scheme of ocean micro structure measurement system and the results of few ocean front demonstrations carried out using drones.

Key words: Drone, CTD sensor, Automatic water sampler, Beach topography, Water Quality monitoring, High resolution measurement system.

1. INTRODUCTION

Data collection and observing the shallow regions of ocean play a major role in studying and monitoring water quality because they are sources for deep water pollution, migration of eco system and marine habitat. Monitoring the highly dynamic shallow water region using the regular buoy system is very tough due to actions of wave braking activities, which releases a huge amount of potential energy. Deep water waves are higher in wavelength and lesser in wave height. When the same wave approaches shallow waters, wavelength reduces and wave height increases due to changes in bottom topography. It is very difficult to collect water quality parameters at this dynamical location. Observatories should be designed in such a way that they sustain in harsh marine condition. Most of water quality observatories are located in deep waters compared to those in shallow waters.

Ganga and Yamuna are the most polluted rivers in India[2]. Domestic sewage and industrial effluents are discharged in the rivers, drains and canals or go directly into the seas either untreated or partially treated mostly from the urban and industrial belts

Water pollution is one of the major issues facing India. As may be evident, unprocessed sewage is the major source of pollution. There are other sources of pollution such as runoff from the agricultural sector as well as unregulated units that belong to the small-scale industry. The situation is so serious that perhaps there is no water body in India that is not polluted to some extent or the other. In fact, it is to note that almost 80% of the water bodies in India are highly polluted1. This especially affects the human habitats living in the immediate vicinity. Ganga and Yamuna are the most polluted rivers in India[2]. Domestic sewage and industrial effluents are discharged in the rivers, drains and canals or go directly into the seas either untreated or partially treated mostly from the urban and industrial belts. Numerous pollutants are added which include, among others, several toxic heavy metals and metalloids[3].

Sea surface micro layer has been defined as the uppermost 30 ~tm of the sea. This layer is exposed to atmosphere and affects and controls the air-sea interaction processes. Therefore, the layer can be expected to contain a high concentration of pollutants as it is enriched with both air and water. Studies on the sea surface micro layer are at an initial stage by Indian research institutions. However, preliminary data indicate a 10-25 times enrichment of the essential nutrients and a few heavy metals of this layer as compared to their concentration in the water just 25 cm below the surface[4].

The technology on unmanned aerial vehicle (UAV) has been maturing and widely used in the field of military affairs and civil purpose. Due to the good flexibility, high efficiency, low cost, low risk, and excellent monitoring ability and widespread coverage, the UAV is capable of the waterborne supervision. At the same time, the UAV has been put into monitoring oil leakages at sea[5]. The UAV that is used for water quality monitoring needs to be able to carry the additional weight of the sampler mechanism, collected water, and additional parts that allows the UAV to float on the water surface in case of an emergency landing. These attachments are called as **payload**[6]. The UAV has to produce enough thrust for lifting its payload[7].

Thrust is one of the basic motions of a multi rotor generated by its propellers. Developed thrust force is directly proportional to the rotating torque of motors[8]. Therefore, motor size is a significant part for generating required thrust for the UAV. There are many types of motors in the market that are used for UAVs. Each of these motors has different power utilisation, and propeller size needed to create enough thrust to lift the UAV with its payload. The accurate size of the motors must be chosen to generate enough thrust for the UAV, and keep it floating in the air (hovering) during data sampling[9].

2.0 DRONES FOR OCEAN OBSERVATION APPLICATIONS

India's drone journey which began more than two decades ago, deploys one of the largest fleet of military drones in the world. Its journey in the civilian and commercial arena has only just begun. India with its smart city program, spread across its diverse landscape, provides an ideal laboratory for the deployment of UAVs, and in keeping with the global trend of transforming existing cities into smart cities. Prior to deployment of drones, it is important to understand that a UAV is a platform to carry the sensors which forms the core of the desired operation, minus the sensors – it is just a fancy toy. With the miniaturisation of sensor technology, UAVs are finding new ways to solve myriad problems and with the advent of low cost 3D printing technology and off the shelf kits, the design and development costs have gone down drastically, making deployments possible for wide-ranging applications. UAVs today carry advanced sensors such as Hyper-spectral imager, Synthetic Aperture Radars (SAR) and Light Detection and Ranging (LIDAR) scanners which are beginning to revolutionise agriculture, search and rescue, town and country planning.

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The phrase precision agriculture is now synonymous with the use of drones which are being deployed for crop spraying, dusting, monitoring, and crop insurance. Terra Drone India said it has completed the aerial survey of 4,200 sq. km of agricultural land for the water resources department of the Maharashtra Krishna Valley Development Corporation (MKVDC). The survey helped government officials get a clear picture of the crops sown and the type of irrigation used and allows MKVDC to update its archaic maps in half the time of traditional surveying methods. Along with sensors, the development and integration of sense and avoid technologies, UAVs are poised for a quantum leap in drone delivery performing complex flight operations in the national airspace.

Ocean observations at shoaling zone is very challenging task and it requires innovative way of approach to collect real time observational data in this zone. Shoaling zone is a combination of transition zone and shallow zone, mostly located at continental shelf. Deformation of waves can be observed and causes decreasing of wave length


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and wave height increases due to change in bottom topography continental shelf. Rapid mixing process takes place in shallow water zone and dynamic in nature. Due to this dynamic movement of waves creates unfavourable conditions for measuring real time observational data. Dynamic nature creates mixing of vast water bodies at surf zone as well as near shore zone which triggers rapid change of physical, chemical and biological properties in sea water. In order to measure these parameters there should be an observatory which able to collect data in harsh condition and can sustain in wave impacts. To overcome this problem, drone based observation is being considered, which improves quality of real time data collection at shallow water zone, compared to existing shallow water observations.

2.1 Hexa Copter - a system description

Heavy lifting Hexa Copter is a multipurpose heavy-lift platform as shown in **Figure 1**. The Heavy Lift hexacopter is sturdy and has very good stability. The technical specification of Hexa Copter is detailed in the **Table 1.** It is made of carbon fibre material which features light weight and high strength. The arm of the multi copter is foldable; it can be locked with the quick locking knobs. This foldable design makes it easy to transport and quick to setup. The heavy-lift drone is equipped with powerful motor and high efficiency 30-inch propeller to ensure long flight time, this heavy-lift drone is able to carry a lot more weight than a typical quad copter, and maximum thrust of one rotor can reach 13kg. The multi copter is equipped with dual landing gear system; it has enough space between the centre board and the ground. So, this strong body can be equipped with much equipment, the motor and ESC adopt the water-resistant design, and can be applied in different weather conditions. Highly rugged and stable, the UAV is made of full composite material, enabling it to stand against the strong wind conditions up to 10 m/s.

2.2 Multi Copter Drone System consists of the following subsystems

1. Airframe system
2. Propulsion
3. Power system

Figure 1. Heavy Lift Hexa Copter

Table 1. Technical Specification of Drone

Wheelbase	1630mm
Dimensions	1528*1326*730mm
Material	Composite material
RTF Weight:	23Kgs
Max. Take-off Weight	42 kg
Endurance	35-45 Minutes with 10 kg payload
Suggested Max Payload	10Kgs
Suggested Cruising Speed	10 m/s
Landing Space	3m X 3m
Wind Resistance	10m/s
Max Bank Rate	35°
Operational Altitude	100 m AGL
Max. Takeoff Altitude	2000 m
Take-off/Landing	VTOL
Working Voltage	48V
Working Temperature	10°C - 55°C
Deployment Time	10 mins
Terrain follow	Support with on-board Barometer and Sensor
Power	Battery powered
Range	3+ Kms
Flight Modes	Fully Autonomous Mode
Semi-Autonomous Mode	
Return to home mode	
Loiter Mode	
Altitude Hold	

4. Electrical system
5. Avionics system

a). Airframe system

The airframe is the main structure of the drone. Moreover, the airframe needs to be adequately designed to withstand the forces that can occur during the flight and not cause any deformation and vibration. **Airframe is generally manufactured with four different materials such as carbon fibre, aluminum 6061, glass fiber & steel.** The air frame Hexa-copter is made of carbon fiber frame with multiple swiping application system and connecting parts made of aluminum, landing gear made of steel rods and battery enclosure made of ABS plastic. These materials are corrosion resistant, designed and manufactured according to industrial grade standards. The parts are manufactured locally and assembled in-house. To reduce vibrations to the inertial measurement unit or sensors, will provide the damping system to some of the components which are sensitive to vibrations. The air-core damping ball within the dampers will absorb the high frequency vibration. It effectively reduces the high frequency vibration influence to the Inertial Measurement Unit and gimbals.

Air Frame Specifications:

- Airframe Weight : 6 kg
- Maximum Takeoff Weight : 15 kg
- Factor of safety : 1.6
- Periodic inspection after a flight, if any crack or deformation will replace particular part.

b) Propulsion system

Propulsion system consists of Motors, Electronic Speed Controller (ESC) and Propellers. **Brushless direct current motors (BLDC) are used for propulsion.** Using special alloys makes them lighter with high efficiency and reliability. Electronics Speed Controller (ESC) is an electronic circuit that controls and regulates the speed of an electric motor. The BLDC motor and its view are shown in **Figure 2**. It provides information of the speed and better stability is achieved. The purpose of Hexa copter propellers is to generate thrust and torque to keep drone flying, and to manoeuvre. It is made up of carbon fibre material. Each propeller of Hobbywing X9 plus power systems with 34-inch propeller generates a load carrying capacity of 12kg per axis and peak thrust of 72 kg shall be produced. The propellers are 180 KV rated electronically operated BLDC motors.

c) Battery

Lithium polymer of 14S standard with 50.4 V is used to power the Drone. The battery is used as a main power source and provides the complete peak power requirements by the systems. In case of system failure, the reserve battery capacity will provide a backup of 10 minutes for safe landing. This ensures a failsafe system to ensure drone safety.

d) Electrical system

A power distribution board is a component of an electricity supply system that divides an electrical power feed into subsidiary circuits and the Power Converter are used to convert the input voltage to a constant output voltage to the equipment, such as receiver, servos or

Figure 2. Sample BLDC Motor ESC and Propellers Set

> *The GPS gives a positioning of the drone with respect to the satellites present in the contact in particular area. The IR camera is used to capture the images and the video and transmit it to the ground control station through the autopilot for various applications*

flight controller. A power monitor is a device that is used to provide the necessary power to the equipment and monitor the electricity consumption and battery voltage. Cables used can withstand current ratings higher than the maximum current through the system. It can operate efficiently at extreme temperatures. Power connectors are used to connect between power sources and different systems. Power connectors also follow military grade standards. It has anti spark protection and can operate at extreme temperatures.

e) Avionics system - Autopilot

An autopilot has its inertial measurement unit which helps to navigate the drone in a particular direction and also it controls the trajectory of a drone. Autopilot has various ports like UART, telemetry, serial communication etc., as indicated in **Figure 3**. In the present drone system, the interfacing of GPS, communication system, camera, electronic speed controller, all these take place through these ports. An autopilot is a heart of the system. In the present system, it is connected to the various modules for better performance or the operation of the drone. It has the inertial measurement unit which consists of gyroscope, accelerometer and magnetometer these IMUs are typically used to manoeuvre the drone or UAVs. It also provides drone's orientation information to the autopilot.

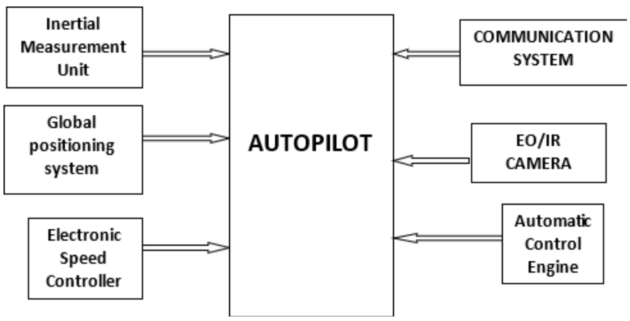

Figure 3. Autopilot block diagram

The autopilot is connected to electronic speed controller (ESC) which provides controlled outputs to the motor. It provides the communication between the air unit and the ground unit through the telemetry port. The GPS gives a positioning of the drone with respect to the satellites present in the contact in particular area. The IR camera is used to capture the images and the video and transmit it to the ground control station through the autopilot for various applications.

2.3 Communication System

Advanced autonomous flight control board by STM32 F7, 216 MHz processor having PX4, Ardupilot software support system with 6 PWM I/O ports, 6 Servo I/O ports and built in data recorder is used I Hexa-Copter. Assistance software such as the mission planner, Imax GCS and Ground control and new parameters setting using telemetry is possible. **Features like altitude stabilisation, fixed height mode, automatic return mode, out of control return mode, low voltage protection, one button traverse function etc., are available in flight controller module.** The communication system consists of an air unit and the ground unit. It is the main relay unit which provides information to the pilot about the operation of the drone.

The ground unit is consisting of ground station and the radio controller which helps the pilot to understand working of the drone. The air unit is used for the communication with the ground unit and captures video, images, data and transfers it to the ground unit

The ground unit is consisting of ground station and the radio controller which helps the pilot to understand working of the drone. The air unit is used for the communication with the ground unit and captures video, images, data and transfers it to the ground unit. The communication system provides the second method of controlling the UAV. It allows operator to work with the powerful GCS (Ground control station) in a real time. The communication system transmits signal over radio frequency to communicate with the ground control. The receiver takes 2.4 GHz signals from the transmitter allowing the operator to low latency control over UAV.

2.4 Ground Control Station (GCS)

A GCS refers to complete set of ground-based software and hardware system which are used to control the UAV. A ground control station is used to control the drone during manual operational mode. It includes telemetry module, data link system, user control, and a graphical user interface. This ground control station provides the interface between the pilot and a drone. Through GCS pilot can give command to drone for various operations. The wireless data link module establishes remote communication between GCS and drone.

2.5 Global Positioning System

GPS is a satellite-based radio navigation system. It is used to know the accurate position of the vehicle. It is one of the global navigation satellite systems (GNSS) that provides geo-location and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.

2.6 Camera

The camera payload is a 15 MP Day light sensor. They are helpful in various operations like recording, compression; snapshots while live feed to the ground control station (GCS).

2.7 Features of Drone systems

2.7.1 Extended Flight Time

The UAV can achieve Flight Time of 40+ Minutes along with the payload capacity. The Battery + Generator Hybrid System provide longer flight. The fuel tank can be easily refilled to continue the operation while charging the on-board batteries.

2.7.2 Heavy Lifting – 10 Kgs

With the advanced propulsion system, the payload capacity is greatly enhanced to support 10 kg of task loads. Each motor having maximum thrust capacity of 13 kg with 30 inch propellers, gives a stable and smooth flight with better flight control and drone speed. The proper cooling of the propulsion system facilitates the flight time of the drone without heating or malfunction.

2.7.3 Type – VTOL

With vertical take-off and landing capabilities, the drone can take off from smaller and constraint spaced without difficulty and without additional setup. Landing area of size 3 m X 3 m is sufficient to take off and land. The drone also has autonomous take-off and landing capabilities and can take off from almost any surface textures like grass, gravel, concrete, sand etc.

2.7.4 Launch and Land from any platforms

With advanced landing system, the drone can take off and land any platform. The drone maintains stability and precision during landing and take-off from the landing Pad. This enhances the options and safety of the drone and thereby tough and critical operations can be tackled with ease. The drone also comes with Sensor for Altitude to maintain the altitude from the surface.

> *The drone also has autonomous take-off and landing capabilities and can take off from almost any surface textures like grass, gravel, concrete, sand etc*

2.7.5 Communication Range

With good range, the requirement for better communications is of utmost consideration for many applications. Transmitter with R12 receiver and HD camera integrated control video and telemetry system covering 20 km range is built with drone. Skyroid H12 digital video data at 2.4 GHz, 1080P transmission telemetry transmitter 12 Channel Drone UAV drone remote control is equipped in Drone. We have flexibility in using the handheld Ground Control Station (GCS) and laptop based GCS to provide better controllability and operation of drone. Frequency option of telemetry system is 2.4 GHz. All radio control, data link and video link controllable from a single communication system and GCS, one to two people is more than sufficient to operate the Drone and do the mission. With AES 128 Bit encryption, the data sets are secure and safe.

3.0 WATER QUALITY MEASUREMENT METHODS IN PRACTICE

Currently there are many types of water quality monitoring systems are in use. One of these methods is **satellite-based turbidity sensor.** These satellite-based turbidity sensors in river streams are in use to calculate the sediment amount in water (SCWRRI, 2004). Satellite-based turbidity sensors are inaccurate and dependable due to the signals interactions with the atmosphere. Atmospheric effects such as attenuation caused by cloud, rain, and atmospheric gases may affect the quality of data that the sensors measure[10].

Another technique for water quality monitoring is using autonomous vehicles in water sampling and one of these is the Autonomous Underwater Vehicle (AUV). AUVs have been used for water quality monitoring in current times. Recently, underwater gliders are considered as vital platforms for high resolution in situ ocean observation[11].

Gliders are unmanned autonomous underwater vehicles with variable buoyancy[12-15]. The first underwater glider flight trials began in 1992 at Webb Research Corporation, East Falmouth, USA[16].The first Glider Sea trials were conducted with a Slocum Glider at New Jersey site in July 1998[17-18]. A glider voyaged 7400 km in 221 days and crossed the Atlantic Ocean in 2009[19]. Currently, three notable underwater glider designs are widely used; Slocum[20], Spray[20] and Seaglider[21-22]. The gliders, Slocum, Spray and Sea glider, are designed to operate at maximum depths from 1000 to 2000 meters. Indian institutes carried out few deployments of gliders in the Bay of Bengal during the year 2014[23] for high resolution measurements but still these vehicles are not suitable for measurements at shallow water regions.

These vehicles autonomously monitor the water quality while they navigate in under water areas. However, it will be a very challenging task. The major disadvantage with underwater is that the GPS system cannot be used for perfect positionin[24]. Because of this reason, the AUV has to be installed with additional navigational systems. **Autonomous Surface Vehicle (ASV)** is also used for water quality monitoring purpose. The vehicle automatically navigates to predefined sampling path and measures pH, DO, EC, turbidity, temperature, sensor depth, water depth, chlorophyll-a concentration, and NO_3. Disadvantages of automatic sampling with a boat were the operational difficulties and unsure engine-control system[25].

Unlike the above example, an aircraft or an UAV can be used to capture aerial images of water bodies of our own interest. Aerial images that are captured remotely by a UAV can help visualise the disturbance or oil spills in the water and provide enhanced spatial water quality monitoring data. An aerial survey with a high resolution camera attached to a UAV can also show the locations of water contamination. Aerial images taken from a UAV can provide the coordinates of contaminations which can help determine more accurate water sampling locations. These sampling points would increase the accuracy and precision of water quality data. Necessary actions regarding public safety can be taken with the help of rapid water quality data[9].

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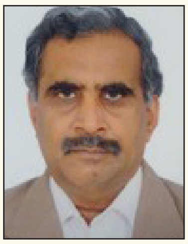

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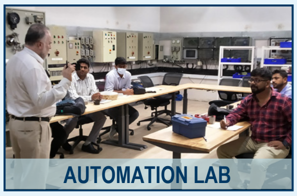

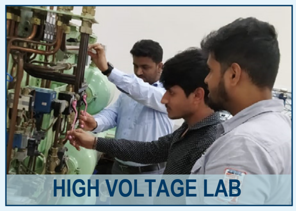

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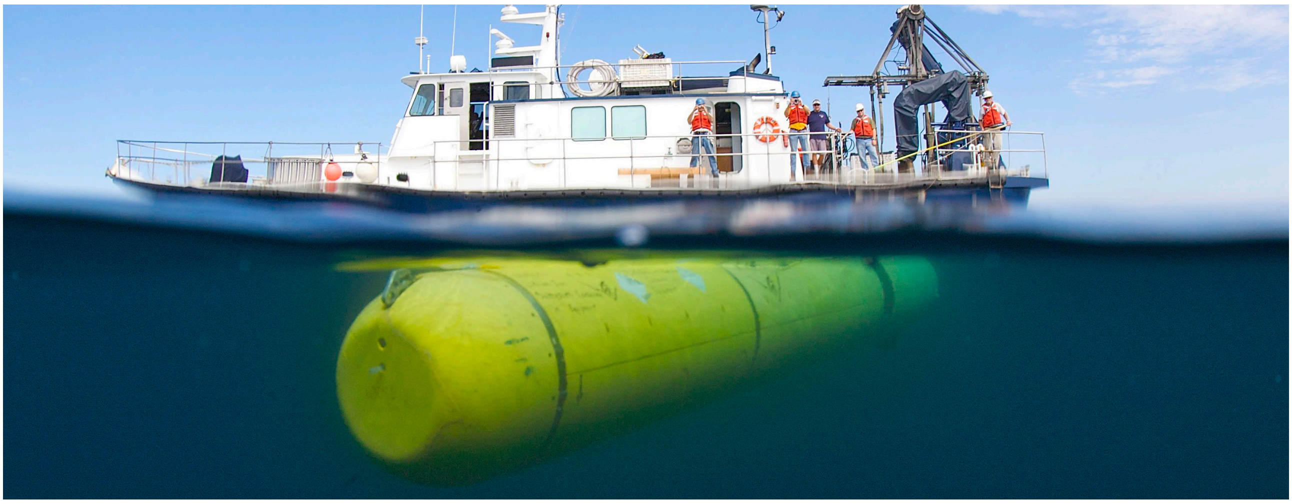

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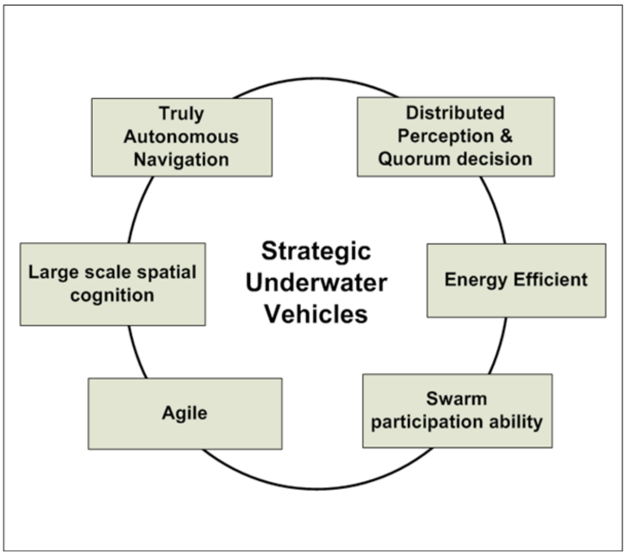
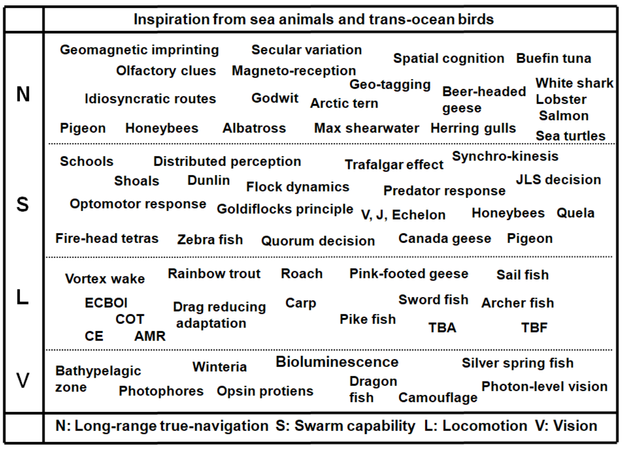


Abstract

Intelligent and efficient autonomous underwater vehicles (AUV) are vital for exploring the vast marine resources, spatiotemporal monitoring of the oceans for understanding climate change patterns, monitoring marine pollution, defense and identification of assets lost in the oceans. The article is published in three parts. The first part reviewed the trends in bio-inspired engineering, maturity of underwater navigation, abilities of sea animals including turtles, lobsters, salmon, whales and trans-ocean birds in long-range true-navigation with large-scale spatial cognition abilities that helps to establish idiosyncratic routes and the developments in bio-inspired magnetic homing guidance systems for AUV.

This (second) part discusses on the present maturity of AUV locomotion, energy-efficient locomotion of aquatic animals and the recent developments in bio-inspired continuum and soft robotics. The last (third) part shall bring out the need for swarm operations, fish flocking/shoaling abilities with intra-swarm intelligence supported by precise optomotor mechanisms, distributed perception, quorum decision process during predation and extreme low light vision capabilities in deep sea fishes. The observations presented could help in developing strategic bio-inspired agile AUV with improved propulsion, sensing, vision, control, navigation, machine-learning driven artificial intelligence and swarm capabilities.



Efficient and agile locomotion

Maturity of AUV locomotion

The AUV locomotion is enabled by a power source, power electronics based variable frequency driven brushless direct current (BLDC) motor that directly drives a multi-bladed propeller positioned at the rear of the AUV, control surfaces including fin and rudder for effective manoeuvring in multiple degrees of freedom

(DoF), motion reference unit (MRU) for measuring the attitude, Doppler Velocity Log (DVL) and a programmable automation controller for implementing the control algorithm for navigation and mission control. **Figure. 1** represents the propulsion-related components of the AUV with reference to earth-fixed reference frame and six DoF.

The operating range of an AUV is represented as,

$$\text{Range} = \frac{EV}{1000(P_P + P_H)} \quad (1)$$

Where E is the energy in joules, derived from the batteries, V is the velocity in m/s at which the AUV travels, Pp is the propulsion power and P_H is the hotel load required to operate all the internal systems and sensors.

The matured Nickel-Manganese-Cobalt (NMC) cathode based Lithium-Ion batteries have energy density of 75-200Wh/kg, a specific density of 150-315 Wh/l, cycle stability, efficiency, reliability, low self-discharging rate and low memory effect. The pressure-balanced oil-filled (PBOF) propulsion thrusters operated using direct-driven BLDC motor with rare earth magnets (having high magnetic flux density) and magnetically coupled propeller eliminates shaft seals and speed reduction gear boxes. These thrusters are compact, weighing ~3 kg/kW in air and produce ~15kgf/kW at vehicle/water advance velocities of 5 knots.

The on-board battery energy and the hydrodynamic shape of the vehicle determine the speed and endurance of the AUV. The hydrodynamic design includes the design of the hull fairing, control surface (including the fin and rudder) design, calculation of the AUV propulsive power (resistance and propulsion) and estimation of the directional stability and manoeuvrability. The hydrostatic stability, buoyancy control mechanisms and the control surfaces determine the manoeuvrability. **Hydrodynamic drag prediction methods based on experimental and numerical methods are presently matured to estimate the drag acting on an AUV hull form comprising various payloads.** The hydrodynamic in-service drag (ISD) is defined as,

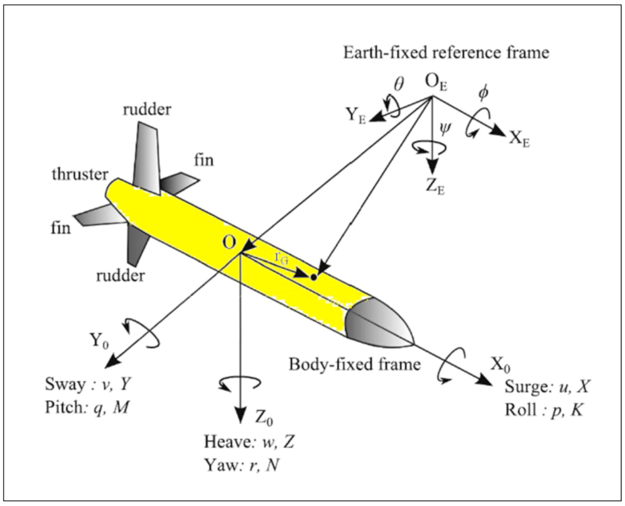


Figure 1. Propulsions systems of an AUV and degrees of freedom

The hydrodynamic design includes the design of the hull fairing, control surface (including the fin and rudder) design, calculation of the AUV propulsive power (resistance and propulsion) and estimation of the directional stability and manoeuvrability

ISD =Bare hull drag + Appendage drag + Protrusion drag + Induced drag (2)

The appendage (control surface) drag adds to both the skin friction and the pressure drag, usually ~13% increase from the bare hull resistance. Operational AUVs differ from the smooth-hull assumption as various instruments protrude through the hull, each of these protrusions has an incremental effect on the total drag on the vehicle. The induced drag is associated with the control surfaces when maintaining depth.

The control surfaces provide sufficient course-keeping stability for straight-line performance and the required turning forces for maneuvers while minimising the contribution of the control surfaces to the total drag. When the AUV uses its control surfaces to adopt a nose down when flying attitude to maintain depth, a component of the propeller thrust and hydrodynamic lift from the hull is used to oppose the net positive buoyancy. This nose-down attitude results in a non-zero angle of attack on the hull, generating lift and induced drag. The dynamic stability of an AUV is represented by a horizontal stability margin G_H as,

$$G_H = 1 - \frac{N_v(Y_r - mU)}{N_r Y_v} \quad (3)$$

where Nv is the partial derivative of yaw moment considering the sway velocity, Yr is the partial derivative of sway force considering the yaw angular velocity, m is the mass, U is the velocity, Nr is the partial derivative of the yaw moment with respect to the yaw velocity, and Yv is the partial derivative of the sway force considering the sway velocity. For more advanced control algorithms, both the velocity- and acceleration-based hydrodynamic derivatives are required to provide details of the hydrodynamic control forces and moments acting on the vehicle.

The precision of vehicle attitude control depends on the accuracy of the hydrodynamic parameters of the AUV. Computational Fluid Dynamics (CFD) models based on the Reynolds-averaged Navier–Stokes (RANS) and continuity equations determines the drag force and added mass coefficients in multiple DOF. Models such as k-ε standard, RNG k-ε model, SST k-ε model simulate the turbulence effect in the flow around the AUV hull.

The accuracy of CFD calculation results depends on the quality of grid division, the choice of calculation mode, the setting of parameters and the boundary conditions. **The parameters for hydrodynamic propulsion studies include hull Reynolds number, propeller tip Reynolds number, vehicle advance ratio, thrust coefficient, torque coefficient, open water efficiency, relative rotative efficiency, thrust detection, taylor wake fraction, hull efficiency and quasi-propulsive coefficient.**

The David-Taylor Model Basin (DTMB) approach is widely used for experimental determination of the hydrodynamic parameters. The approach is more suitable for variable configuration AUVs, is based on the force-response principle, in which the hydrodynamic parameters are determined by the vehicle actuators (propeller, rudder and fin) and the precision vehicle on-board MRU and DVL. The drag force coefficients are identified from the thrust force required for moving the vehicle at a constant velocity. The added mass is identified by subjecting the vehicle to sinusoidal motion and measuring the thrust required for achieving the acceleration and matching the velocity profile.

The developments in titanium alloys, ceramics, copper, beryllium, duplex steel and composites have resulted in low weight, high strength and reliable pressure resistant housings used for housing the vehicle electronics. The syntactic foam that is used for making the vehicle near-neutrally buoyant are available with densities of ~600 kg/m^3 and low water absorbing characteristics offers effective buoyancy at full ocean depths. The precision buoyancy adjustment systems help in effective serving at desired water depths with minimal usage of thrusters.

The design of the AUV requires optimisation for achieving the required speed and range with an appropriate design trade-off of various parameters including battery size and volume, propeller performance, hull propeller interaction, size of the aft and forward control surfaces for dynamic stability and required maneuverability, hull shape having minimum volumetric drag, wake fraction and hydrodynamic derivatives for implementing control.

The accuracy of CFD calculation results depends on the quality of grid division, the choice of calculation mode, the setting of parameters and the boundary conditions

With the present advancements in vehicle hydrodynamics, stability, maneuverability design and matured electric propulsion systems, the present matured 6m long, 1m diameter, 2T AUV cruising at 3 knots speed has a locomotion energy efficiency of ~7kms/kWh. Commercially available AUV have an endurance of 100h at 4 knots speed and a turning radius of <15m. However, strategic vehicles demand higher energy efficiency, increased endurance and improved maneuverability.

Bio-inspiration

Aquatic animals and birds are endowed with several morphological and structural features that enable stability, maneuverability and efficient swimming performance. The flow of energy through a swimming fish from metabolism to wake momentum, and through the locomotor system is being studied for several decades. Swimming involves a series of interlinked processes whose combined efficiencies dictate energy flows through the system, the efficiency of converting metabolic energy to muscle mechanical power, the efficiency of transferring the power to the water, and the proportion of this power that is available to generate thrust.

Studies on the energetics of a swimming fish, relating swimming speed to size, wavelength, tail beating frequency (TBF) and tail beating amplitude (TBA) provide valuable inputs for AUV propulsion system design. During swimming, the undulating fish body captures the energy from the fin-induced wake and uses varied behavioural strategies to exploit effectively the environmental vortices to increase their swimming performance such as recycling of energy from self-shed vortices.

The first realistic values obtained using estimates of metabolic power, mechanical power output derived from a swimming rainbow trout fish with the overall efficiency approaching 15% at the upper end of the sustainable speed range is shown in **Figure. 2** [1].

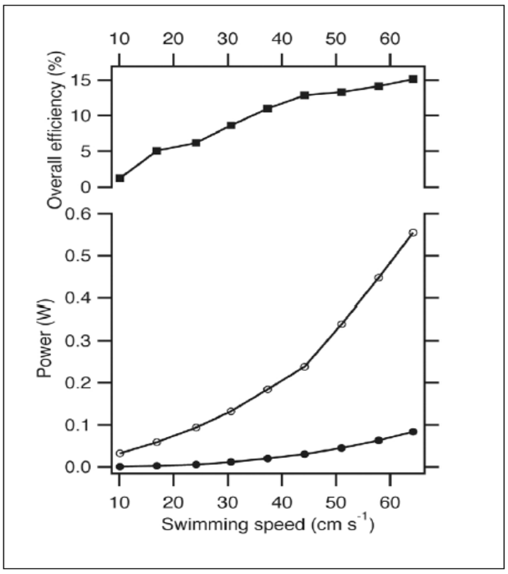


Figure 2. Power and efficiency of fish swimming (bottom curve represents metabolic and swimming energy) [1]

Swimming involves a series of interlinked processes whose combined efficiencies dictate energy flows through the system, the efficiency of converting metabolic energy to muscle mechanical power, the efficiency of transferring the power to the water, and the proportion of this power that is available to generate thrust

In fish schools/shoals, individuals reduce the cost of movement (energy) by exploiting the flow patterns generated by the individuals swimming ahead of them. From the videographic observations done on groups of rainbow trout at sub-fatigue cruising to sprint speed, and subjected to extra drag loads, shows that the swimming speed varies linearly with the product of TBF and specific TBA.

Experimental studies reveal that, when the longitudinal distance (S) is half of the length of the fish body (S=0.5 L) it could be easier for the followers to exploit the energy from the upstream vortex wake. The most significant power saving could be 20% when D = 0.15L and S = 0.5L (**Figure. 3**). Studies were carried out on focal fish schools when swimming solo and in a school at various speeds and different relative positions by measuring the TBF, TBA and energy cost based on oxygen intake (ECBOI).

At a swimming speed of 10 cm/s, the reduction in TBF and ECBOI were 30% and 18% compared to solitary swimming, and they are both 15% when swimming at 30 cm/s. The cost of transport (COT) is the energy spent per unit distance travelled is used as a measure of the energy efficiency of movement. From the allometric scale derived from swimming and flying animals over various orders of magnitude by mass, the COT obtained by regression analysis for viscous swimming, inertia swimming and inertia flying are $0.76M^{0.57}$, $7.3M^{0.69}$, and .5.476 $M^{0.685}$, respectively [2]. The allometric scaling of frequency and velocity of swimming and flying organisms vary over >20 orders of magnitude of mass.

The energy consumption coefficient (C_E) of swimming and flying animals, shown in **Figure. 4**, compares animals of different masses. In the equation embedded in the figure, ρ and ρ_b represent the density of sea water and body mass density, respectively. **All fliers and swimmers < 1kg are almost equally efficient. Larger animals are not mechanically more efficient.** C_E is ~$M^{-1/6}$ for swimmers with smaller mass, which is consistent with COT scaling of $M^{1/2}$ in the viscous regime.

C_E transits from a lower value to a higher value around 10^{-2} kg and the transition ends around 1 kg. Flying animals are found to require relatively more energy efficient compared with the swimmers. This is presumably because flying animals spend energy to not only move forward but also to overcome gravity. Thus C_E captures the non-dimensional trend of COT and also of COT/ body length and of COT/body length/ mass.

The body morphology highly influences the energetic costs and efficiency of swimming, as well as sets the general limits on a species capacity to use habitats and foods. Based on the active metabolic rate (AMR) studies conducted on two cyprinid fishes with different morphological characteristics, including carp and roach, the COT were found to be allometric functions of fish mass. Body fineness ratios are used to quantify the influence of body shape on activity costs. The total energy used during steady swimming is referred to as the active metabolic rate (AMR) expressed in mgO_2h^{-1}.

This factor proved to be significantly different between the species, indicates a better streamlining in roach with values closer to the optimum body-form for efficient swimming. The relationship between minimum AMR and swimming speed is best described by the power function. High-drag morphs have higher speed exponents, which result in steeper power curves and thus lower swimming efficiencies compared to low drag fishes (**Figure. 5a and 5b**) [3]. Fin stiffness, and more specifically, the ability to actively modulate the stiffness is important for maximising the thrust forces, which is the key for improved manuverability of strategic AUVs.

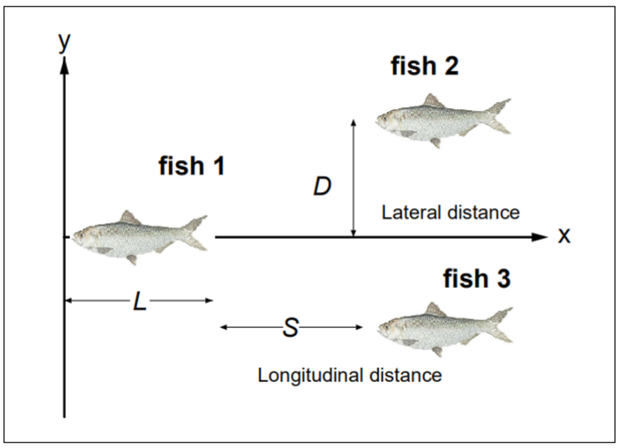


Figure 3. Exploiting energy from upstream vortex wake

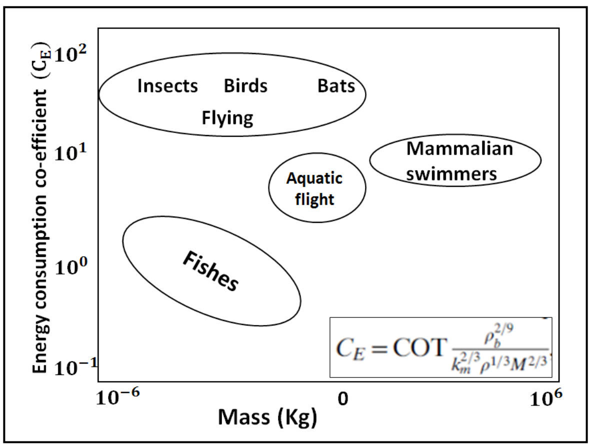


Figure 4. Energy consumption coefficient variation for animals [2]

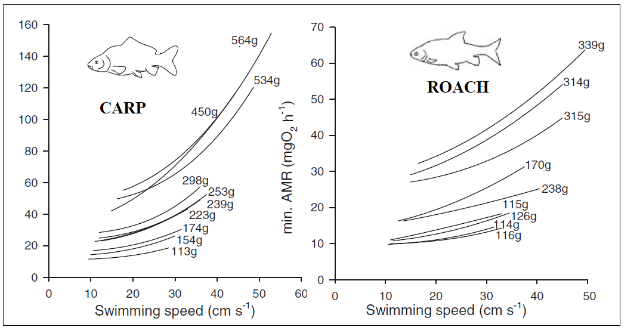


Figure 5. Variation of AMR with swimming speed [3]

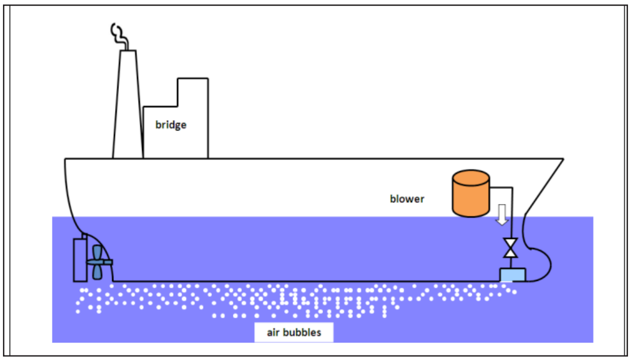


Figure 6. Schematic illustration of air lubrication system

Among the intriguing characteristics observed in nature organisms, their drag reduction abilities with low energy consumption have always attracted wide attention in various fields including marine vehicles, aircraft, pipeline, transportation, micro-fluidics etc. Investigations on the hydrodynamic characteristics of high speed fishes (such as sail fish, sword fish, blue fin tuna, rainbow trout, pike and dogfish) by installing taxidermy specimens in a wind tunnel reveal that their hydrodynamic coefficients were in the range of 0.005 to 0.02 in gliding positions at cruising speeds and they have multiple drag-reducing adaptations.

The fatty oil gland producing water-repelling layer across the front of the swordfish's head and the super hydrophobic skin surface helps to reduce the hydrodynamic drag and achieve top speeds up to 90 km/h. The tiny placoid scales (also known as dermal denticles) typically of 0.2-0.5 mm size embedded in the deeper collagenous layer of the shark's skin greatly decrease turbulent skin friction. The regularly spaced longitudinal grooves (of width ~ 100μm) growing on the face of placoid scales (riblets) aligned in the direction of fluid flows efficiently delay the occurring of turbulent vortices. Thus placoid scales and riblets help to reduce drag and achieve outstanding speed and agility.

The drag-reduction mechanisms of the dolphin, including body and appendage shape, viscous damping, dermal ridges and skin folds, secretions, boundary layer acceleration, and the behavioural mechanisms helps them to achieve a cruising speed of 1.5–2 m/s (with 700N) and a burst speed of over 9 m/s by generating up to 1468N.

The bio-inspired approach which was first proposed by McCormick and Bhattacharyya in 1973 is adopted for hull drag reduction by inserting an air layer (with micro-bubbles of < 0.1mm diameter) as lubricant between the submerged part of ship's hull and surrounding water using Air Lubrication Systems (ALS) (**Figure. 6**). **The ALS is recognised by IMO Energy Efficiency Design Index (EEDI) as category B-1 of Innovative Energy Efficiency Technology for vessel speeds < 14 knots.** There is a net savings in fuel by 3.2% at13 knots and 1.7% at 12 knots, compared to non-ALS vessels [4].

The archer fish aided by direction sensitive retinal ganglion cells preys (with 99% success rates) up to 3m above the water surface by shooting them down with water droplets from their specialised mouths (**Figure.7.C**). The produced water jets are six times stronger than their muscular power. They have turning angular speed of 4500º/s, linear speed of more than 20 body lengths s^{-1}. Pike fishes perform rapid start (approaching 249 m/s^2) and stop movements by abrupt high-energy explosions accompanied by unstable swimming. During such accelerations, the pike fish (during carangiform swimming) makes S conformities (bends its body into an S-shape and then uncoils it very rapidly to send a traveling wave along its body) to achieve high acceleration.

While decelerating they make a C compliance (usually mediated by the Mauthner neurons, associated networks and contra-lateral electromyographic signal which lasts for ~ 10ms) dramatically hindering their speed so they can rapidly stop. The mechanisms controlling S-starts needs to be studied, although Mauthner neurones can be active during the terminal phase of prey capture in goldfish.

In 1926, Breder built two working physical fish models based on oscillatory tail fin and undulatory fin. It was followed by various robo fishes mimicking various forms of fish locomotion such as anguilliform, carangiform, thunniform, labriform and ostraciforms [5]. Various mechanical designs for fish robot were developed based on its fish swimming styles and modes that are detailed in **Figure 8**. The recent robot fish developments include MIT

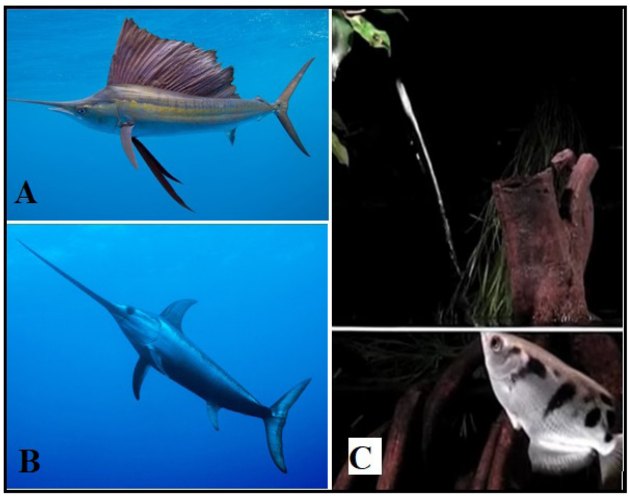


Figure 7. View of (a) sail fish (b) sword fish and (C) and Arcer fish hunting prey

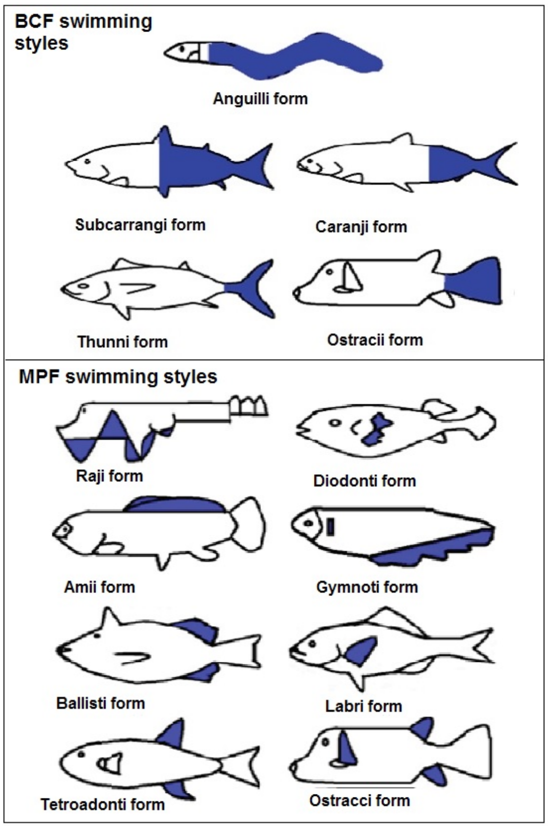


Figure 8. Classification of swimmers highlighting sections of its body that undergo flapping [5]

Soft robotics is an emerging area in underwater systems that could offer solutions for locomotion and manipulation in unstructured environments

Robo Tuna, Ichthus and ISplash. Their actuators based on electrical (DC and servo) motors, smart materials (Shape memory alloys, PZT, IPMC etc), pneumatic and hydraulics are being used.

The control systems for robotic fish shown in **Figure. 9** include a controller capable of providing the control command for the actuators in multiple DoF based on inverse kinematics, with sensors and environmental disturbances as input. The inverse kinematics is the use of kinematic equations to determine the position/actuation angle fish actuator so that the fish reaches a desired position. They are also referred to Denavit–Hartenberg (DH) parameters**.** The electronic controllers are based on classical (PID, Sliding mode control, predictive mode control, LQC), Intelligent (fuzzy, ILC, neural network) and hybrid (Fuzzy-PID, Fuzzy-SMC, Robust-PID-SMC and PID-ILC).

The comparison of locomotion capabilities based on smart actuators and electrical actuators with that of natural fish (**Figure. 10**) clearly indicate that there is a significant gap between man-made and natural systems. These data are based on the recorded performances of fast-acting fishes shown in **Table. 1**, in which the relative turning radius of a fish is estimated as turning radius/body length. This gap is due to the variations in the structure, body length, undulation/oscillation frequency, and actuation principle that are presently used for propulsion.

Soft robotics is an emerging area in underwater systems that could offer solutions for locomotion and manipulation in unstructured environments. Traditional articulated robots or hard robots generate motion using numerous rigid links connected by joints. Their motion is kinematically constrained by the DoF at the joints, with minimum deformation in the linkages during normal operations. Either or both the number of joints and the DoF at certain joints are to be increased to achieve higher degree of dexterity.

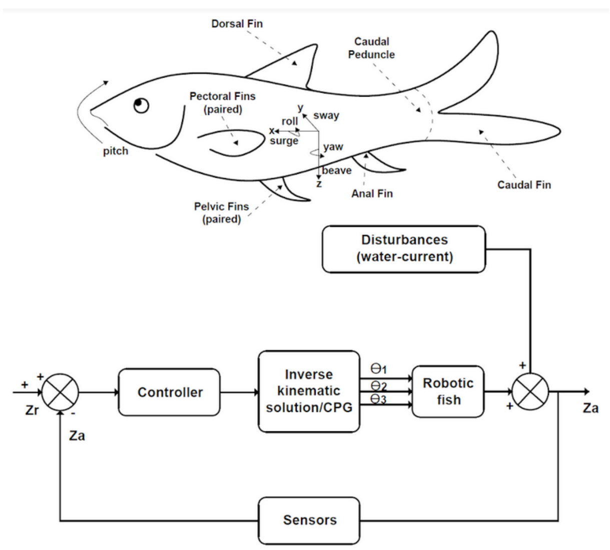


Figure 9. Classification of swimmers highlighting

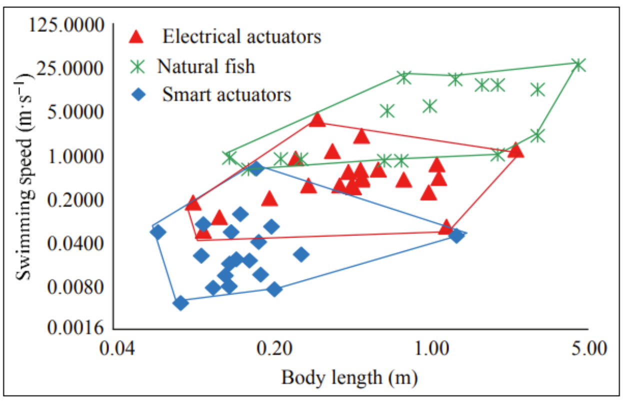


Figure 10. Classification of swimmers highlighting [5]

Table 1. Performances of raid action fishes [6]

	Max acceleration (m/s^2)	Max velocity (Length/s)	Relative turning radius (m)
Rainbow trout	60	16	0.17
Pike	150	21	0.09
Angel fish	115	26	0.065
Knife fish	128	13	0.055

The robots without rigid links or rotational joints and capable of bending constantly along their length and produce smooth curves are classified as hyper-redundant/continuum/soft robots. They can potentially work in unstructured environments, where environmental constraints, such as position and size of the obstacles, are not known a priori.

The design of continuum robots is bio-inspired, resembling the biological spine of sea mammals, sea snakes, octopus arm, jelly fish, manta ray, biological vine and sea plants. Octopus vulgaris, a class of cephalopods, whose structure is symmetric along the axis bisecting its two eyes, performing crawling movements using the same limbs for grasping and manipulation, provide inputs for the development of bio-inspired continuum robots. They vary their stiffness and apply relatively high forces during locomotion, when squeezing into very small and narrow holes and when splaying over the prey.

The kinematics of swimming jelly fish is by skirt-propulsion through interplay of active muscle contraction, passive body elasticity and fluid–body interaction. The contraction and relaxation process creates alternating areas of low and high pressure. The high-pressure vortices or turbulence generate lift from a pressurised fluid exiting the bell shape to push the body forward, and low-pressure vortices create suction to pull the body forward.

One of the most remarkable features of octopus is their nervous system that comprises of 300-500 million nerve cells. The complex nervous system and their cognition skills make them one of the most intelligent of all vertebrates. Their neural system structure is unique. Interestingly, intelligence of octopus is not centralised, and have highest brain-to-body mass ratio within all invertebrate.

Their nervous system is divided into central nervous system and the peripheral nervous system that enables sensory perception, perception-based cognition, learning and memory. Several studies are being conducted by researchers for the last 150 years to understand the inner structure of Octopus brain. Recently, neurophysiological methods and modern imaging techniques are used to understand the neurological procedures and the connection between the different brain sections.

Octopus arms are one of the most flexible appendages found in nature. In a recent kinematic study on Octopus, based on videographic observations, more than 16500 arm deformations (including bending, torsional, elongating, and shortening) were observed. Analysis indicates that all eight arms were capable of all four types of deformation along their lengths and in all directions.

These findings on the biomechanics of arm musculature, neural sensing and motor control, decentralised embedded intelligence and ecologically relevant behaviours demonstrate the exceptional flexibility of octopus arm. This could aid future bio-inspired soft robotics developments with particular interest to materials scientists and engineers who deem the octopus arm to be an inspirational model for designing new soft robotic appendages [7].

There are ~2000 species of sea stars (starfishes) living throughout the world's oceans. Star fishes (with 5 or 11 arms) have an oral surface lined with hundreds of tube feet enabling them to crawl on various terrains, from smooth sand and glass surfaces to rocky substrates. To achieve this locomotion capability, individual tube feet are equipped with integrated sensing and actuation, and the activity of arrays of tube feet is orchestrated by a nervous system that is distributed throughout the body.

Lacking a brain, the central nervous system comprises a ring nerve at the centre of the body with radial nerves that innervate the tube feet and extend to a simple eye at the distal tips of each arm and innervates the tube feet.

This distributed nervous system and numerous tube feet interacting to form the coordinated motion is a significant area of research. The behaviour of tube feet is being studied by recording the stepping phases (power and recovery strokes) that each tube foot undergoes during locomotion. **Figure 11** shows their nervous system comprising a circumoral nerve ring and radial nerves and same figure depicts hierarchical motor control of the tube feet consisting of global directionality commands issued

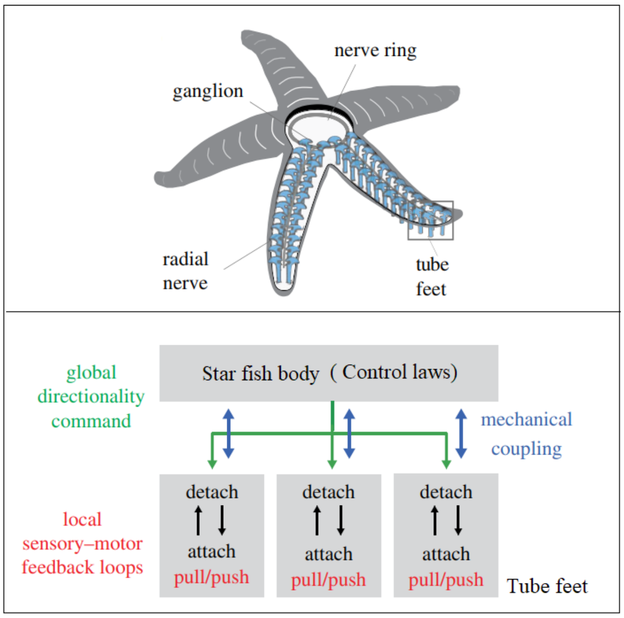


Figure 11. Locomotion of star fish applied to soft robotics [8]

by the radial nerves and nerve ring and local sensory–motor feedback loops at the tube foot level [8].

Batoids are a monophyletic group of elasmobranchs that possess dorsoventrally flattened bodies and expanded pectoral fins that are fused to the head to a form a broad flat planform. Pelagic rays use oscillatory locomotion (mobuliform mode) and swim by flapping the pectoral fins dorsoventrally to produce lift to generate thrust analogous to bird flight. The family has a manoeuvring performance with angular velocity and turning radius of 40°/s @ 0.5m, 30°/s @ 1m and 10°/s @ 3m.

Manta rays (of Batiod family), also known as devil fish, have evolved for ~100 million years, still retain the appearance of their ancestors. The have a flat body in the shape of a diamond, two large triangular pectoral fins that extend out like wings on either side of their body, wide but short mouth with two head fins, and the tail, which has a smaller triangular-shaped caudal fin but no dorsal fins. In addition, the distance between the two pectoral fins of the manta ray is greater than its body length. This unique physiological structure makes the manta rays behave more similar to a bird flying in the ocean.

These features enable them with high maneuverability and agility, as well as carry out sharp turns, despite their large body size. This is useful when escaping predators or catching prey, as well moving in/around obstacles in complex underwater environments [9]. Inspired by Manta ray, the ongoing Bionic Observation Survey System (BOSS) project undertaken by Evologics (supported by the German Federal ministry) comprises self-coordinating swarm of autonomous underwater bionic vehicles linked into a multi-media network with the latest communication and navigation technology (**Figure. 12a and 12b**) [10].

Inspired by sea snakes, Kongsberg Marine developed the continuum robot Eelume for subsea pipeline inspection applications that can swim like a snake, using lateral undulation to provide thrust. It combines this with on-board motors for faster movement, and can straighten out like a torpedo for long-distance cruising. Its ability to twist and turn lets it travel through previously inaccessible gaps and wrap around subsea installations

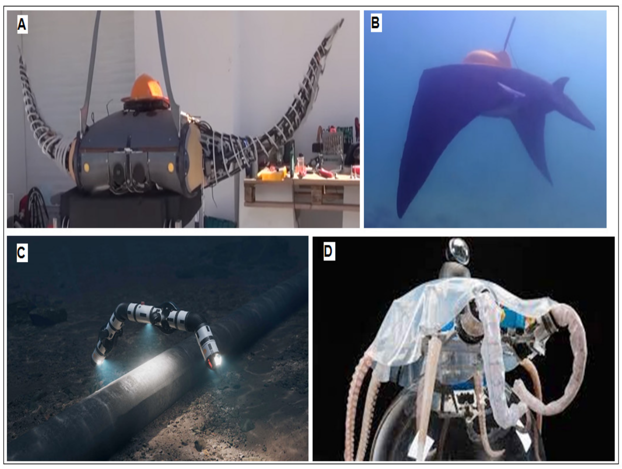


Figure 12. Recent developments in soft robots [9][10][11]

(**Figure.12c**) [11]. The Octbot is the brainchild of the Biorobotics Institute at Scuola Superiore Sant'Ánna in Pisa Italy focuses on the development of squishy robots using shape memory alloys (SMA) for its arms and embodied intelligence (**Figure.12d**).

In bird schools and flocks, the propulsion energy saving is achieved by the individuals through capturing the upwash produced by the preceding bird by which positive aerodynamic interactions occur between members of the formation. The pink-footed geese when flying in V-shaped formation saves between 2.4 and 14% of the energy compared to a solo flight. Weimerskirch measured the heart beat rates as an estimate of the energy expenditure in imprinted white pelicans trained to fly in V-formation and reported power savings in the range of 11–14% [12].

Summary

The first part of the article reviewed the abilities of sea animals including turtles, lobsters, salmon, whales and trans-ocean birds in long-range true-navigation with large-scale spatial cognition abilities that helps to establish idiosyncratic routes.

This second part discussed the present maturity of AUV locomotion, energy-efficient locomotion of aquatic animals and the recent developments in bio-inspired continuum/soft robotics.Experimental hydrodynamics of fast swimming and flying animals presents the latest research on the physiological, morphological and evolutionary factors in mimicking aquatic animal and bird locomotion aiding in the development of energy efficient autonomous underwater vehicles. Quantitative data on fish swimming and bird schools using of modern fluid mechanics experimental aids such as digital particle image velocimetry and theoretical advances such as vorticity control could help in developing more efficient robotic designs with performances approaching extreme capabilities found in sword fish, archer fish, pike fish and trans-ocean bird flocks.

Octopus, star fish, jelly fish, manta rays and sea snakes are remarkable sources of inspiration to design and build continuum robots with soft arm, capable of pushing-based locomotion and object grasping aided by soft materials and actuators. The advancements in electro active polymers such as ferroelectric polymers, dielectric elastomers, electrostrictive graft elastomers, liquid crystal elastomers, ionic polymer gels, ionic polymer-metal composites and conducting polymers shall open up new developments in energy-efficient actuation and AUV locomotion.

The third (final) part shall explain the opto-motor response mechanisms and intra-swarm communication in fish shoal and bird flocks that help them in achieving synchrony with neighbour's kinematics, construction, synchronisation, distributed perception, quorum decision and the spontaneous emergence of leader-follower relationship, predation and foraging capabilities that helps in participating in a swarm.

ACKNOWLEDGEMENTS

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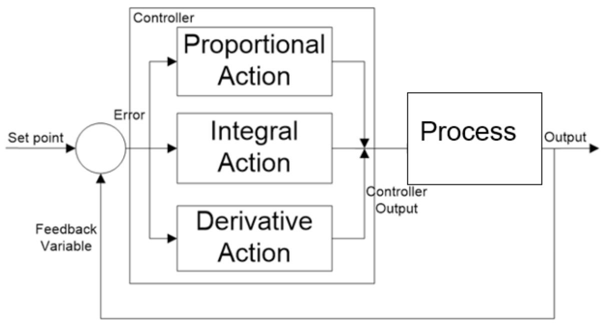
PID CONTROLLER TUNING

Jagabandhu Majumder

PID (Proportional, Integral, Derivative) controller is universally accepted and most commonly used controller in marine application because PID controller provides good stability and rapid response.

PID controller is a close loop system, which has a feedback control function. It compares the process variable (as a feedback variable) with the set point and generates an error signal. According to the signal, the coefficient of these three actions (PID) are varied to get an optimal response and then the output signal of controller is generated, in such a way that the system always tries to achieve the desired value, to maintain the set point irrespective of any type of load changes.

The determination of corresponding PID parameter values for getting the optimum performance from the process is called tuning. This is obviously a crucial part in case of all closed loop control systems.



PID Modes of Control:

As discussed above, PID controller uses the control algorithm as three modes, i.e., proportional + integration + derivative.

The proportional term applies appropriate proportional changes for error (which is the difference between the set point and process variable) to the control output.

The integral term examines the process variable over time and offset of set point and then corrects the output if necessary.

Derivative control monitors the rate of change of process variable and accordingly changes the output when there are unusual changes.

Let us understand the response of three terms Proportional Control, Integral Control, Derivative Control individually.

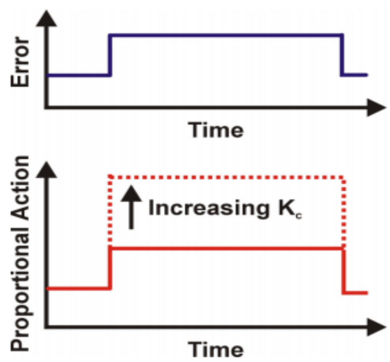
Each of the three modes reacts differently to the error. The amount of response produced by each control mode is adjustable by changing the controller's tuning settings.

Proportional Control Mode

The proportional control mode is the main driving force in a controller. It changes the controller output in proportion to the error. If the error increases, the control action increases proportionally.

The adjustable setting for proportional control is called the Controller Gain (Kc) / Proportional band.

Proportional band=100/Gain

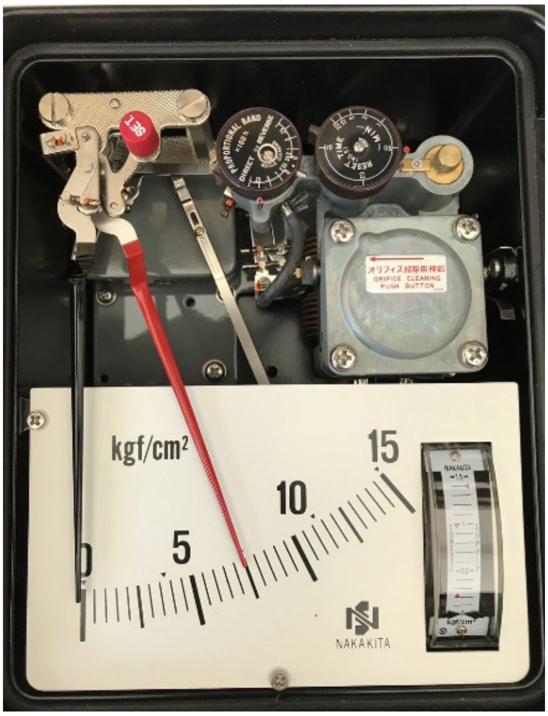


A higher controller gain or lower P-Band will increase the amount of proportional control action for a given error. If the controller gain is set too high the control loop will begin oscillating and become unstable.

If the controller gain is set too low or P-Band is too high, it will not respond adequately to disturbances or set point changes.

The use of proportional-only control has a large drawback – offset as shown in the **Figure 1**.

Offset is a sustained error that cannot be eliminated by proportional control alone.



P+ I Controller

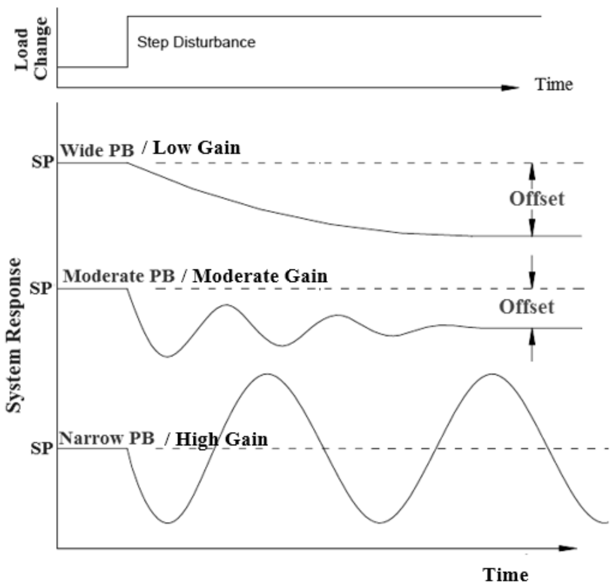


Figure 1. Response of Proportional Control with Variation of Gain/ P-Band

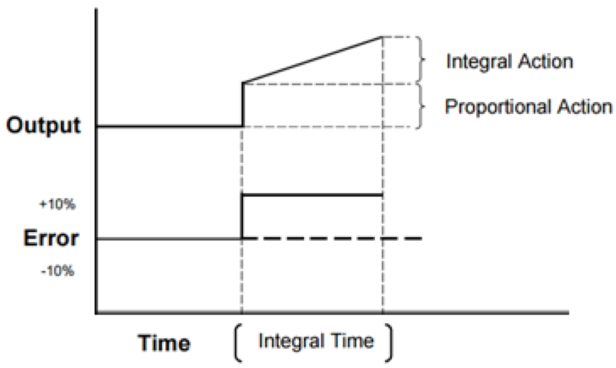
Integral Control Mode

Integral action corrects for any **offset** between setpoint and process variable automatically by shifting the proportional band over a pre-defined time by increment or decrement the controller's output over time to output until the error is zero. The integral time repeats the proportional action over the time set.

If the error is large, the integral mode will increment/ decrement the controller output at a fast rate; if the error is small, the changes will be slow. For a given error, the speed of the integral action is set by the controller's integral time setting (Ti).

A large value of Ti (long integral time) results in a slow integral action, and a small value of Ti (short integral time) results in a fast integral action as shown in the **Figure 2.**

If the integral time is set too long, the controller will be sluggish; if it is set too short, the control loop will oscillate and become unstable.



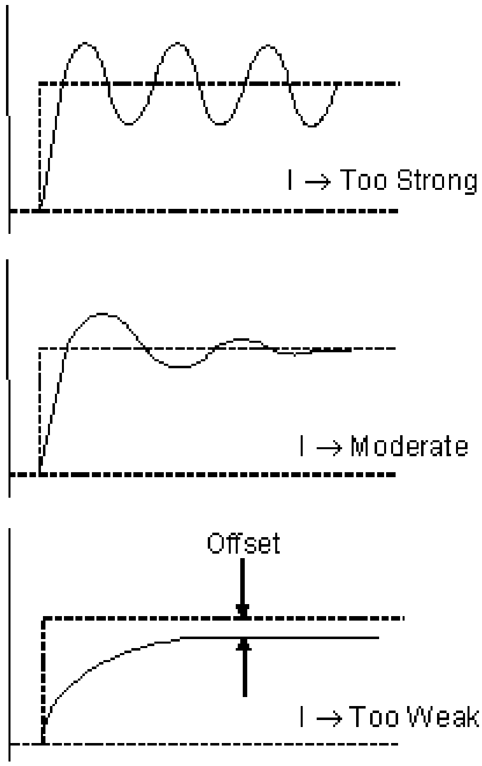
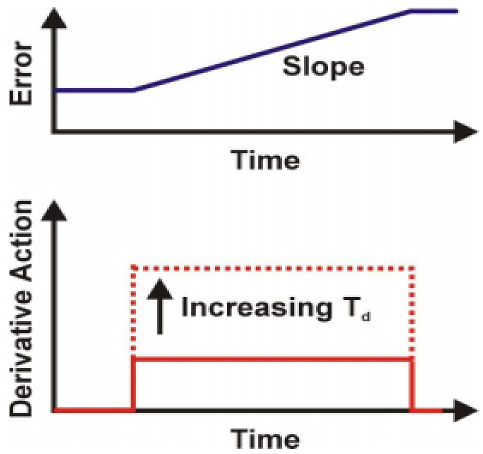


Figure 2. Response due to Integral Action

Derivative Control Mode

With derivative action also called "rate control", the output signal change due to this action is proportional to the rate of change of deviation. To improve the limitation of the P + I controller's slow response in case of a sudden change in loading conditions, derivative action (rate action) is added to the controller, which will make sure that the process response is faster and stable. It is measured in terms of the Derivative Action Time which is the time taken for the proportional component to become equal to the derivative component under ramp conditions.

The larger the derivative time setting, the more derivative action is produced. A derivative time setting of zero effectively turns off this mode. If the derivative time is set too long, oscillations will occur and the control loop will run unstable as shown in **Figure 3**.



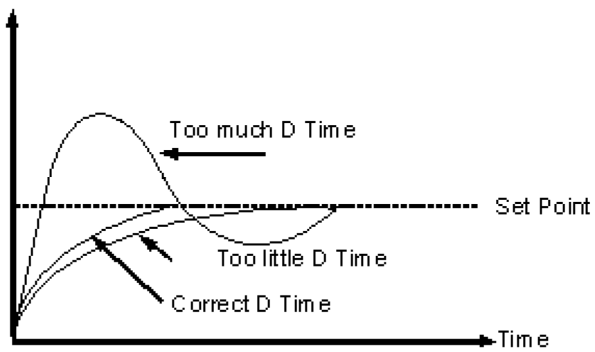


Figure 3. Response due to Derivative Action

PID Controller Tuning. Why??

- Change in Various parameter in The Process Component

Example: - Pump Pressure / Drift in Electronic components

- Change in flow pattern in case pipe line modification
- Change in stiffness Characteristic in valve due to diaphragm etc.
- Any Change in process control components

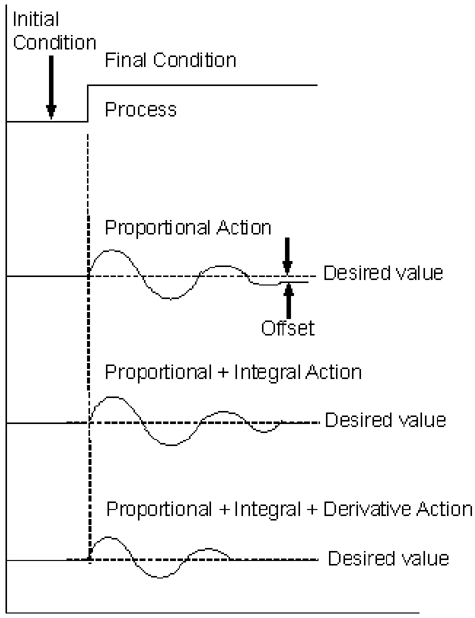


Figure 4. Response of P, I and D Control to a Step Input

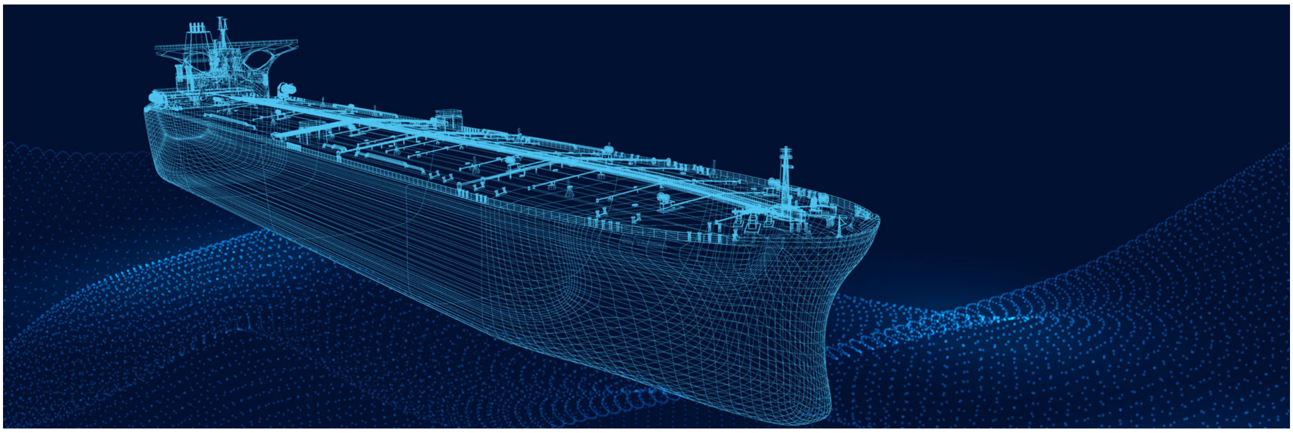
Requirement before PID Controller Tuning

1. Signal Transmitter of MV calibrated.
2. Controller Working Condition - COLD TEST (Ship at Anchorage /Port)

Change the Set point and observe the following output for Direct Acting Controller (Vice versa for Reverse Acting Controller)

- ➢ SP = MV output 9 psi/ 12 mAmp
- ➢ SP Min Output Max 15 psi/ 20 mAmp
- ➢ SP Max Output Min 3 psi/ 4 mAmp

3. Full process control responds correctly Check Control Valve linear and smooth movement also matching with controller output.
4. Process running under full load condition and no external load (Good weather)



1. The Gain should be set minimum or Proportional Band setting should first be at its maximum value.
2. The Integral or Reset Action setting should also be at its maximum value
3. The Derivative of Rate Time setting should be at its minimum value
4. Create disturbance step change in SP and back to SP again and observe the response of controller output.

Trial and Error Method

This is the simple method of tuning a PID controller. Once we get the clear understanding of PID parameters, the trial-and-error method becomes relatively easy.

- Increase the proportional gain/

  Decrease P-Band until the output of the control loop oscillates at a constant rate.

  This increase of proportional gain should be done such that response of the system becomes faster without making the system unstable.

- Once the P-response is fast enough, set the integral term, so that the oscillations will be gradually reduced. Change this I-value until the steady state error is reduced, but it may increase overshoot.
- Once P and I parameters have been set to a desired values with minimal steady state error, increase the derivative gain until the system reacts quickly to its set point. Increasing derivative term decreases the overshoot of the controller response.

Zeigler-Nichols Method

It is another popular method for tuning PID controllers. Ziegler and Nichols presented method for determining values of proportional gain, integral time and derivative time based on transient response characteristics of a given system.

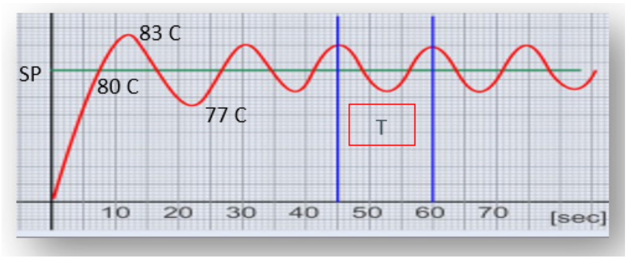
It is very similar to the trial-and-error method where integral time set to Ti High and derivative time Td to zero.

- Create disturbance step change in SP and back to SP again and keep Increasing the proportional gain/Decreasing Proportional Band such that the output exhibits sustained oscillations. Note down the gain/P-Band at which sustained oscillations produced is called as critical gain(K_C) or P_B and time taken for one oscillation is critical period (T).
- Once the sustain oscillations are produced, set the tuned values of Gain/P-Band, Ti and Td as per the given table for PI and PID controllers based on critical gain and critical period.

Controller with P-Band Setting

Tuned Value	P-Band	T_I	T_D
PID	1.7x P_B	T/2	T/8
PI	2.2x P_B	T/1.2	

P_B – P-Band value at which system responded sustained oscillation



Controller with Gain Setting

Tuned Value	Gain	T_I	T_D
PID	0.6 x K_C	T/2	T/8
PI	0.45 x K_C	T/1.2	

K_C – Gain value at which system responded sustained oscillation

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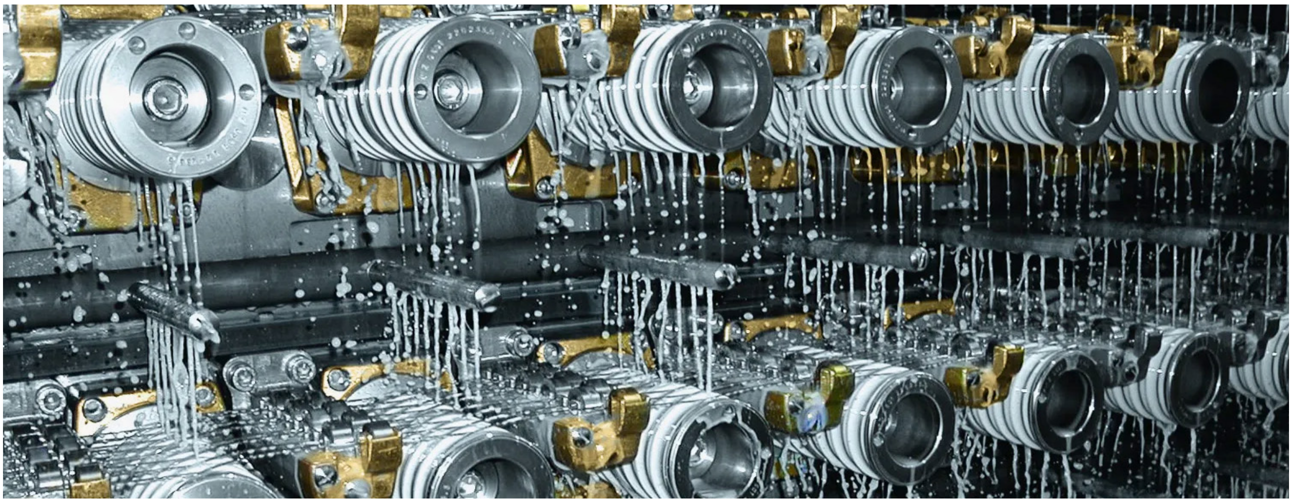
LUBE MATTERS # 15

SYNTHETIC LUBRICANTS



Sanjiv Wazir

Introduction

Synthetic hydrocarbon technologies were being developed in Europe & USA from the 1930s.The development of processes for catalytic polymerisation of olefins led to the formulation of automotive engine oil with improved low temperature characteristics. Initially, these products were not commercialised due to the high cost of the synthetics and concurrent improvements in performance of mineral oils with newer additives.

However, during and after WWII, requirements from military & aviation industries for lubricants to perform over increasing temperature ranges stimulated the development of synthetic lubricants. Today they are used in all areas of lubrication. More than 25 types of synthetic compounds have been used as lubricants.

Aliphatic diesters and polyol esters

Long before mineral oils became widely available, lubricants were based on natural esters contained in vegetable oils (castor oil, olive oil, etc) and animal fats (sperm whale oil, lard, etc). Development and use of synthetic esters was driven by the development of aviation gas turbines. Aviation turbines have higher temperatures (than the preceding piston engines), and jet aircraft can fly at much higher altitudes, with very low ambient temperatures. Lubricants were required to have very good high temperature stability and good low temperature flow characteristics, and Diesters were adopted for the purpose. As gas technology progressed, higher temperatures were encountered and diesters were replaced by polyol esters, which continue to be the main base fluid for aviation turbine lubrication.

In addition to their good properties at extreme temperature conditions, synthetic esters also exhibit other desirable qualities such as high viscosity index, low volatility, good lubricity, good compatibility with common lube oil additives, mineral base oils and other synthetic hydrocarbons. The inherent biodegradability of ester molecules offers an added advantage.

Esters are manufactured by reacting the desired acid and alcohol in the presence of an esterification catalyst. The esterification reaction is reversible, and hence it is necessary to drive the equilibrium over to the desired product by removal of water. The reaction temperature (200-250°C) and pressure are selected so that water can be removed by distillation as it is formed (2).

There are three main types of synthetic esters in use as lubricant base fluids: aliphatic diesters, polyol esters and aromatic diesters.

Esters are now widely used in automotive engine oils, gear oils, 2-T oils, air compressor lubricants, refrigeration compressor lubricants, gear oils, greases, etc.

Some common applications of ester-based oils in marine usage are:

-Reciprocating air compressor oils

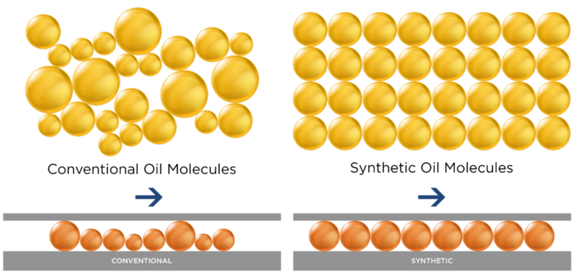


Figure 1. Mineral Oil: natural compounds separated from the crude oil
Synthetic oil: man-made compounds with planned and predictable properties (1)

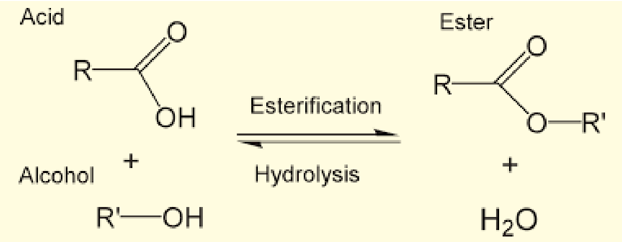


Figure 2. Chemistry of esterification (2)

-Synthetic 2-T high speed engine oils (e.g.: outboard engine oils)

-Refrigeration compressor oils for chlorine free HFC refrigerants R134a, R404a, R410c, etc. systems

-Environmentally friendly lubricants & greases (e.g.: EAL Stern tube & bow thruster oils)

Polyalphaolefins (PAO)

PAOs are hydrogenated hydrocarbons of linear alpha-olefins (usually 1-Decene), that have themselves been manufactured from ethylene.

In comparison to mineral oils, PAOs have excellent physical properties, wide operating temperature range, high flash point, high viscosity index, low volatility, excellent thermal, oxidative and hydrolytic stability. PAOs are the most widely used class of synthetic lubricants. They are widely used in automotive engine oils, automatic transmission fluids, multigrade gear oils, high performance greases, hydraulic fluids, compressor oils, heat transfer fluids, and food grade oils & greases. PAOs are generally classified by their viscosity at 100°C. The common PAO grades are 2, 4, 6, 8, 10, 40 and 100 cSt.

Four-Stroke engine crankcase lubricants require good thermal and oxidative solubility, low volatility, and good low temperature pumpability. These requirements are met using mixed PAO/Ester base fluids.

Common applications of PAOs in marine usage are:

-Compressor oil for rotary air compressors

-Synthetic gear oil for very high or very low operating temperatures, and for highly stressed components.

Polyalkylene Glycols (PAG)

The term PAG refers to a large family of products formed by the polymerisation of a variety of alkylene glycols. Depending on the chemical structure, a wide range of physical and chemical properties can be obtained. E.g., PAGs can be solid or liquid, water soluble or insoluble. PAGs can be made to meet almost any viscosity requirement. When PAGs decompose, the final decomposition products are all volatile, thus leaving no carbonaceous solid or liquid residue.

By themselves, PAGs are excellent lubricants, and they are also used as thickeners, lubricity improvers, etc. They are widely used in industrial gear oils and greases, fire resistant hydraulic oils, heat transfer fluids, metal working fluids, aqueous quenching fluids, metal working fluids, air compressor oils (when combined with esters), etc.

Common application of PAGs in marine usage is:

-Gas Compressor Oil

Compression of process gases presents a unique lubrication challenge. Due to the direct contact between gas & lubricant, there can be dissolution of the gas into the lubricant resulting in drop in viscosity of the lubricant, potentially leading to complete loss of lubricant from the contacting metal surfaces. Owing to the polar nature of PAGs, they are well suited for the lubrication of gas compressors used for low polarity process gases (e.g., methane, ethylene, nitrogen, etc). Since there is very little gas dissolution, the viscosity and lubricity of the lubricant are well maintained.

Alkylated aromatics

A variety of alkyl benzenes are available for use as lubricants. Properties such as sulphur-free chemistry, low pour point, good thermal stability & good solvency enable use as detergents in engine crankcase lubricants (as Ca or Mg salts), as emulsifiers in metal working fluids (as Na salts), etc.

Common application of Alkyl- Benzene based lubricant in marine usage:

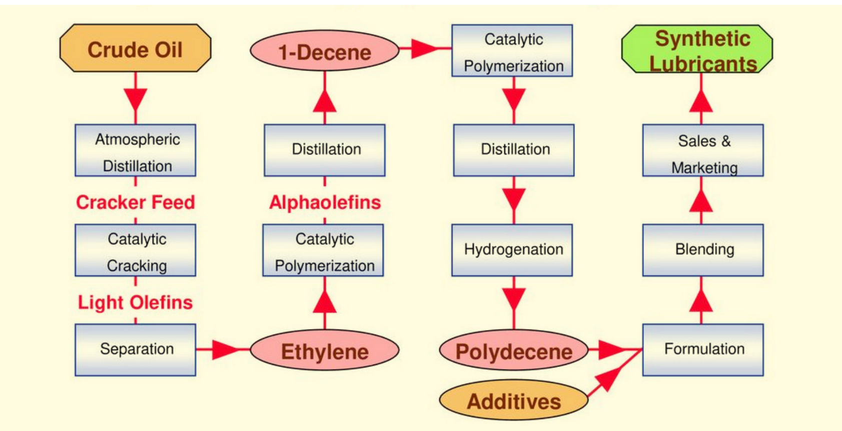


Figure 3. From Crude oil to Synthetic; many manufacturing steps lead to higher costs (3)

-Refrigeration compressor oil in chlorine containing refrigerants R22, R502a, R402 a/b, R402 a/b, in addition to R600a, R290a, R717, etc

Alky-Benzene properties are well suited for lubricants used in extremely low temperature applications such as arctic greases, gear oils, hydraulic fluids, etc. AB fluids are most widely used as refrigerant compressor oils, where the oil may be carried through the entire refrigeration circuit and experience extremes of temperature. Natural solvency, low pour point and good thermal stability properties minimise formation of sludges, varnishes, and other deposits.

Polyisobutenes (PIBs)

Widely used in many industries for various purposes. For lubricant applications, PIBs are used as viscosity index improvers, and as base fluids in the manufacture of dispersants.

Perfluoroalkyl Ethers (PFAE)

PFAEs structure is like that of PAGs, except all the hydrogen atoms are replaced by fluorine. Their main chemical characteristic is outstanding resistance to oxidation. They are also resistant to attack by corrosive chemicals including strong acids & alkalis.

Their very high cost has limited their applications to high value equipment such as spacecraft. Another area is as speciality vacuum pump oil for use in contact with very reactive chemicals. Oxidation is often the life-limiting factor for lubricants & hence PFAEs are very well suited for "sealed for life" bearing applications.

Silicones

Silicones are polymers containing siloxane (Si-O-Si) backbone structure with alkyl sidechains. They can be prepared with viscosities ranging from <1 to >500,000 cSt. They are characterised by low pour point, low surface tension, high compressibility, virtually no change in viscosity with temperature. They are also highly fire resistant, have good thermal stability and chemical resistance and low volatility. This makes them suited for demanding applications like heat transfer fluids & transformer dielectric fluids. They have low load bearing strength and poor miscibility with mineral base oils & other synthetics. This precludes their use as a lubricant base fluid (except in some speciality greases). They are used as anti-foaming and pro-foaming additives in conventional base oils.

Other Synthetic fluids

While the synthetics described above and the mineral base oils + additives described in earlier articles meet most requirements of liquid lubricants, many other synthetics have been developed and found usage in niche applications. E.g.,

Phosphate Esters: Fire-resistant fluids

Polyphenyl Ethers: Aviation turbine fluids for supersonic military aircraft

Alkylated Cyclopentanes: Spacecraft applications

Cyclohexane derivatives: Automotive Transmission fluids

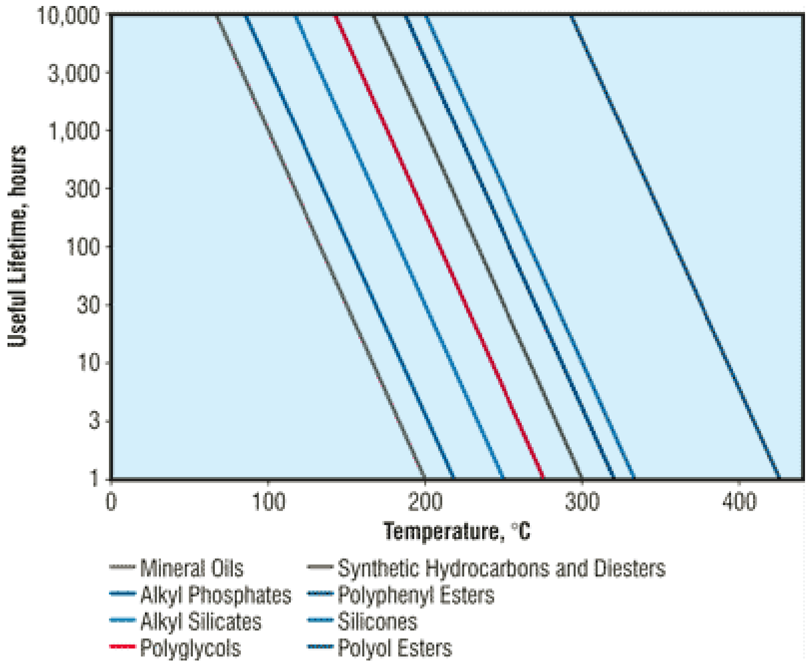


Figure 4. Comparison of oil life of a range of synthetic lubricants (2)

Conclusion

Synthetic lubricants possess many superior performance characteristics compared to mineral oils.

- Improved oxidative and thermal stability
- Improved lubricity
- Improved performance at very low or very high temperatures
- Lower environmental impact

Although more expensive than mineral oils, synthetics can lead to reduction in running and maintenance costs and be cost-effective. For some applications, there are no mineral oil substitutes.

Importance of synthetic lubricants is likely to rise significantly in the future.

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COLUMN

HERITAGE HOURGLASS

Nautical Iconography in Heraldic Insignia as a Remnant of India's Maritime Past

Janhavi Lokegaonkar

The significance of heraldry: The origins of heraldry can be stretched back into ancient times. Warriors often decorated their shields with different patterns, colours and motifs. The carrying of armorial insignia on shields, flags and banners was crucial for a warrior in battle as he had to be recognized at a distance. Thus, systematic use of heraldry developed with which their particular marks and colours were worn outside their armours- on a surcoat. Hence, we have the expression "Coat of Arms."

Insignia is defined as the systematic hereditary use of an arrangement of charges or devices on a shield

Over time, insignia and coat of arms gained more prominence. By the sixteenth century, heraldry was used by family networks to help them maintain and develop their social position. Insignia is defined as the systematic hereditary use of an arrangement of charges or devices on a shield. **Heraldic crests and insignia were the central elements of a Coat of Arms**. The heraldry was used to express ownership by or loyalty to a family. Nevertheless, the significance of heraldry and armorial symbols did not recede.

Maritime influence in Indian heraldry: India had a large number of princely states and dominions before independence. Each royal principality played a role in the socio-political fabric of Indian society. Consequently, the insignia and Coat of Arms of these princely states and royal families have been a part of their identity, each of which was designed with careful meaning and symbolism.

The common thread among the insignias is the symbol associated with the maritime domain

In the photo collage here, we can look at a select few insignias of various Indian principalities of the past. The common thread among the insignias is the symbol associated with the maritime domain. This nautical influence warrants a closer look at the heraldry of various Indian princely states and dominions that have an impact on the vast maritime expanse.

The year 1858 was a landmark event in India's colonial history. The Government of India Act of 1858 was

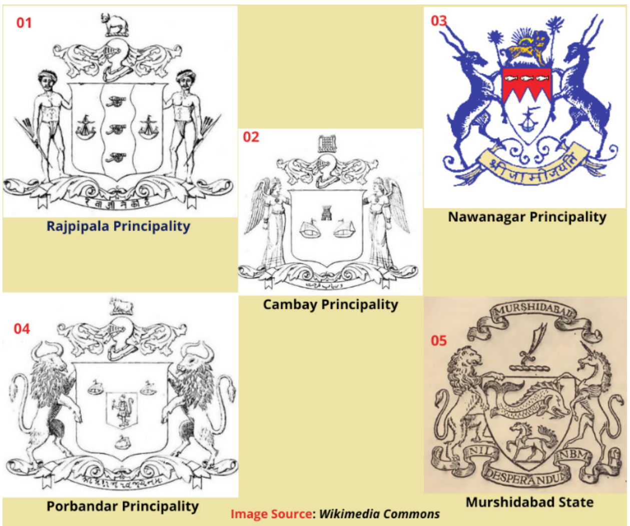

Image 1. A photo collage of coats of arms of Indian Principalities. Source: Wikimedia Commons

passed that brought about a transfer of power from the English East India Company to the English Crown. This marked the beginning of Imperial rule in India which effectively meant that India was to be governed directly and in the name of the Crown.

For imposing Queen Victoria's stature and dominance as the 'Empress of India' in the Indian sub-continent, preparations commenced in 1876 for the Imperial Assemblage which would be held at Delhi on the first day of January in 1877.[1] The proclamation of the Indian Empire under the reign of Queen Victoria took place in the presence of governors, lieutenant-governors, and heads of administration from all parts of the Queen's Indian dominions, as well as Indian princes, chiefs, and nobles of different states and principalities.

'In order to further sanctify the affiliation imposed upon the complying Indian Princes by the dominant Imperial government, royal insignias and personal Coats of Arms were specially commissioned under the authority of the British Crown.'[2] Robert Taylor, a member of the Bengal Civil Service designed the Coats of Arms for the Delhi Durbar. There was an understanding that there would be a procession of the 'native princes' and hence, Taylor was to design heraldic crests, banners and insignia for every attending native chief. These banners would depict what might be taken for their arms.

At the Durbar of Delhi in 1877, Maharaja Jam Sahib Vibhhaji II Ranmalji (1859-1895) of Nawanagar principality was granted a coat of arms. "*In 1877, the Jam was an invited and honoured guest at the Imperial assemblage at Delhi, on the occasion of the Proclamation of Her Most Gracious Majesty as Empress of India; and he then had the honour of receiving an addition of four guns to his salute,*

Image 2. Coat of Arms of Kutch State Principality
Source: Wikimedia Commons. https://en.wikipedia.org/wiki/Cutch_State#/media/File:Cutch_State_Achievement_Badge.jpg

> ***Out of these, princely states like Nawanagar, Porbandar, Morvi, Cambay, Junagadh, Kutchh and Kathiawar had an undeniable maritime connection. Geographically, these states bordered the coastline of western India***

as a personal distinction. On 1st January 1878, he was conferred a Knight Commander of the Most Exalted Order of the Star of India."[3] Similarly, a coat of arms was also granted to Rana Sahib Vitematji IV Khimaji (1831-1894) from the principality of Porbandar and to Maharana Shri Gambirsinhji Vairisalji (1860-1897) from the state of Rajpipala at the same historic event.[4]

Many princes and men of nobility attended the Imperial Assemblage. Out of these, princely states like Nawanagar, Porbandar, Morvi, Cambay, Junagadh, Kutchh and Kathiawar had an undeniable maritime connection. Geographically, these states bordered the coastline of western India. These coastal principalities were engaged in trading and a host of maritime activities. Nawanagar, for instance, was one of the two most prominent of the Kathiawar states in western India. The state was famous for its pearl fishery and generated revenue through the same. Thus, the fishes and a galleon occupied prominent space of the state crest. Their presence and position in the crest sum up the importance of their maritime connection.

Similarly, states like Porbandar and Cambay that had bustling mercantile trade activities due to their access to the maritime frontiers flourished as their economy swelled. The ships in their crests are in all probability a reminder of these trading and mercantile activities of these port towns. The ships depicted in the crests of the respective states are a reminder of the trading and mercantile activities.

The aforementioned princely states and their subsequent heraldic crests had a clear maritime connection. But, some of the land-locked principalities like Darbhanga also depict nautical elements on their coats of arms which makes it even more interesting. Corresponding to the present-day area of Bihar and its northern frontiers, the princely state of Raj Darbhanga was ruled by the Mithila Brahmins of the time. During the Imperial Assemblage of 1877, even this princely state was invited to the grand celebrations in Delhi. "*On the occasion of the Jubilee of the reign of Her Most Gracious Majesty the Maharaja Bahadur of Darbhanga was created a Knight Commander of the Most Eminent Order of the Indian Empire. The family cognisance is the Gangetic dolphin or sacred fish of the Hindus.*" The presence of the Gangetic Dolphins on the armorial bearings of this princely state marks the importance of the mighty

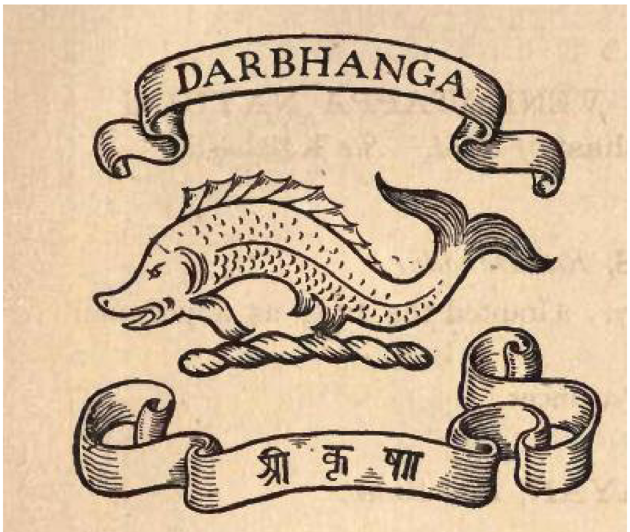

Image 3. Coat of Arms of the princely state of Raj Darbhanga.
Source: The Golden Book of India: A Genealogical and Biographical Dictionary of the Ruling Princes, Chiefs, Nobles, and other Personages, titled or decorated of the Indian Empire by Sir Roper Lethbridge

Image 4. Coat of Arms of the princely state of Bhopal.
Source: The Golden Book of India: A Genealogical and Biographical Dictionary of the Ruling Princes, Chiefs, Nobles, and other Personages, titled or decorated of the Indian Empire by Sir Roper Lethbridge

Ganges and symbolises its vitality amongst the Hindu traditions.

Furthermore, there is the most important princely state of Bhopal. 'In the year 1872, the Begum of Bhopal - Her Highness Nawab Shah Jahan Begum - was created a Grand Commander of the Most Exalted Order of the Star of India in recognition of her high administrative qualities. Subsequently, she had been appointed to the Order of the Crown of India by the Queen and a coat of arms was bestowed on the princely state of Bhopal as well in 1877 during the Imperial Assemblage.'[6]

The coat of arms of the princely state of Bhopal also depicts two fishes. This can allude to the state paying an ode to river Narmada and assessing the importance of this riverine connection.

Although some of the heraldic insignia changed over time, adapting new motifs and designs, but the fact that the recognition of the maritime heritage was identified in these initial crests makes these designs of heritage value point to the seaward perspective and that of a maritime vision!

The symbolism of maritime iconography: The emblematic coat of arms was exclusive only to the particular royal family to whom it was issued to. **The inclusion of nautical motifs in the heraldic symbols of royal families depicts the importance of the maritime medium, thereby upholding their history and heritage.** The designs and drawings of each coat of arms and insignias are rich with meaning. Each representation

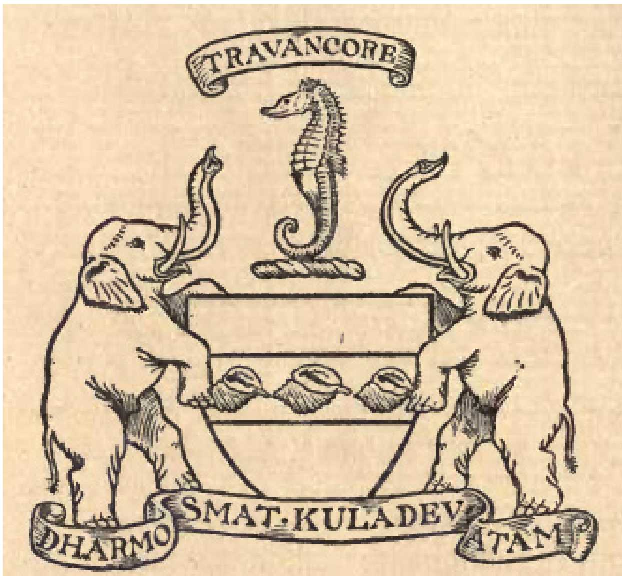

Image 5. Coat of Arms of the princely state of Travancore.
Source: Wikimedia Commons. https://commons.wikimedia.org/wiki/Category:Coats_of_arms_of_princely_states_of_India#/media/File:CoA_Travancore_1893.png

The coat of arms of the princely state of Bhopal also depicts two fishes. This can allude to the state paying an ode to river Narmada and assessing the importance of this riverine connection

> *In heraldry, the seahorse is an emblem of safe travel, particularly by sea*

carries with it a wealth of history, legends and allusions. Every colour, theme and motif is chosen with care and deep consideration.

The nautical motifs as seen in the Indian heraldry represent their association with the maritime expanse. The crests are an ode to the maritime legacy of these coastal states. Motifs that are used in the artistic representations are symbolic, although, they are also susceptible to varied interpretation. The representation of fishes are the most common nautical motifs. The images of fishes are held to be suitable marks for armorial bearings as they are symbols of prowess and fortitude. The coat of arms of the state of Travancore depicts a sea horse. **In heraldry, the seahorse is an emblem of safe travel, particularly by sea.** Anchors are another popular motif in nautical iconography and an appropriate motif for the coat of arms of a family with a seafaring tradition. An anchor symbolises salvation and hope. Ships and boats used as motifs in iconography connote to joy, happiness and the spirit of adventure or tradition of seafaring. Since there are different types of ships- sambuks, galleys being the most prominent in the Indian heraldry, they were carefully described with respect to the number of masts, the sails and the rigging etc.

While the status of princely states and privy purses of the Indian principalities were abolished in the year 1971 by the Government of India, the royal families continue to use it on official papers and invite cards as a remnant of their legacy even today.

Prominent influence in Bombay: Although the city of Bombay was not a princely state under the British Raj, it was an important administrative centre. Bombay was the nerve centre of the economy for the Crown. The influence of nautical iconography in this city was quite prominent. Many heritage buildings, monuments, and docks display nautical elements carved on their exterior. The crest logos of the Mumbai Port Trust (erstwhile Bombay Port Trust) and the University of Mumbai (erstwhile, University of Bombay) were designed keeping the maritime character of the city in consideration. Two important families that contributed to the fortunes of erstwhile Bombay city also boast nautical iconography adorning their family crests and coats-of-arm. They are the Jeejeebhoy and Wadia families.[7]

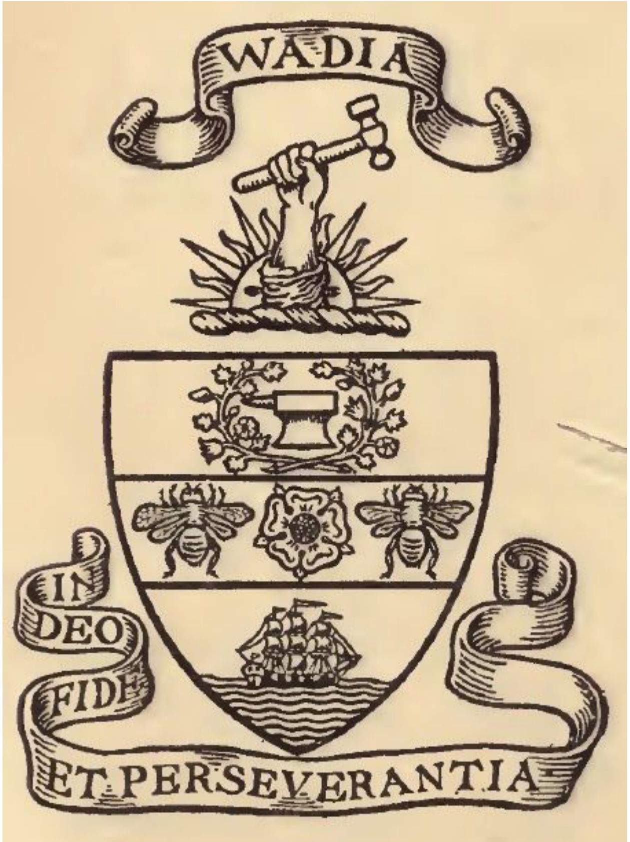

Image 6. Insignia presented to the Wadia Family in 1889.
Source: The Golden Book of India: A Genealogical and Biographical Dictionary of the Ruling Princes, Chiefs, Nobles, and other Personages, titled or decorated of the Indian Empire by Sir Roper Lethbridge

Image 7. Heraldic crest of Jeejeebhoy Family. Source: Digital Archives, Maritime History Society.

With their prowess in shipbuilding technology, the Wadia family contributed immensely to the English Crown by building ships-of-the-line and dockyard facilities in the city of Bombay. It was Naoroji Nasirwanji Wadia who was created a Companion of the Most Eminent Order of the Indian Empire on 25th May 1889. Through the Garter

King of Arms, he was granted arms, as shown in Image 6. The ship depicted in the insignia recognises their shipbuilding prowess and the ball peen hammer appears to be a homage to it their craftsmanship.

The baronetcy for Sir Jamsetjee Jejeebhoy of Bombay was created in May 1857, in recognition of his unbounded generosity and public spirit, and his undoubted loyalty and benevolence.[8] Although, this is an exceptional case. It was in the year 1842 when Jamsetjee received knighthood by the Queen that he also received the heraldry, with a gold medal, inscribed with the following words: "*To Sir Jamsetjee Jejeebhoy, Knt, from the British Government, in honour of his munificence and his patriotism.*"[9] The family crest of the Jeejeebhoy baronetcy represents the *ghats* of Bombay city-in recognition of the service and benevolence of the first baron towards the city. Thus, the connection of the maritime city of Bombay and its significance for the Crown and the Jeejeebhoys are represented in their insignia as a fitting tribute.

Thus, the use of nautical elements in Indian heraldry, crests and designs represent the maritime character of the nation. It is pertinent to take cognisance of our maritime heritage and legacy that is portrayed through the medium of art and literature.

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With an educational background in core history subjects, she brings an interdisciplinary approach to research projects. Maritime and military history of the modern and contemporary period along with the history of diaspora studies and migration studies are her areas of interest. She has been actively presenting papers in addition to shouldering academic activities of MHS.

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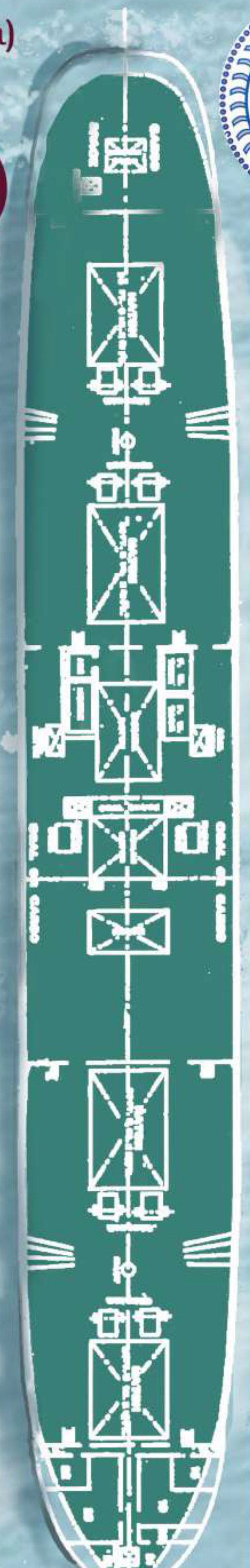

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MUMBAI BRANCH AND ITS NAVI MUMBAI & GUJARAT CHAPTERS

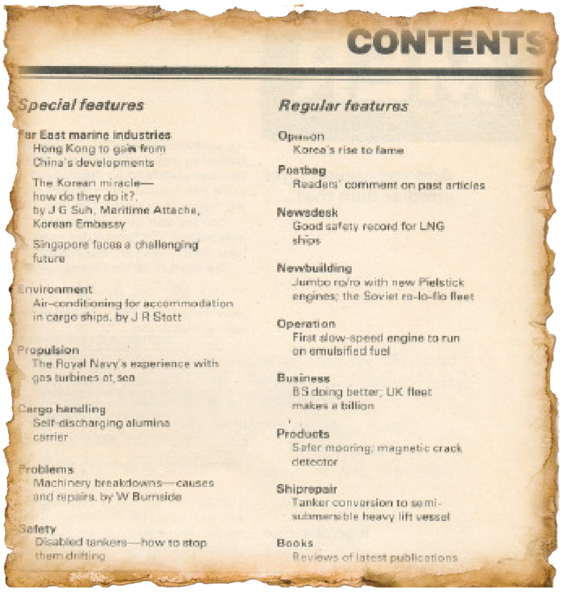
GOING ASTERN INTO MER ARCHIVES

MER... Four decades back... The September 1982 Issue

The article on Korean shipbuilding has few takeaways. South Korea being surrounded mostly by seas and the north having a hostile armistice line (particularly) leaves no option but to have a merchant marine connection for establishing world trade. Other significant factors include the Government's subsidies, development of coastal shipping and importantly, an advanced educational system. The success of Korea from importing ships to building ships for others is one to learn from.

The technical article on designing the air conditioning system for cargo ships' accommodation will be interesting for practicing marine engineers.

On the breakdown front, an interesting discussion was on rudder and damages to the four-ram steering gear. The 'rudder touching the quay side' would have been experienced by many of the marine engineers and this article could bring in some discussions on that. Few extracts from the write-up are inserted.



CONTENTS

Special features

Regular features

In the Postbag, there were two interesting discussions... one on rudder failures and the other on water lubricated bearings. We insert the discussion with highlights.

And there are news items on first slow speed engine (MAN KZ) running on emulsified fuel, self-polishing hull coatings, fuel savings & autopilot etc.

Machinery breakdowns —causes and repairs

Steering gear

Damage to the four-ram steering gear on the bulk carrier MV *Gerringong* appeared as if it had taken a great deal of battering. The four rams and trunnions were broken, with the ends of the rods facing in all directions.

The first thing considered was what measures should be taken to effect repairs. In the short term, new parts were out of the question owing to the time delay. Dimensions were taken for new 9 in dia hollow rams and for the other broken castings. Arrangements were made for the castings to be available within three days. Broken trunnion bolts had damaged the holes, which necessitated boring and sleeving.

All other broken parts were also renewed. At the end of 12 days, repairs were completed. All the air was removed from the hydraulic system, allowing the steering gear once again to function satisfactorily.

While we were reassembling the parts, a sketch arrived from the manufacturer showing how to repair the rams. As the repair we had carried out was identical, we felt they had knowledge of similar cases.

The background to the failure was that the captain was certain he had not hit the bank while swinging the vessel at the berth. It was found that the rudder stock had not twisted, and therefore the superintendent engineer was inclined to agree, because, on a previous occasion at the same berth, the rudder had hit the bank and twisted the stock, without causing any other damage.

However, on examining the steering gear prior to dismantling, it was discovered that the rudder was hard to starboard, which was the direction of the swing, and also the needles of the gauges on the non-pressurised cylinders were bent and were hard over (Fig 1). This indicated that an external force had been applied to the rudder in a direction which would increase the helm. Assuming the hunting gear was stationary at the time, all valves and ports would be locked hydraulically, therefore reversing the forces on the trunions. When the helm was on the force along the inclined plane produced by the tiller head was directed towards the rudder stock instead of the guide bars. This resulted in the light cross-head guide-plate retaining bolts breaking, allowing the rams to bend and break.

After calculating the tensile strength of the bolts, it was found that a force of 20 t on the outer edge of the rudder blade would be sufficient to cause this disaster.

It is worth noting that, had the rudder been to port or midships, this damage would not have occurred when the rudder hit the bank.

Clutch failure

This case concerns the failure of an hydraulic clutch to disengage. The vessel was a tug with twin engines and fluid couplings driving into the twin-input single-output gearbox. The tug, while swinging in the river, did not respond to astern movement, and continued on ahead. It was found that the ahead clutch had not disengaged, therefore the gearbox was opened up.

A Lloyd's Register representative considered that small scuff marks on the brass moveable plates were the cause. Therefore, these were polished out and the gearbox reassembled. After a short time, the problem happened again, resulting in the tug sideswiping another vessel. On inspection, it was found that the scuff marks had returned, and Lloyd's suggested improving the finish.

This indicated that an external force had been applied to the rudder in the direction which would increase the helm.

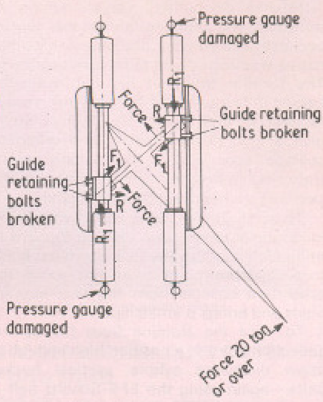


Fig 1: FINDING
Force introduced through tiller head arms produced reaction force 'R', which in turn produced a force up incline plane 'F' introducing a resultant force 'R' which was sufficient to snap all guide retaining bolts and permit a bending moment to be applied to the C.I. rams, which subsequently broke.
NOTE:—Had the rudder been in midships or force applied from the opposite direction the rudder stock would have twisted first.

Ships in shallow water

Sir,

I found the article on operating ships in shallow waters (May MER) most interesting. The author made some very discerning observations of the problems encountered and has made useful suggestions on the means of improving the situation.

The suggestion that the lower bearing on vertical seawater pumps should be removed, and a top water-lubricated bearing fitted (presumably to avoid sediment etc), is a sound one as far as it goes. Unfortunately, it is likely that any water-lubricated bearing using traditional materials, such as asbestos reinforced cresylic resin or rubber would still suffer considerable wear in this environment. The consequent change to shaft dynamics would result in a short life for a packed gland as well as aggravate the original bearing wear. Under these conditions a mechanical seal, which is even more intolerant of shaft angular and radial movement, would fare no better; it would have the additional disadvantage of being expensive to replace.

I believe the author is correct in recommending a shorter, and hence stiffer, pump shaft but I suggest that a low-clearance bearing of the rolling element type would be better than a water-lubricated bearing for this application. In this instance a mechanical seal should be used because it has the benefit of virtually zero leakage; the (necessary) flow of water across the seal faces usually vapourising at exit. The seal should be fitted as near to the bearing as possible to reduce the effects of radial or angular movement.

The provision of clean water to lubricate the faces of the seal is important. Use of fresh-water for this purpose (or for packed glands) is one solution but since it needs to be continuous to yield any worthwhile benefit, this is likely to be prohibitively expensive in terms of fresh/feed-water consumption. The problem can be overcome by tapping a supply from the pump discharge and leading it to the seal via a cyclone separator· these are particularly effective in removing solids from water, efficiencies of

For this application in particular, integration of the mechanical seal arrangement with the overall pump design is vital. The clean water supply must be copious and fast-flowing with no 'dead legs' in order to discourage the collection of sediment or the development of corrosion. Involvement of the seal manufacturer at this stage in the design is prudent as is the involvement of the shipbuilder in order to clarify the intended pump orientation.

Packed glands must leak in order to function properly. As suggested by the author, the judicious siting of electrical equipment away from the vicinity is virtually the only means of preventing consequential damage from leaking glands (apart from the use of multi-purpose polyethylene sheeting so familiar to all marine engineers).

With mechanical seals, however, the effects of eventual leakage can be considerably reduced if this is an absolute requirement: a lip seal can be incorporated as a back-up seal. If such a device is used, the chamber between the mechanical seal and the lip seal should be vented to a tundish and hence to bilge. The vent has three purposes, namely:

- It indicates when the mechanical seal is leaking
- It prevents a full pressure build-up behind the lip seal which, although theoretically capable of withstanding pressures of up to 10 bar (depending on type), would be unlikely to last long under such conditions
- It prevents equalisation of pressure on either side of the mechanical seal, thus allowing hydraulic forces to assist the seal spring(s) in keeping the faces in contact. By this means the mechanical seal continues to provide a useful contribution to watertight integrity, albeit a degraded one.

There are other, more radical, approaches that can be used to improve the mean-time between failures of seawater pumps in a dirty environment but that is another story. My notes have had to be restricted for obvious reasons but I hope they are of some interest. I welcome any comments from fellow engineers on this subject.

Lt Cdr G Carr RN
Trowbridge, Wilts.

Packed glands must leak in order to function properly.

With mechanical seals... a lip seal can be incorporated as a back-up seal.

Merits of a vent

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

MASSA Academy Chennai
Inaugurates Refurbished Electrical & Electronics Laboratory

On Friday 12th August 2022, MASSA Academy in Chennai inaugurated its Refurbished Practical Electrical & Electronics laboratory at the hands of Capt Deepak Correa, COO, Elegant Marine Services, Mumbai.

The refurbished and augmented laboratory has equipment to enable the following training capabilities:

PLC - Construction of ladder network, Programming and HMI. Programming of on board control panels and simulation (Package boiler, OWS, Purifier and Sequential start after blackout).

VFD & SOFT STARTER - Understanding of various types of start-up and speed control methods of motors. Pulse width modulation & Firing of scr and thruster. Understanding of Electrical propulsion system & Flow controls.

FAULT MODULE STARTERS - Troubleshooting practice given in various types of starters, understanding of various types of electrical circuits.

DEMO MODULE STARTERS - Retro fit practice to handle the emergency situation to build own bypass circuit, small control and power circuit.

TRANSDUCERS (Sensors) - Familiarisation of types of sensors and testing methods.

BATTERY - Types of batteries, Testing and routine maintenance of battery.

MOTOR OVERHAULING - Types of motor, Routine test and maintenance of motors, Before and After tests to be conducted in rewound motor. Overhauling of motor, Insulation resistance and coil resistance test.

TRIP & INTERLOCK COILS OF ACB - Understanding the arrangement of protection system and ACB tripping and interlocks.

ELECTRONICS - Familiarisation of electronic components and testing methods, Soldering and desoldering practice.

PARALLEL OPERATION OF ALTERNATORS & PROTECTION DEVICE TEST - Practice given in parallel operation of alternators in various mode and methods, simulation of reverse power, under voltage, overload, preferential trip, over frequency,

HV BAY - Operation and Maintenance procedure in HV system, Familiarisation of switchgear, measuring device and special test equipment in HV system in on board. Demo and practice given in 6.6KV HV panel.

MASSA Academy Chennai delivers a 6 days Practical Electrical & Electronics Workshop at it academy that is targeted at ETOs and Engineers up to 2nd Engineer level.

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BRANCH NEWS

KARNATAKA CHAPTER

IME(I) Karnataka Chapter Technical Meeting: "Retrofits as a Bridge on the Road to Net Zero Shipping"

A technical meeting of the Karnataka Chapter was held on Tuesday 23rd August 2022 at Eden Club. The resource person, C/E Ms. Rupali Joshi, HOD Marine Engineering Division, New Mangalore Port Authority spoke on "Retrofits as a Bridge on the Road to Net Zero Shipping."

Ms. Rao gave an in depth view on goals to zero emissions and how to plan to achieve them. The meet was appreciated by all. Shri. Keshava Rao, Hon. Secretary, Karnataka Chapter proposed the Vote of Thanks.

Shri. Pavithran Alokkan, Chairman, IME(I) Karnataka Chapter, welcomed the speaker and the gathering. Shri. Amitabh Bhargava, Hon. Treasurer, Karnataka Chapter, introduced the speaker.

GOA BRANCH

IME(I) Goa Branch Technical Meet: "Ballast Water Treatment System - Its Operational Challenges and Breakdowns"

The Goa Branch of the Institute organised a technical meet on the topic "Ballast Water Treatment System - Its Operational Challenges and Breakdowns" on 15th July 2022 at IME(I) House, Goa. The topic was presented by Chief Engineer Mr. Sunil Hajare.

The technical meet was attended by 66 participants, which included master mariners, marine engineers and engineer cadets. Being organised after a long gap of pandemic, the talk was well received and appreciated. There were requests to organise such informative meetings in future as well.

IME(I) OPENS OVERSEAS CHAPTERS

Saturday 20th August 2022 was a Red Letter Day in the history of 'The Institute of Marine Engineers (India) [IME(I)]' when three overseas chapters were opened simultaneously in London, Singapore and Hong Kong.

The opening of these International Chapters brought a new dimension between marine engineering and maritime interests of a modern India and marked a milestone in the growth of the Institute since its formation on 19 Jul 1972, as the India Division Council of The Institute of Marine Engineers (IMarE), London.

IME(I) was registered initially on 29 Oct 1977 under 'The Societies Registration Act 1860' at Mumbai and has grown into India's largest Marine Engineering body with a strength of over 11,000 Members from both sexes. The members are spread globally both on ships and ashore. With the opening of international chapters in Singapore, United Kingdom and Hong Kong, the Institute today stands tall with 8 Branches & 5 Chapters in India and 3 Chapters, overseas. Its membership now spans 15 countries and include members from the merchant marine and the Indian / Sri Lankan Navy with over 150 overseas Members.

The opening of these branches was done in a hybrid mode. Mr. Vikrant Rai, Engineer & Ship Surveyor-cum-Deputy DG(Tech) inaugurated the Chapters digitally at MCA Club, Mumbai (He stood in for Mr. Amitabh Kumar, DG Shipping). Over 200 invitees, dignitaries and members graced the occasion, which included attendees from all over India and abroad in different time zones. Mr. Rai while congratulating IME(I) on this landmark step towards global outlook, urged the overseas Chapters to contribute to the knowledge quest of IME(I) and the Directorate. He hoped that the overseas Chapters would enable larger participation from the international community in the events organised in India.

The event was conducted by Cmde. Bhupesh Tater (Retd.), Honorary General Secretary of IME(I) who called upon its President to address the gathering. Mr. Vijendra Kumar Jain, President IME(I) welcomed all the past Presidents in his opening remarks. He highlighted the journey and efforts put in by the earlier teams at IME(I) and the present dispensation to realize this big achievement. Acknowledging the silent efforts of countless marine engineers in strengthening the core values of IME(I), Mr. Jain laid the road map for the Institute's future growth. He sought the support of its members, the maritime community and the Directorate General of Shipping , particularly in spreading marine engineering knowledge and country's prowess globally.

The founding chairmen of overseas Chapters then delivered their talks. Speaking from London, Mr. Vijay

Jain, Chairman of the United Kingdom Chapter thanked all present and expressed his gratitude to past office bearers of the Institute who have been instrumental in keeping this initiative of starting international chapters on their agenda for over two decades. He made special mentions of Mr. B Saraswat, Mr. R.C. Bhavnani and the past presidents. Mr. Jain lauded the efforts in overcoming the challenges of opening the Chapter in UK, which is considered to be the mother of modern maritime industry. He assured the gathering that these efforts would continue tirelessly with the support of Members from UK and Mr. Mazumdar.

Mr. Jagmeet Makkar, Chairman of the Hong Kong Branch, who was present virtually with his newly formed team highlighted the efforts of members overseas over the last four decades to keep the flame alive on being associated with IME(I). He laid down his plans for sharing and spreading of knowledge from Hong Kong and pondered that soon more marine engineers of non-Indian origin would aspire to be the members of IME(I).

Supporting these views, the Chairman of Singapore Chapter, Mr. Kaushik Kumar Seal assured that his team would leave no stone unturned to increase the overseas membership. He expressed his confidence that IME(I) and its overseas chapters would collaborate with more vigour to strengthen and enhance the capability of the international maritime community in times to come, on the basis of the feedback received by him and his interaction on other international events.

Cmde. Tater brought out that the tremendous ground work Mr. Arun Kumar Gupta, the Chairman on IME(I)'s International Relations Sub-Committee(IRSC) and his team in realising the plans for the three International Chapters. Thanking him and his entire team of IRSC, he invited Mr. Gupta to share his experience of this endeavour. Recalling the difficulties faced as an office bearer in 2007, Mr A.K. Gupta drove home the point that the collaborative efforts of all stakeholders has enabled simultaneous commencement of three overseas chapters. He assured that IRSC would not rest with these Chapters and is already working on future growth, the next stop being Dubai. He thanked all present and sought the continued support of Mr V.K. Jain in future.

Mr. Yatinder Nath, the Chairman of IME(I)'s Publications Library and Website Sub-Committee (PLWSC) highlighted IME(I)'s latest digital endeavours to empower students and its members with knowledge and enhanced interaction. He brought out that as India celebrates Azadi ka Amrit Mahotsav, IME(I) has digitised all its monthly editions of Marine Engineers Review (MER) since its inception and nearly 400 priceless books on marine engineering held in the IME(I) Library. With the launch of "i-Library", these books, numerous technical and non-technical maritime publications and the MER would be available on-line to all Members of IME(I) and other organisations with whom the IME(I) is in the process of sharing resources for the benefit of maritime community. After highlighting various features of the i-Library, Mr. Nath also unveiled the rejuvenated "IME(I) i-Connect" mobile application covering the database of over 20,000 members of IME(I). This latest version of the App would facilitate seamless connectivity amongst members of the IME(I) for social, technical and personal exchange.

Concluding the event and presenting the Vote of Thanks, Mr. Amit Bhatnagar, Vice President IME(I), announced that IME(I) Mumbai Branch's quadrennial flagship event INMARCO will be held at Hotel Sahara Star, Mumbai from 17th to 19th November 2022. Urging wider participation for INMARCO-2022, he thanked all stakeholders, invitees present physically and on-line, print and digital media, staff/ office bearers of IME(I) - HO / PLWSC / IRSC / ITSC and the Mumbai Branch for the tremendous support extended, to make this event successful.

THE INSTITUTE OF MARINE ENGINEERS (INDIA)

1012, Maker Chambers V, Nariman Point, Mumbai – 400 021.

The Institute of Marine Engineers (India)

The 39thAnnual General Meeting will be held on Sunday, 25th September, 2022 at 1815 hours at Head Office, Nerul, Navi Mumbai 400 706.

AGENDA

1. Welcome address by the incumbent President, IME(I).
2. Adoption of the Minutes of the 38th AGM held on Saturday, 02 October, 2021.
3. Adoption of the audited accounts for the period 01 April 2021 to 31 March 2022
4. Confirm appointment of Auditor, for the financial year 2022-2023.
5. Presentation of the 'Council Report' for the period 16 July 2021 to 15 July 2022.
6. Submission of the amendments / changes to the Operational Rules & Procedures after the 38th AGM.
7. Declaration of the "P.C. Jain Memorial Student Award" for 2021-2022.
8. Declaration of the "H S Rao Memorial Award" for 2021-2022.
9. Declaration of the "R L Jain Memorial, IME(I) Lifetime Achievement Award" for the year 2022.
10. Nomination of the Election Officer for the next Election of Office Bearers for the term 2023-2025
11. Nomination of the Jury for the selection of the R L Jain Lifetime Achievement Awards -2023
12. Change of Objects and Proposed Amendments to MoA and AoA of the Institute
13. Any other matter with the prior permission of the Chair.
14. Vote of thanks.

RSVP

Bhupesh Tater, Honorary General Secretary

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OBITUARY

Vajrapu Butchi Raju (F 12507)
01.07.1966 – 15.08.2022

Born on 1st July 1966, Shri. Vajrapu Butchi Raju started his sea career with Irano Hind Shipping Company. He worked with HMS, Gesco, Wallems and Bernhard & Schulte also and worked as a Chief Engineer with Andromeda from 2014. He was known for his polite and humble nature and was highly respected by his community and the society.

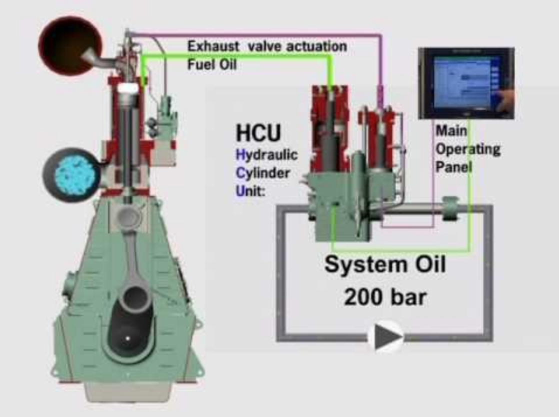
After his sign-off from his last vessel in July 2021, he was facing several health issues. Two months back he was admitted in the hospital for treatment of breathing problem, underwent tracheostomy surgery. On 6th August, he was shifted to the rehabilitation centre. Due to lung infection, he did not recover and breathed his last on 15th August 2022.

May his soul rest in peace.

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.

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Coverage / Program Focus:

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- **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 : 20th to 22nd **Sep'22**
8:00 am - 4:00 pm IST

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

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