ISSN 2250-1967

MARINE INDIA ENGINEERS REVIEW

JOURNAL OF THE INSTITUTE OF MARINE ENGINEERS (INDIA)

Volume : 20 Issue : 2 January 2026 ₹ 90/-

Engineering the Future of Shipping: Decarbonisation, Design Risk and Operational Resilience

The Institute of Marine Engineers (India)

IMEI HOUSE, Plot No.94, Sector-19, Nerul, Navi Mumbai.

Tel: +91 – 8454847896/ 022-27711663
Email: training@imare.in. Website: https://imare.in/

REGISTRATION OPEN FOR Following DGS APPROVED COURSES

- Basic Training for Ships using Fuels covered within IGF code ***Course Id – 5311*** (OFFLINE) – (5 Days) - 05th Jan 2026 / 19th Jan 2026 / 02nd Feb 2026 / 23rd Feb 2026 / 09th March 2026 /23rd March 2026
- Assessment, Examination and Certification of Seafarers ***Course Id – 1062*** (OFFLINE) – (12 Days) - 12th January 2026 / 09th March 2026
- Advanced Training for Ships using Fuels covered within IGF code ***Course Id – 5312*** (OFFLINE) – (5 Days) - 13th Jan 2026 / 10th Feb 2026 / 02nd Mar 2026
- MEO Cl. I (FG) : 2- months course (OFFLINE) - 2nd March 2026 / 2nd May 2026 / 1st July 2026 / 1st Sep 2026 (followed by Simulator course) **Discount on combined bookings of Class I Course with Simulator**
- MEO (CEO – NCV) – STCW 2010: 2 month course (OFFLINE) – 02nd March 2026 / 01st July 2026 / 02nd November 2026
- MEO (SEO – NCV) Part-A - STCW 2010: 2-month course (OFFLINE) – 02nd Feb 2026
- MEO (SEO – NCV) Part-B - STCW 2010: 4-month course (OFFLINE) – 02nd May 2026
- MEO Cl. IV (NCV) - STCW 2010 - 4 months course (OFFLINE) – Commencing Soon
- MEO (CEO – NCV) BRIDGING COURSE: 15 Days (OFFLINE) – 01st April 2026 / 01st June 2026 / 03rd Aug 2026 / 01st Oct 2026 / 01st Dec 2026
- MEO (NCV – SEO) BRIDGING COURSE: 1 Month (OFFLINE) – 2nd Feb 2026
- MEO CL. II (FG): 4-month Course (OFFLINE) – 2nd Feb 2026/ 2nd March 2026 (Discount on combined bookings of Class II Courses with Simulator)
- REFRESHER & UPDATING TRAINING (RUT - 4 DAYS) COURSE FOR REVALIDATION OF COC FOR ALL ENGINEERS and ETOs (OFFLINE) – 2nd Feb 2026/ 2nd March 2026/ 2nd May 2026/ 1st July 2026/ 1st Sep 2026
- ENGINE ROOM SIMULATOR MANAGEMENT LEVEL (3 DAYS) COURSE FOR MEO CLASS I (OFFLINE) – 26th Feb 2026/ 2nd March 2026/ 28th April 2026/ 2nd May 2026
- ENGINE ROOM SIMULATOR MANAGEMENT LEVEL (5 DAYS) COURSE FOR MEO CLASS II (OFFLINE) – 27th Jan 2026 / 02nd Feb 2026 / 24th Feb 2026 / 2nd March 2026/ 26th March 2026 / 1st Apr 2026/ 25th Apr 2026/ 2nd May 2026/ 26th May 2026/ 1st June 2026/ 25th June 2026
- ENGINE ROOM SIMULATOR OPERATIONAL LEVEL (3 DAYS) COURSE (OFFLINE) - 12th Jan 2026 / 19th Jan 2026
- MEO Cl. IV(FG) non mandatory course (2months duration) – On request

For Payment: Visit https://imei/mum.marineims.com/course/register

For enquiries contact on training@imare.in

For registration of Courses, visit:
https://imeimum.marineims.com/course/register

Features:
Experienced Faculty,
Individual Attention

AMET City College

(Post Sea Training Centre)

AMET, the Pioneer of Maritime Education with 32 + years of existence announces its expansion into the furtherance of Seafarers Career Path through AMET CITY COLLEGE, a Post Sea Training Institution situated at Villivakkam, the heart of the Chennai City.

S.NO	ID	COURSE	Duriation
ENGINE ROOM SIMULATOR			
1	3241	Diesel Engine Combustion Gas Simulator MEO Class I	3 Days
2	3221	Engine Room Simulator - (Management level) MEO Class II	5 Days
3	3121	Engine Room Simulator - (Operational level) MEO Class IV	3 Days
NAVIGATION SIMULATOR			
4	4211	Global Maritime Distress Safety System (GMDSS)	12 Days
5	2121	Radar Observer Simulator - (ROSC)	10 Days
6	2122	Automatic Radar Plotting Aids - (ARPA)	5 Days
7	2123	Electronic Chart Display And Information Systems - (ECDIS)	6 Days
8	2221	Radar And Navigation Simulator (RANSCO)	6 Days
ADVANCED MODULAR COURSES			
9	5312	Advanced Training for Ships using Fuels covered within IGF code (AIGF)	5 Days
10	5112	Advanced Training for Oil Tanker Cargo Operations (TASCO)	10 Days
11	5122	Advanced Training for Gas Tanker Cargo Operations (GASCO)	10 Days
12	5113	Advanced Training for Chemical Tanker Cargo Operations (CHEMCO)	10 Days
13	1061	Vertical Integration Course For Trainers - (VICT)	10 Days
14	6421	Medical Care (MC)	10 Days
BASIC MODULAR COURSES			
15	5311	Basic Training for Ships using Fuels covered within IGF code - (BIGF)	4 Days
16	3123	High Voltage Safety And Switch Gear - (Operational Level)	1 Days
17	6101	Basic Safety Training [BST= EFA+FPFF+PST+PSSR]	12 Days
18	6621	Security Trng. for Seafarer with Designated Security Duties - (STSDSD)	3 Days
19	5121	Basic Training for Liquified Gas Tanker Cargo Operations (BTLG)	5 Days
20	5111	Basic Training for Oil and Chemical Tanker Cargo Operations (BTOC)	7 Days
21	5211	Crowd Management, Passenger Safety & Safety Traning - (PSF)	3 Days
22	6511	Ship Security Officers - (SSO)	3 Days
23	6411	Medical First Aid (MFA)	4 Days
REFRESHER COURSES			
24	1118	Revalidation / Refresher and Updating Training for Engineers and ETO (REO)	4 Days
25	6412	Refresher Training in Medical First Aid Course (RMFA)	1 Day
26	6122	Refresher Training for Proficiency in FPFF	Half Day
27	6112	Refresher Training for Proficiency in PST	Half Day

COMPETENCY COURSES			
28	3231	MEO Class I	2 Months
29	3211	MEO Class II	4 Months
30	-	MEO Class IV (Value Added)	2 Months
31	2211	Chief Mate (FG) Phase - I	3 Months
32	2212	Chief Mate (FG) Phase - II	3 Months
33	2111	Second Mate (FG)	4 Months

ADMISSION

+91-91760 79666

+91-91760 44766

PRINCIPAL : +91 94449 62378

DIRECTOR : +91 91768 34833 , +91 88258 77750

ametcitycolleggeadmissions@gmail.com

R.R. Towers, 61/54, Jawaharlal Nehru Inner Ring Road (200 Feet Road) Villivakkam, Chennai - 600 049

THE INSTITUTE OF MARINE ENGINEERS (INDIA)

KOLKATA BRANCH

MTINO.307030

31/3, Sahapur Colony, Flat No. A-1/2, New Alipore, Kolkata-700053.
Tel. (M): +91 8697430058 | 9820484498
E-mail: principalkolkata@imare.in | enquirymetckol@imare.in

Course Fee & Schedule for DGS approved Courses at IMEI, Kolkata Branch

Sr. No.	Name of the course	Course Fee	Course Duration	Schedule
1.	Basic Training for Ships using Fuels covered within IGF Code (IGFB)	Rs.15,500/- (including lunch & one time Exit Examination fees)	5 days	5th January - 9th January, 2026 / 2nd February - 6th February, 2026
2.	Crisis Management & HumanBehaviour	Rs.9,500/- (including lunch & one time Exit Examinationfees)	5 days	12th January - 16th January, 2026 / 9th February - 13th February, 2026
3.	Crowd management, Passenger Safety and SafetyTraining	Rs.4,000/- (including lunch & one timeExit Examinationfees)	3 days	19th January- 21st January, 2026/ 16th February- 18th February, 2026
4.	Security Training for Seafarerwith Designated Security Duties (STSDSD)	Rs.2,500/- (including lunch & one timeExit Examinationfees)	2 days	22nd January - 23rd January, 2026 / 19th February - 20th February, 2026
5.	Ship SecurityOfficer (SSO)	Rs.5,000/- (including lunch & one timeExit Examinationfees)	3 days	27th January - 29th January, 2026/ 23rd February- 25th February, 2026

- **Discount of 5% for Group Booking of more than 5candidates.**
- **Discount of 10% for Group Booking of more than 10candidates.**
- **For IMEI Member, 10% Discountavailable.**
- **Rs.50/- for DGS Fees for issuance ofcertificate.**
- **If more candidates are available, we can schedule a special batch as and whenrequired.**
- **Special Discount may be available for block booking and studentcandidates**

EDITORIAL

"Walk toward the light, and each new horizon glows with promise."
- Ralph Waldo Emerson

Maritime World at the Threshold of Reinvention

At the dawn of the new year, the maritime sector stands at a decisive inflection point. Geopolitical realignments, accelerating technology cycles and climate-driven regulation have converged to create a clear operational reality: incremental improvement is no longer enough. Reinvention—strategic, technological and human—has become imperative.

Globally, shipping is aligning with strengthened IMO decarbonisation pathways and complementary regional instruments such as the EU Emissions Trading System and FuelEU Maritime. Circular economy principles are increasingly embedded across ship design, fuel selection, port operations and lifecycle compliance. Sustainability and inclusion are no longer peripheral considerations; they are now integral to risk management, capital allocation, regulatory credibility and long-term stakeholder value.

Technology is acting as a force multiplier. The accelerating adoption of dual-fuel propulsion, alternative fuels, digital twins, AI-assisted planning and advanced simulation platforms is reshaping operational decision-making. However, technology alone does not deliver resilience. The true differentiator lies in accelerating adaptation—building organisational capability through learning by doing, multidisciplinary training and pedagogy aligned with evolving policy and regulatory frameworks.

India's maritime ecosystem reflects this transition. National initiatives increasingly emphasise *Vidya Viniya Vikasa*—knowledge refined through application—bridging regulatory understanding with operational competence. Training institutions are evolving to foster cognitive flexibility, ethical judgement and system-level thinking, enabling professionals to manage complexity across engineering, compliance, safety and environmental performance.

In an era defined by rapid AI adoption, geopolitical uncertainty, and generational change, leadership is shaped less by hierarchy and more by lived experience, empathy and service. Value creation must precede profit; when value is delivered consistently, outcomes follow naturally.

The oceans may be uncertain, but the course is clear. Maritime progress will belong to those who anticipate change, pursue excellence with discipline and remember that in shipping—as in seamanship—sound fundamentals never lose relevance**.**

Summary of papers

This paper offers a technically grounded, policy-aware overview of modern wind-assisted ship propulsion, positioning WASP as a pragmatic, near-term decarbonisation lever. Blending regulatory context, real-world performance data and technology maturity assessment, it balances engineering rigor with commercial realism, highlighting wind propulsion's growing relevance in today's carbon-constrained shipping landscape. A good highly information read aligned with decarbonisation objectives of IMO.

This next paper continued from Dec edition on the same topic on shipping contracts. It examines how misalignment between shipbuilding contracts and technical specifications creates major legal and commercial risks. It explains how ambiguous language, poor document hierarchy, regulatory changes and weak change control lead to disputes and provides practical drafting, integration and governance strategies to prevent arbitration and protect project outcomes.

The third paper traces the historical development of magnetohydrodynamic (MHD) marine propulsion, from early theoretical concepts to Japan's landmark *Yamato-1* trials. It explains Lorentz-force propulsion principles, engineering challenges and strategic motivations. While technically rigorous and well written, the paper is intellectually dense, concluding that despite proven feasibility, efficiency, power and material limitations currently confine MHD propulsion to specialised future naval and research applications.

The fourth paper presents key advancements in India's Tsunami Early Warning System, highlighting improvements in offshore buoy reliability, network optimisation, submerged buoy concepts and hybrid satellite telemetry. It examines reliability-centred engineering approaches, challenges in accurately estimating tsunami wave energy and robust warning dissemination protocols, demonstrating how integrated technology, systems engineering and coordinated institutional governance enhance the timeliness and dependability of tsunami warnings across the Indian Ocean region.

The fifth paper marks the inauguration of our marine accident investigation series. This monthly series is dedicated to extracting practical, operational learnings from accident investigation findings, results and conclusions. The first article focuses on fatigue failures in ship structures, presenting a forensic, engineer-centric framework that traces failures from micro-crack initiation to major structural casualties. By integrating metallurgy, non-destructive testing (NDT), S–N fatigue analysis and regulatory context, the paper distils clear, actionable lessons to help prevent recurrence and reduce safety, legal and financial risks across the maritime industry.

I am sure the readers will definitely benefit from the reading...

Here is the January 2026 issue for your reading pleasure and intellectual rumination.

Mani Ganapathi Ramachandran
Honorary Editor
Head – Engineering, HIMT
editormer@imare.in

THE INSTITUTE OF MARINE ENGINEERS (INDIA)
MUMBAI BRANCH ALONG WITH ITS CHAPTERS
GUJARAT AND NAVI MUMBAI

In association with

MINISTRY OF PORTS, SHIPPING AND WATERWAYS

IRCLASS Indian Register of Shipping

Platinum Sponsor

Theme: Maritime Landscape 2030 Opportunities and Challenges

INMARCO 2026

Request you to kindly "save the date" for

International Maritime Conference cum Exhibition 2026

WHEN 27th to 29th Oct 2026

WHERE Westin, Powai, Mumbai

ABOUT THE CONFERENCE:

Since its inception in 1982, INMARCO has always witnessed an overwhelming response from the Maritime sector which in turn had inspired IME(I) to organise INMARCO quadriennially.

Papers are invited from Engineers, Manufacturers, Designers, Shipbuilders, Operators, Students, Educators, Researchers, Recyclers, Adjudicators, Salvors, Class, Administrators, Marine Infrastructure Companies, Port Operators, Surveyors, Maritime Lawyers, Navies, Coast Guard and other Maritime related stakeholders.

Sessions on current topics with emminent panelists and moderators.

Curated Competitions for Students from MTIs, Maritime Universities and Marine Divisions of Engineering Colleges.

Contact us for more details: info@inmarco.in | inmarco@imare.in Mr. Suraj Negi +91 9967481448

MARINE ENGINEERS REVIEW INDIA

JOURNAL OF THE INSTITUTE OF MARINE ENGINEERS (INDIA)

Administration Office
IMEI House
Plot No. 94, Sector - 19, Nerul,
Navi Mumbai 400 706.
Tel. : +91 22 2770 16 64
Fax : +91 22 2771 16 63
E-mail : editormer@imare.in
Website : https://imare.in/

Editor
Mani Ganapathi Ramachandran

Editorial Board
Dr Rajoo Balaji
David Birwadkar
Vivek Kumar
Laltendu Acharya
Shishir Dutt
Rashmi Tiwari *(Associate Editor)*

Printed, Published and Edited by:
Mani Ganapathi Ramachandran on behalf of The Institute of Marine Engineers (India). Published from 1012 Maker Chambers V, 221 Nariman Point, Mumbai - 400 021, printed by Corporate Prints, Shop No.1, Three Star Co-op. Hsg. Society, V.P Road, Pendse Nagar, Dombivli (E) - 421 201. District – Thane

Print Version: **Corporate Prints**

Typesetting & Web designed by:
Kryon publishing (P) Ltd.,
www.kryonpublishing.com

In This Issue

ARTICLES

COLUMNS

Cover Credits: **Kryon**

D. G. SHIPPING APPROVED

Extra First Class Course

Distance Learning - Correspondence Course

PART PAYMENT AVAILABLE

DURATION
1 YEAR
(2 Semesters)

COMMENCING
Jan 2026

ELIGIBILITY
MARINE ENGINEERING OFFICER Class I CoC

Choose any five subjects in each semester.

Timeline for Course Completion: Within 5 years

NEW YEAR OFFER

Limited Offer for Special Batches

COURSE	DURATION	OLD FEE	NEW FEE
Basic STCW Safety Training (BST)	11 Days	~~11900~~	9900
Advanced Fire Fighting (AFF)	5 Days	~~8900~~	5900
Proficiency in Survival Craft and Rescue Boats (PSCRB)	5 Days	~~8900~~	5900
Advanced Training for Oil Tanker Cargo Operations (TASCO)	10 Days	~~12900~~	9900
Advanced Training for Chemical Tanker Cargo Operations (CHEMCO)	10 Days	~~12900~~	9900
Advanced Training for Liquefied Gas Tanker Cargo Operations (GASCO)	10 Days	~~12900~~	9900
Radar Observer Simulator Course (ROSC)	10 Days	~~10900~~	9900
Electronic Chart Display and Information System (ECDIS)	5 Days	~~13900~~	11900
Refresher and Updating Training for all Engineers / ETO (REO)	4 Days	~~9900~~	8900
Refresher and Updating Training for Masters & Deck Officers (RUT)	4 Days	~~9900~~	8900
High Voltage Safety and Switch Gear – Operational Level Course (HV-O)	1 Day	~~3900~~	2900
Vertical Integration Course for Trainers (VICT)	10 Days	~~12900~~	9900

Hindustan Institute of Maritime Training

Online Booking at www.himt.co.in

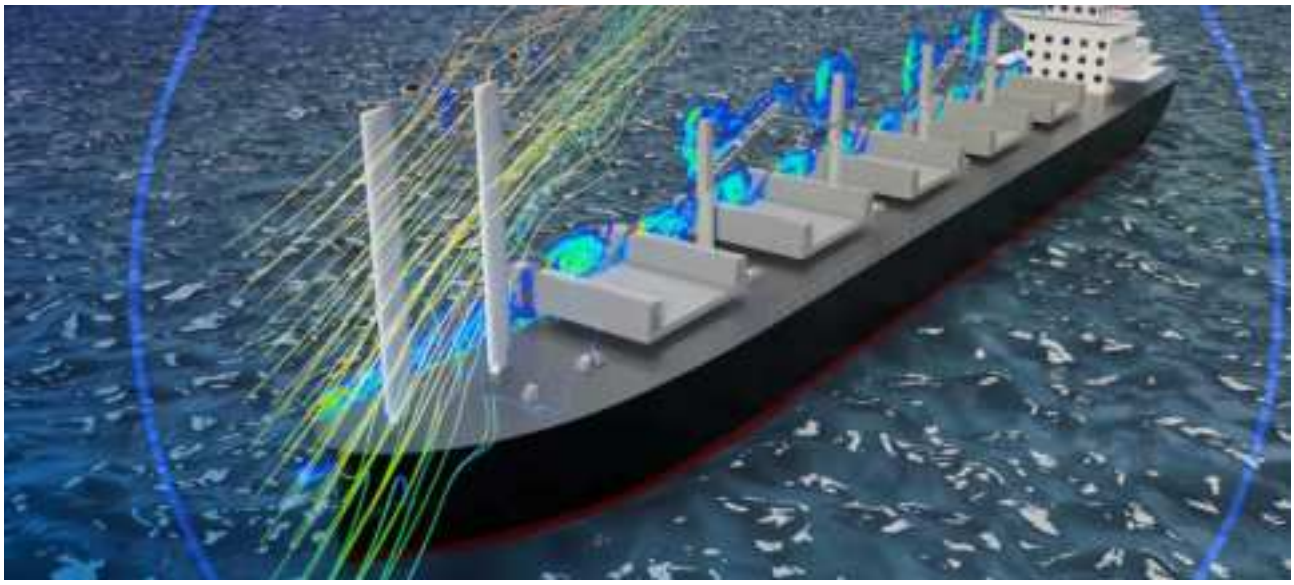
Phone: 98404 00000 | Email: help@himtmarine.com

Book your Course through our App

Download on Android | HIMT Booking

SCAN TO LEAN MORE

Wind Assisted Ship Propulsion (WASP) Technologies: An Overview



Shishir Dutt

Abstract

The IMO's 2050 net-zero carbon framework is a deliberate step to restore balance and accelerate emission reductions. Building on measures such as EEDI, EEXI and SEEMP, together with the recently implemented EU-ETS and FuelEU Maritime regulations, the sector now faces renewed urgency to curb GHGs. In this context, wind, the earliest form of ship propulsion, has re-emerged as a practical and near-term solution. Wind-assisted ship propulsion (WASP) technologies promise meaningful fuel and CO_2 cuts across today's fleets. This paper reviews the principal modern WASP options that are commercially available, summarising for each technology type, major players, product configurations and sizes, number of installations and current orderbook, technology status and maturity and expected versus verified fuel and CO_2 savings.

Keywords: Wind-assisted ship propulsion; Rotor sails; Rigid wing sails; Suction sails; Kite propulsion; Maritime decarbonisation; IMO net-zero strategy; Fuel savings; EU-ETS; FuelEU Maritime

Introduction

Shipping is currently responsible for 3% of global greenhouse gas (GHG) emissions and, at the present growth rate, this could rise to 10%. In July 2023, the IMO adopted an enhanced GHG-reduction strategy calling for net-zero emissions from international shipping by "around 2050," with interim targets of a 20–30% cut by 2030 and 70–80% by 2040 (against 2008 baselines). However, the World Bank expects global trade to grow; simply cutting total GHG by 30% by 2030 and 80% by 2040 will not suffice. To hit those absolute cuts while moving more cargo, each unit of transport work must become much cleaner, so emissions per tonne-mile (GHG intensity) must fall much faster—about 61% by 2030 and 91% by 2040 compared with 2008 **(see Figure. 1).**

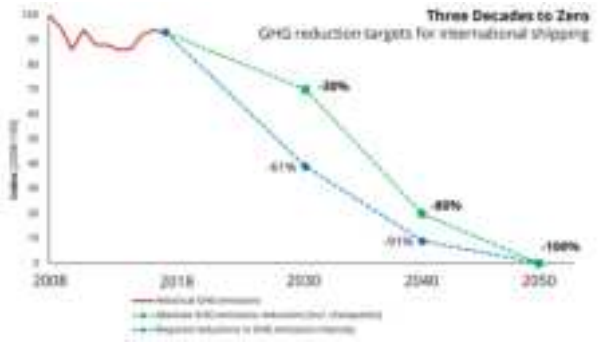


Figure. 1: GHG Reductions-IMO Net Zero vs World Bank estimates

Meeting these targets will require a portfolio of solutions, including more efficient ships, alternative fuels and operational measures. However, net zero fuels remain costly, face availability and infrastructure constraints and are unlikely to scale overnight. In this context, non-conventional energy sources such as wind can provide earlier and more affordable mitigation by directly cutting fuel use. Wind-assisted ship propulsion (WASP) has therefore re-emerged as a practical near-term option, with several technologies now commercially available and supported by growing operational experience. The main barrier to wider

adoption remains capital cost and return on investment, although the IMO net-zero framework and regional measures such as EU-ETS and FuelEU Maritime, which increase the cost of emitting and of purchasing remedial units, are expected to improve the business case and accelerate WASP uptake.

> *Wind propulsion re-emerges as shipping's most practical near-term decarbonisation solution*

This paper examines how modern WASP technologies fit into the maritime decarbonisation puzzle by comparing the principal commercial systems in use or under development today (Soft sails excluded from discussion). It outlines the drivers behind renewed interest in wind propulsion, summarises each major technology's concept, status and maturity and collates real-world performance data, expected versus verified savings, installation numbers and current orderbooks, together with key economic and policy considerations, to assess the potential of WASP to deliver meaningful fuel and GHG reductions across the global fleet.

Decarbonisation context and role of WASP

IMO has already introduced technical and operational measures to curb GHG emissions, such as the Energy Efficiency Design Index (EEDI) for newbuilding's and the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII) for existing fleets. In parallel, interest in low and zero carbon fuels such as LNG, methanol, ammonia and hydrogen is growing, although these options still face cost, availability and infrastructure constraints. Wind-assisted propulsion offers a complementary, fuel-agnostic route, because it reduces fuel demand at source, regardless of the fuel that is burned. By tapping free wind energy, WASP technologies can lower both emissions and fuel costs.

Modern WASP systems exploit an abundant zero-carbon resource available on all ocean routes. Devices are usually retrofitted to augment conventional propulsion, allowing engine power to be reduced when wind conditions are favourable while maintaining schedules. Case studies report typical average savings of about 5–20% per voyage, with higher peaks in good wind conditions. The basic idea is not new: after millennia of soft-sail shipping, early twentieth-century projects such as Anton Flettner's rotor ship *Buckau* demonstrated the Magnus effect in practice, but cheap oil prevented wider uptake. The current wave of development builds on projects such as Enercon's *E-Ship 1* and later Norsepower rotor installations on *MS Estraden* and *Maersk Pelican*, which delivered verified fuel savings on regular trades. These experiences show that WASP is now a technically mature option that can support regulatory decarbonisation pathways.

WASP Technologies

Contemporary WASP technologies encompass a range of designs, each leveraging wind in a different manner. In this section, we examine the main categories of wind-assist systems currently deployed or in late-stage development (excluding purely speculative concepts). For each type, we discuss the working principle, notable deployments and typical performance characteristics.

The WASP technologies can be broadly classified into four categories, namely Rotor Sail, Rigid Sail, Soft Sail and Kite. Some of these technologies can be further classified, with the biggest sub-classification coming under Rigid Sail technology. **Figure. 2** illustrates the classification of various WASP technologies in the form of a flowchart. An overview of modern WASP technologies has been compiled in **Table. 1** at the end of this paper.

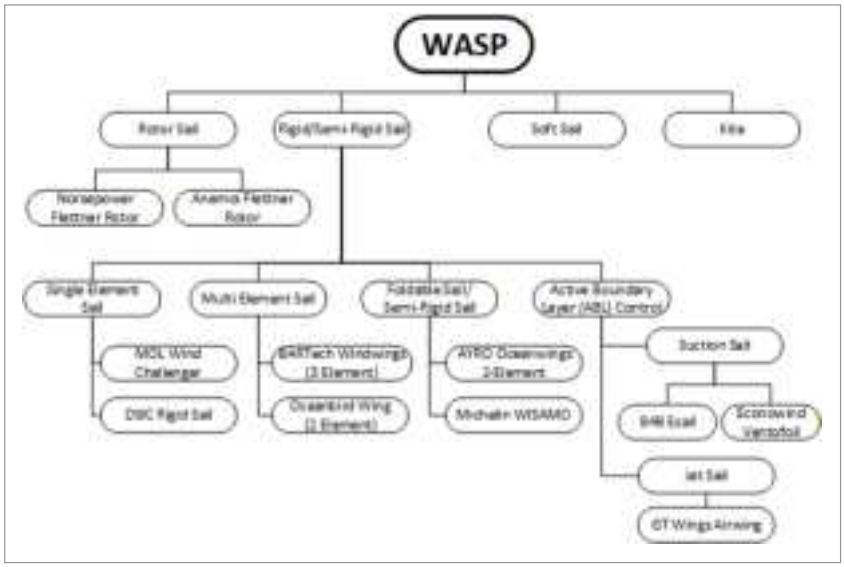


Figure. 2: Contemporary Wind Assisted Ship Propulsion (WASP) Technologies

Table. 1: Modern WASP Technologies: An Overview of Rotor sail, Rigid Sail and Kite systems

Tech Type	Product	Major players	Max. Size (H x W)	Installed		Upcoming		Tech status	Early Examples	[Expected] Reported Savings	Retrofit	Retraction option
				Ships	Units	Ships	Units					
ROTOR SAILS												
Rotor sails	Flettner Rotor	Norsepower (Finland); Anemoi (UK)	35 m × 5 m	31	75	22	52	Most mature, Commercial Installations	E-Ship 1 (2010); Estraden (2014) Maersk Pelican (2018)	[5–20%] Maersk Pelican: 8.2% verified by LR	Yes	Tiltable
RIGID SAILS												
Single Element	Wind Challenger	Mitsui OSK Lines (MOL)	53 m × 15 m	2	2	10	17	Matured, Commercial Installations	Shofu Maru; Green Winds	[15-50%] Wind Challenger: 5–8% avg. per voyage; Max/ 17% per day (MOL data)	Yes	Telescopic
	DSIC Rigid Sail	Dalian Shipbuilding Industry Company (DSIC)		2	6	—	—		New Vitality (2018 New Aden (2022)			—
Multi-Element	Windwings	BAR Technologies	37.5 m × 20 m	3	7	20	40	Matured, Commercial Installations	Pyxis Ocean (2023); Brands Hatch (2025)	[≥1.5 t/day/wing] Pyxis Ocean: 14.5 t/ day/wing 12% annual avg. Max. 17%	Yes	Tiltable
	Oceanbird Wing 560	Alfa Laval & Wallenius Wilhelmsen (joint)	40 m × 14 m	Shore-based prototype testing (2025) MV Tirranna installations planned - 2026						[7–10%] [600 t/year]	Yes	Tiltable
Sem-Rigid	Oceanwings (Multi-Element, Rigid and Sem-Rigid options)	AYRO / Oceanwings	30 m, foldable/ tiltable	1	4	—	—	Prototype Testing onboard	Ro-Ro Ship Canopee (2023)	[25-50%] Avg.: 1.3 t/day/wing (5.2 t/day total); Max.: 2.2 t/day/wing (8.8 t/day);	Yes	Foldable/ Tiltable
	WISAMO (Inflatable)	Michelin	24.6 m × 9.3 m 170 m^2 area; telescopic mast	1 x 100 m^2 prototype sail on MN Pelican (2022) tested for 1 year MN Pelican sail has since been removed 1 commercial installation announced for 2027						No claims	Yes	Inflatable
Active Boundary Layer (ABL) Control	eSAIL (Suction Sail, Oblong shape, Multi-element, Flap Control)	Bound4Blue	36 m × 6 m	7	18	13	37	Mature, Commercial Installations	La Naumon (2021)	[20%-40%] Ville de Bordeaux: BV Verified (x3 sails): Yearly avg- 1.7 t/day, Max.- 5.4 t/day;	Yes	Tiltable
	Ventofoil (Suction Sail, Aerofoil Shape)	Econowind	30m x 5m	—	32	—	70		M.V. Ankie (2020)	Customer Claims: 10% savings	Yes	Tiltable
	Airwing (Jet Sail, Suction + Jet)	GT Wings	20 m	Installed on 1 General cargo ship -Vectis Progress (2025) Prototype testing						[5–30%]	Yes	Tiltable
KITES												
Kites (Parafoil Wings)	Skysails	Skysails	160m^2	1	1	—	—	Tested on MV Beluga (2006), Skysails has stopped making Sails for propulsion		[upto 30%] MV Beluga observed 10-15% savings	Yes	Retractable
	Seawing	Airseas	1000m^2	2	2	50	50	Ville de Bordeaux (2021)- 500m^2 Prototype Cape Brolga (2021) – Prototype testing Shore based testing (2025-2027)		[upto 20%] Ville de Bordeaux observed 16% savings	Yes	Retractable

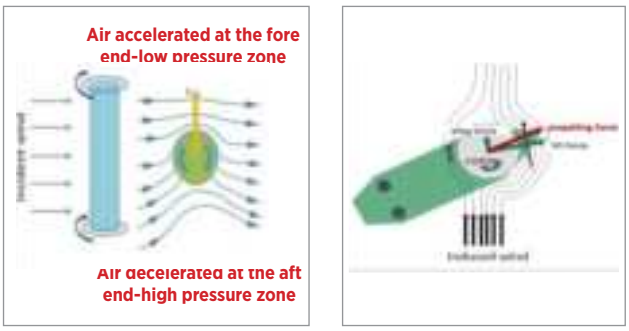


Figure. 3: Rotor Sail producing Magnus thrust (lift force)

Rotor Sails (Flettner Rotors)

Rotor sails work on the Principle of Magnus effect. A rotor sail, mounted on the deck of a ship, is rotated in such a way (clockwise or anti-clockwise) that when it experiences wind flow in athwartship direction, a thrust is produced in the forward direction. This is achieved when the rotating cylinder accelerates the flow on the fore end of the cylinder (pressure decreases) while decelerating the flow at the aft end (pressure increases) creating a pressure differential and hence the thrust in the forward direction. **Figure. 3** illustrates a typical rotor sail installation on a tanker. Modern rotor sails are typically built of lightweight composite cylinders with internal motor drive systems.

Wing Sails (Rigid Sails)

These are basically dual surface sails similar to wings of an aircraft and hence the name wingsail. There are many different types of wingsail technologies available as of date. The classification of various types of Wingsail technologies is given in **Figure. 2.**

Wing sails, also called hard or rigid sails, are tall aerofoil-section structures mounted vertically on the ship's deck that always maintain their cross-section and shape irrespective of wind conditions and they resemble aircraft wings, which is why they are also known as wing-sails. You can imagine a wingsail like a wing of an aircraft which has been placed vertically on the deck rather than horizontal (like in an aircraft).

Figure. 4: Ships installed with Norsepower (left) and Anemoi (right) Rotor Sails

Working Principle

The basic working principle of all wingsails is similar to that of an aircraft wing: a relatively flat lower surface and a cambered upper surface. Air flow over wingsail creates higher air velocity (low pressure) above and lower velocity (higher pressure) below, generating lift by Bernoulli's principle. For a wingsail on a ship, the flatter lower surface is oriented towards the aft and the cambered upper surface towards the bow, so that the resulting lift has a forward component that produces thrust **(Ref. Figure. 5 & Figure. 6.).**

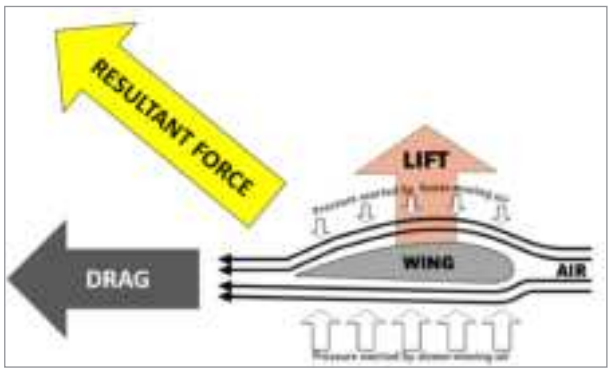


Figure. 5: Working Principle of a Wingsail (Rigid Sail)

Single Element Wingsail

A single-element wingsail has an aerofoil-section main body, as shown in **Figure. 6 and Figure. 7,** with Wind Challenger by MOL as a classic example. The sail angle is adjusted to maximise forward thrust for a given apparent wind, which depends on true wind and ship speed **(Figure. 6);** Wind Challenger achieves maximum thrust when the apparent wind is athwartship and the sail is set at an Angle of Attack (AOA) of about 25° to the apparent wind **(Figure. 7).**

> ***Modern WASP technologies consistently deliver meaningful fuel reductions across global fleets***

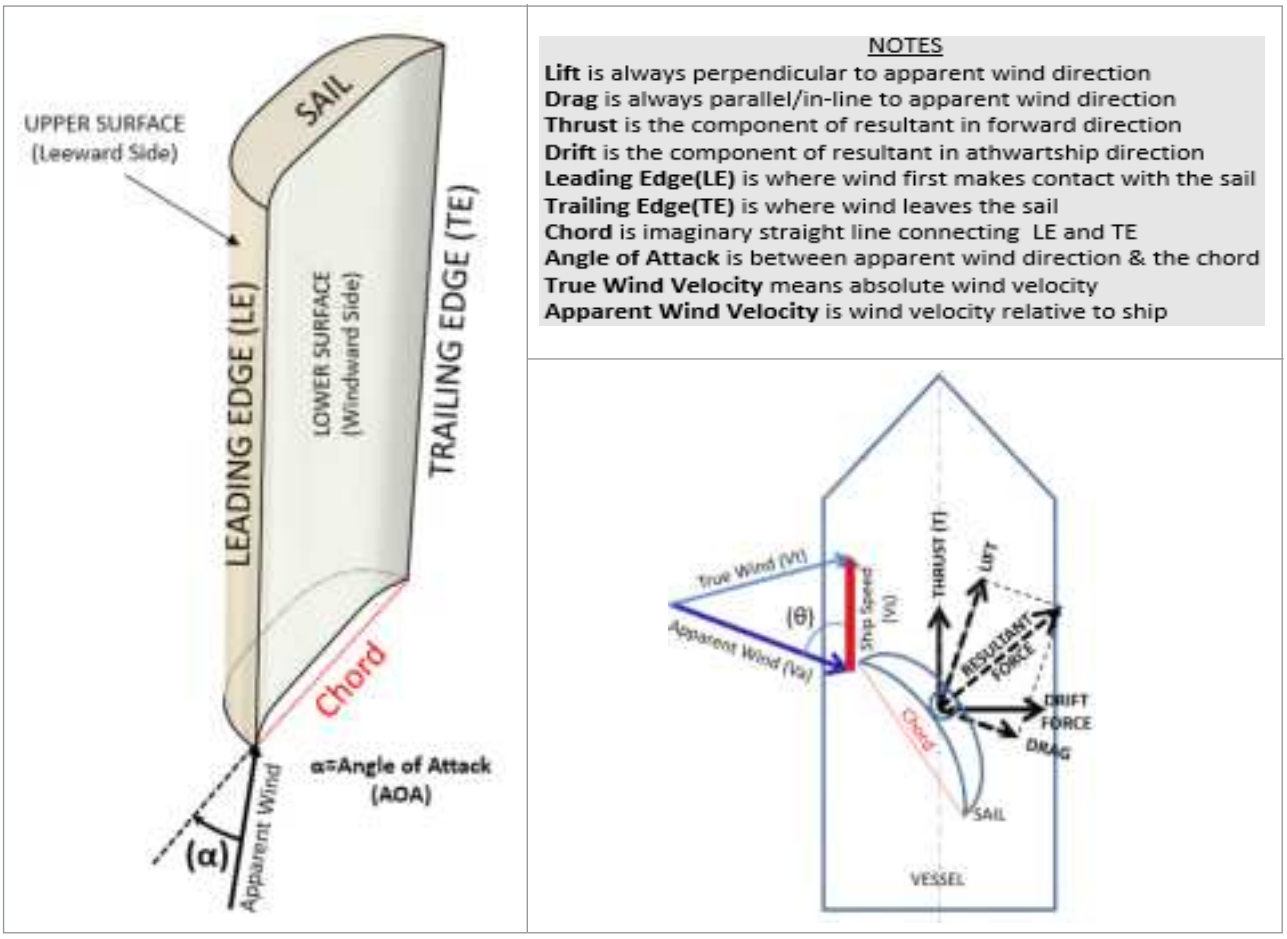


Figure. 6: Resultant of Lift and Drag forces are resolved to calculate thrust and side force on the vessel

Maximum lift occurs at this optimal AOA (about 25° for Wind Challenger), beyond which lift drops sharply; this AOA is termed the stall angle. The stall angle depends mainly on airfoil geometry, aspect ratio, chord length and apparent wind velocity.

Maximum lift is obtained when the wingsail is set at an optimal Angle of Attack (for Wind Challenger, 25 Deg.). When the angle of attack (AOA) exceeds about 25°, the lift generated by the wingsail drops sharply. The AOA at which max lift is achieved before decreasing is called the stall angle. The stall angle depends on factors such as the wingsail's shape (airfoil geometry), aspect ratio, chord length and the apparent wind velocity.

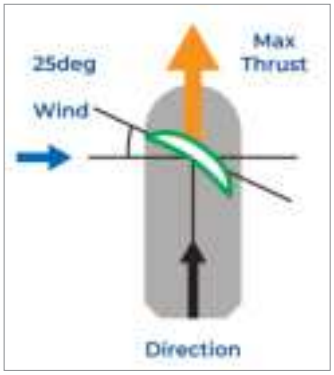


Figure. 7: Wind Challenger Sail setting for Maximum Thrust for athwartship wind

Wind Challenger is a retractable telescopic wingsail developed by MOL and Oshima Shipbuilding, first installed on the coal carrier *Shofu Maru* (2022) and subsequently on *Green Winds*. Early operations on the Japan–Australia route report about 5–8% average fuel savings per voyage, with higher daily peaks. MOL plans wider deployment on additional bulk and LNG carriers, targeting roughly 25 ships by 2030 and about 80 by 2035.

DSIC rigid sails, developed by Dalian Shipbuilding Industry Company, have been installed on the VLCCs *New Vitality* (2018) and *New Aden* (2022) operated by CMES.

Multi-Element Wing Sails

These wingsails use movable flaps at the trailing edge and in some designs at both the leading and trailing edges, to control airflow, increase lift and delay stall to higher AOA.

BAR Tech. Windwings

Windwings is a three-element wingsail with a slat at the leading edge and a flap at the trailing edge, similar to the multi-element wings of an aircraft. By adjusting both slats and flaps, it can generate very high lift over a wide range of angles of attack, reduce

Figure. 8: MOL's Wind Challenger (Telescopic Rigid Sail)
(Clockwise from top: a. Shofu Maru, b. Green Winds, c. MOL LNG Carrier(proposed) d. Chevron LNG Carrier (under construction))

drag and delay stall to much higher angles, so the basic principle is the same as a single-element sail but with greatly enhanced lift per unit area, reportedly even exceeding rotor sails.

Its main drawbacks are complexity and weight: the three-element arrangement requires multiple linkages and control systems for slewing the main sail and for flap, slat and tilting control, giving a unit weight of about 250 tonnes. This added weight reduces available cargo deadweight and earning capacity compared with other WASP technologies.

Figure. 9: BAR Tech Windwings

Oceanbird Wing

It is a two-element control rigid sail system with a flap at the trailing edge of the main aerofoil section body. Similar to Windwings, flap control can improve lift, reduce drag and delay stall to higher AOA. Shore based prototype testing is currently undergoing for this promising technology.

> *Rotor, wing and suction sails now demonstrate verified real-world emission savings*

Figure. 10: Shore based prototype testing of Oceanbird Wing 560

Foldable Sails (Semi-Rigid sails)

These wing sails can fold into a compact form and be stowed to very low height during bad weather, bridge transits, cargo work or maintenance, minimising drag and obstruction; when extended, they perform like any other rigid sail.

AYRO Oceanwings

Oceanwings (ex-AYRO Oceanwings) offers a two-element collapsible/tiltable sail, with trailing-edge flap. It is in prototype testing stage with 4x30 m Oceanwings units installed on Ro-Ro *Canopée* currently under trials.

Figure. 11: Ro-Ro ship Canopee with 4x Oceanwings

Michelin WISAMO

WISAMO (Wing Sail Mobility) is an inflatable, retractable semi-rigid sail developed by Michelin, using an internal compressor and control system to pressurise its flexible windproof fabric skin so that it holds its shape. The wingsail is mounted on a telescopic mast and uses a fully automated, single-button system for deployment, reefing and retraction.

Figure. 12: WISAMO deployed on MN Pelican (left) and rendered visualisation of deployment on Bulk Carrier (right)

Active Boundary Layer (ABL) Control Wingsail

Active boundary layer control uses small amounts of powered airflow to manage the thin layer of air next to the wingsail surface. By drawing air in or blowing it

> *Kite propulsion unlocks powerful high-altitude winds for deep operational efficiency gains*

out through the wing, the flow stays attached at higher AOA, delaying separation and stall. This yields more lift for a given planform and steadier thrust in varying winds, often with modest electrical power compared with the fuel saved. Implementations differ by maker, but the principle is the same: energise the boundary layer to improve lift and control.

Suction Sail

Suction sails are wingsails that draw air off the upper surface to accelerate the flow (higher velocity/lower pressure), increase the pressure differential and lift, and delay stall to higher angles of attack by controlling the suction rate. Econowind Ventofoil and bound4blue eSAIL are the main commercial examples: both apply suction near the trailing edge so the upper-surface flow stays attached as AOA increases, increasing lift, reducing drag and delaying stall. eSAIL, in addition to suction, also uses a tail flap similar to two-element wingsails. In practice, low-power fans pull air through slots or perforations, with control systems adjusting suction and sail angle; this adds modest electrical load and some complexity in ducting, filtration and protection of inlets.

Figure. 13:Econowind Ventofoils

Figure. 14: Bound4Blue Esails

Jet Sails

While suction sails generate extra lift by energising the upper-surface boundary layer through suction alone, a jet sail accelerates this boundary layer using a combination of suction and a controlled pressurised "jet" of air. This keeps the flow attached, strongly increases its speed and lowers upper-surface pressure (Bernoulli), creating a much higher-pressure differential than a conventional rigid sail, so lift increases, drag can be reduced and stall is delayed to higher AOA by adjusting the jet flow. GT Wings Airwing is a commercial jet sail using this principle **Figure. 15.**

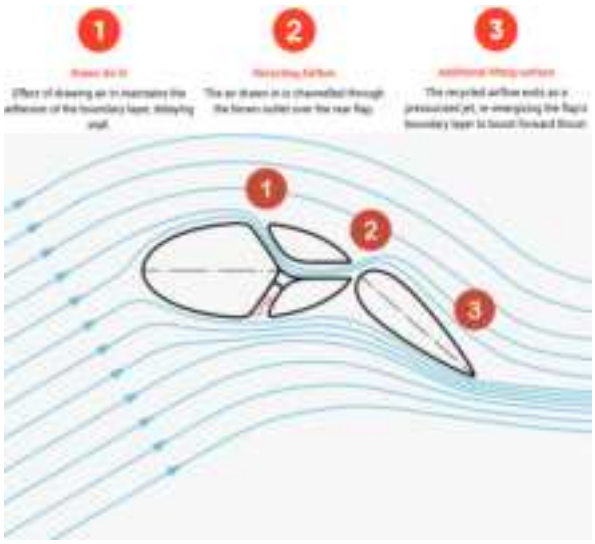


Figure. 15: Working Principle of GT Wings Airwing (Jet-Sail)

Figure. 16: GT Wings Airwing Jet Sail on Vectis Progress

Kites (Towing Kites or Parafoils)

Kite systems use large parafoil kites flying hundreds of metres above sea level to tow the ship via a tether, harvesting stronger and steadier winds aloft. They are fully automated, launched and recovered by a bow mast or crane and controlled by a computer that manages angle and dynamic **"figure-8"** flight patterns to increase pull. SkySails (Germany) pioneered the concept in the 2000s with a 160 m² kite on *Beluga SkySails* (2008), demonstrating roughly 5–10% fuel savings on North Atlantic voyages, but has since left marine propulsion to focus on airborne power generation.

Rising fuel and carbon costs rapidly strengthen the business case for WASP

Airseas' Seawing is the main successor concept. A 500 m² prototype was tested on *Ville de Bordeaux* in 2021 with automatic launch, control and recovery and reported about 16% average fuel savings on a transatlantic route. K-Line ordered several Seawing systems and trialled one on the 212,000 DWT *Cape Brolga*, then acquired Airseas through its subsidiary Oceanicwing. Development is now structured in phases: Phase 1 has tested a 300 m² kite at a land site; Phase 2 will test a full-scale 1000 m² sail over the next couple of years before renewed shipboard deployment.

Working Principle

Seawing is a 1000 m² ram-air parafoil with multiple cells that inflate through leading-edge inlets during flight, flying at about 300 m altitude on a tether of roughly 700 m. It operates only within a favourable apparent wind angle window, avoiding

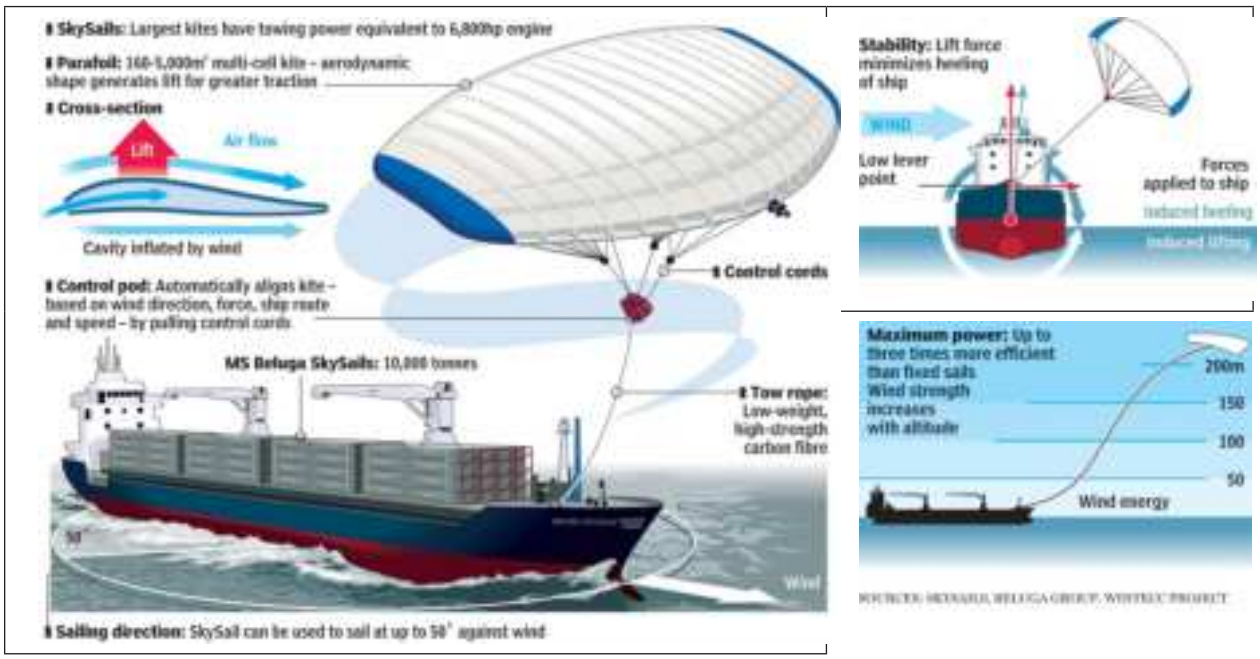


Figure. 17: MS Beluga depiction with Skysails Kite (Source: Skysails)

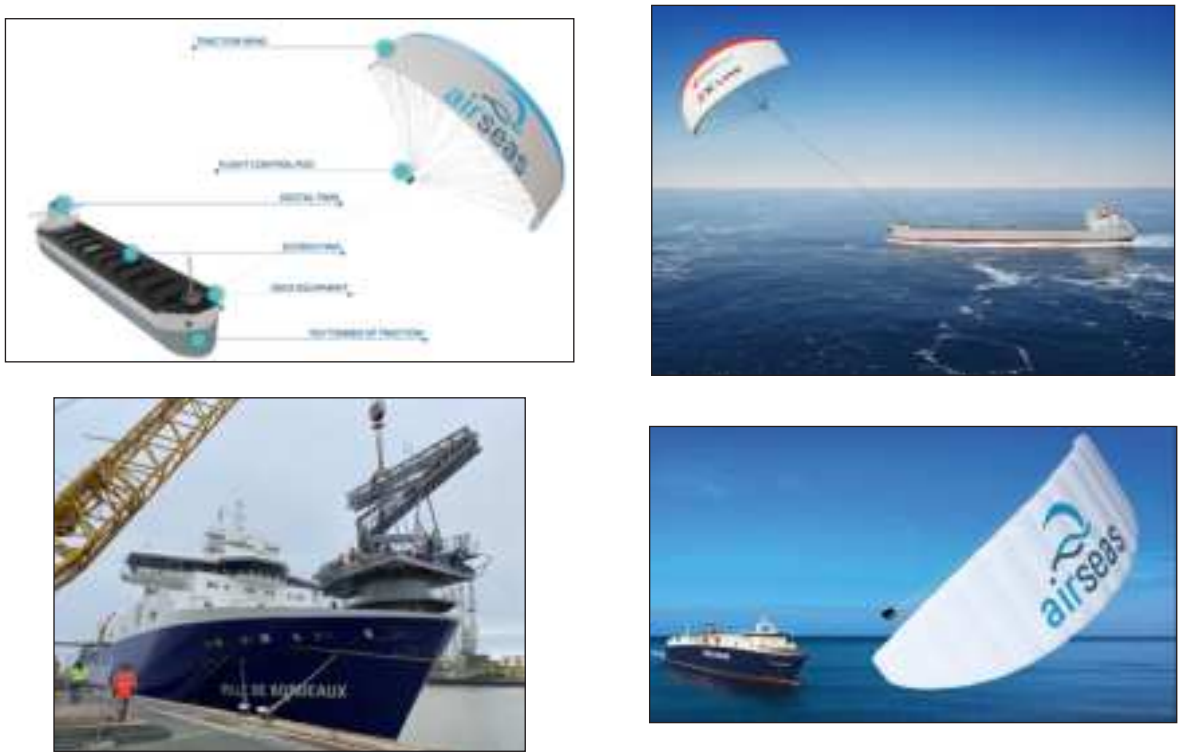


Figure. 18: Airseas "Seawing" Kite (Source: Airseas)

headings where the kite would generate negative thrust and producing effective thrust on off-wind headings. Once deployed, the kite is flown in fast **figure-8** trajectories at speeds above about 100 km/h (≈28 m/s), which can yield traction power around four times that available near sea level **(see Figure. 17 & Figure. 18).** An automated control

system interfaces with the ship's navigation to adjust kite path, power level and routing for fuel savings without affecting ETA. Kites have a small deck footprint and can be retrofitted relatively quickly without drydock; however, reliable launch and recovery in varying weather and sensitivity to heading remain key challenges, so full-scale commercial deployment on ocean-going vessels still appears several years away.

Anticlockwise from Top Left: a. Seawing Graphics, b. Seawing Installation on Ville de Bordeaux, c. Seawing kite in operation on Ville de Bordeaux, d. Seawing kite in operation on Cape Brolg

Conclusion

- Wind assisted ship propulsion has moved from experimental niche to practical decarbonisation option. This review shows that many WASP technologies are now available, from rotor sails to semi-rigid & rigid wingsails, multi-element wingsails to suction-sails and jet-sails and parafoil kites, all aiming to reduce fuel consumption and greenhouse gas emissions while maintaining schedules.
- Operational experience indicates typical average savings of about 5 to 20 per cent per voyage, with higher peaks in favourable conditions. Rotor-sails and suction-sails currently lead in installed base and commercial maturity; rigid and multi element wing sails deliver high lift and promising savings on suitable routes; kites offer a compact solution where deck space is constrained, or deeper reductions are targeted.
- Economics remain the main barrier, but rising fuel and carbon costs, together with measures such as EEXI, CII, EU ETS and FuelEU Maritime, are strengthening the business case. In combination with alternative fuels, intelligent weather-routing and other efficiency measures, WASP can become a mainstream feature of the global fleet and make a visible contribution towards the IMO net zero ambition.

References

[1] IWSA- https://www.wind-ship.org
[2] Wind propulsion in 2025: charting the course toward IMO's net-zero ambition and projected uptake to 2030 and 2050 (https://caponnetto-hueber.com)
[3] Helle J (2025) IMO needs more wind in the sails of its climate plans. Carbon Market Watch, Brussels. (https://carbonmarketwatch.org)
[4] Englert D, Ruta M, Rocha M (2023) A new climate deal for shipping: three decades to zero. World Bank Blogs. (https://blogs.worldbank.org/en/transport)
[5] International Maritime Organization (2021) MEPC.1/Circ.896: Guidance on treatment of innovative energy efficiency technologies in EEDI and EEXI. (https://www.imo.org)
[6] European Union (2023) FuelEU Maritime Regulation (EU) 2023/1805 on the use of renewable and low carbon fuels in maritime transport. Off J Eur Union L234. (https://eur-lex.europa.eu)
[7] European Maritime Safety Agency (EMSA), *Potential of Wind-Assisted Propulsion for Shipping*. Lisbon: EMSA, 2023.
[8] International Windship Association (IWSA), *Wind Propulsion: Zero-Emissions Energy Solution for Shipping (White paper on wind propulsion)*, MEPC 81/INF.39, International Maritime Organization, London, 2024.
[9] https://www.mol.co.jp/en
[10] https://www.norsepower.com
[11] https://www.seatrade-maritime.com
[12] https://skysails-marine.com
[13] https://bound4blue.com
[14] https://gcaptain.com
[15] https://airseas.com
[16] https://maritime-executive.com
[17] https://www.offshore-energy.biz
[18] https://www.tankeroperator.com
[19] https://newatlas.com
[20] https://www.oceanwings.com
[21] https://www.theoceanbird.com
[22] https://www.vaisala.com

About the Author

Shishir Dutt is a senior maritime professional with over two decades of experience spanning seagoing service, maritime education and research and development. A former Chief Engineer with experience on container ships, bulk carriers, VLGCs and LNG tankers, he later transitioned to academia as Associate Professor at Tolani Maritime Institute, leading large-scale internship and training programs. He has served as General Manager – R&D at Synergy Maritime and now works as an independent consultant. An Extra First Class Engineer with an MBA in Shipping and Logistics, he is pursuing a PhD focused on AI/ML applications in shipboard bilge management.

Email: shishirdutt@gmail.com

D-I
INDUSTRIAL CO., LTD.

INCREDIBLE DEPENDABILITY IN THE MIGHTY WATERS

Every marine vessel deserves firm systems at sea.

In marine operations, reliability is never optional.
Every wave tests your equipment. Every task
demands tougher, better, and more precise systems.
That's why the marine world trusts D-I Industrial.

MARINE TRANSMISSIONS

High-Torque, Heavy &
countinous-duty propulsion
built for 75HP ~ 1600HP

POWER TAKE-OFF SYSTEMS

Reliable auxiliary power from
120HP to **1000HP**

SIDE THRUSTERS

Proven maneuvering control
Thrust **300~1500 kgf**

STEERING SYSTEMS

Precision hydraulic steering
Manual: 91~357 Kgf.m
Power: 128~3500 Kgf.m

WATERMAKERS

Advanced freshwater systems
Designed for continuous
onboard supply 4.3 ton per day
(180L per hours)

From tugboats and trawlers to tankers and workboats our solutions are designed to perform under high turbulence.

D-I Industrial. Challenge toward the Best Sailing

13, 1367 beongil, Namgangro,
Jinju-si, Gyeongnam, South Korea

www.d-i.co.kr
+82-55-760-5520

Overseas Sales: dicl@d-i.co.kr
Warranty Service: cs.dicl@d-i.co.kr

Pitfalls in Shipbuilding Contracts – Part 2

Specifications vs Contracts: The Hidden Fault Lines

Narayana Prakash

Introduction

Shipbuilding contracts are among the most complex commercial documents in global industry. They unite heavy capital investment, technical intricacy, and cross-border legal risk into a single framework that must remain valid over several years of construction. Each clause becomes a bridge between the aspirations of owners, the capabilities of shipyards, and the expectations of financiers. A single gap in drafting can trigger multimillion-dollar disputes that ripple across engineering, cash flow, and delivery schedules.

This second article in the three-part series **"Pitfalls in Shipbuilding Contracts"** explores how contract architecture, risk allocation, and early-stage documentation define success or failure long before a vessel takes shape. By dissecting common contractual models and pre-signing missteps, it offers a practical guide for both lawyers and shipyard professionals seeking to prevent disputes rather than litigate them.

1. Learning Objective

The article aims to help marine engineers, site teams, and contract professionals understand:

- The relationship between the **shipbuilding contract** and the **technical specification**
- Why misalignment between the two creates recurring disputes
- How tribunals interpret inconsistencies
- Practical strategies to draft, manage, and control these documents effectively

2. The Two Pillars of Shipbuilding Documentation

A. The Contract – The Legal Framework

- Defines **commercial terms**: price, payment, risk allocation, delivery, and remedies
- Written by **lawyers and commercial managers**
- Focuses on *enforceability, liability, and risk transfer*

B. The Technical Specification – The Engineering Blueprint

- Defines **design, machinery, systems, and performance**
- Prepared by **naval architects and engineers**
- Focuses on *functionality, performance, and compliance*

> *"Every ship begins twice — first on paper and later in steel*

The Problem:

When these documents evolve separately, contradictions arise. The contract is legalistic; the specification is descriptive. If they diverge, ambiguity turns into arbitration.

3. Legal Nature of the Technical Specification

Once annexed to the contract, the **specification becomes legally binding**.

- It is **not a reference document**—it forms part of the contractual obligation.
- Courts and tribunals enforce its contents **unless explicitly excluded.**

Case Reference

- *Korean Shipyard v Greek Owner (EWCA)* – specification clauses expanded builder's liability once incorporated.
- *Lesson:* Engineers' words can carry the same legal force as contractual clauses.

4. Key Legal Distinction: "Shall" vs "Designed For"

Wording	Legal Meaning	Risk Outcome
"Shall achieve 15 knots"	Binding **warranty**	Yard liable for underperformance
"Designed for 15 knots"	Descriptive **aspiration**	No LD or rejection right

Practical Tip:

Avoid ambiguity by linking performance metrics to **defined tests** and **specific remedies** (e.g., LD per tenth knot deficit).

5. Common Fault Lines in Contract–Specification Alignment

A. Ambiguous Language

- Terms like *"good marine practice"* or *"reputable maker"* lack measurable meaning.
- Tribunals interpret them using "commercial reasonableness," leading to unpredictable results.

Best Practice:

Use objective standards – e.g., "ISO-certified manufacturer," "IACS-approved design."

B. Performance Guarantees and Sea Trials

- Frequent disputes over **speed**, **fuel consumption**, and **deadweight**.
- Differences between contract and specification create "dual readings."
- Testing procedures, weather conditions, and correction factors must be defined.

Lessons Learned:

- Clarify whether figures are **design targets** or **guarantees**.
- Specify **test methods** and **exclusive remedies** (rectification or LDs).

C. Regulatory and Classification Changes

- Contracts often last 2–3 years; IMO and class rules may change mid-project.
- If the specification states "latest applicable rules," the builder absorbs extra cost.

Regional Practices:

- **SAJ Form (Japan):** owner bears cost of new rules.
- **Korean forms:** shared responsibility.
- **NEWBUILDCON (BIMCO):** freezes rules at contract signing.

Best Practice:

Freeze applicable rule editions or add a **"Regulatory Change Procedure"** detailing notice, cost/time adjustments, and termination rights.

D. Scope of Supply Conflicts

- The specification lists optional systems; the contract price is fixed.
- Owners assume "included"; yards claim, "extra work."

Example:

Unclear references to scrubbers, BWTS, or LNG-fuel modules → unpriced obligations.

> *Ambiguity does not dilute liability — it multiplies it across the project*

Best Practice:

Include an **Inclusion/Exclusion Matrix** cross-referenced to the price schedule.

E. Hierarchy of Documents

- Absence of a **precedence clause** leads to interpretive disputes.
- Courts under English law usually prioritise the contract body.

Best Practice Clause Example:

"In the event of inconsistency, the order of precedence shall be:

(1) Contract Body

(2) Specification

(3) Drawings and Plans."

This single clause prevents conflicting interpretations.

6. Lessons from Arbitration and Case Studies

Case	Issue	Outcome	Key Lesson
Indian Owner vs Korean Shipyard (LMAA 2015)	Vibration level claimed as defect	Spec ambiguous – yard won	Define quantitative criteria for performance
European Owner vs Chinese Yard (ICC 2019)	Extra safety systems due to rule change	Treated as owner's variation	Define "Regulatory Change Event" clearly
Chinese Shipyard vs Investment Co. (EWCA 2021)	Refund guarantee enforcement	Upheld as independent	Keep refund guarantee wording unconditional

7. Why Misalignment Persists

Root Causes

- **Dual authorship:** Lawyers and engineers work in silos.
- **Scope creep:** Class or owner-driven revisions not reflected in contract.
- **Language gaps:** Poor translations alter intent ("shall" → "should").
- **Time pressure:** Commercial urgency sacrifices cross-verification.

Summary Box:

- 90% of recurring disputes stem from lack of integrated review before signing.
- Each contract should undergo a joint legal–technical audit prior to execution.

8. How Tribunals Interpret Contract–Spec Conflicts

Arbitral and judicial reasoning usually follows three doctrines:

1. **Contra Proferentem** – Ambiguity interpreted against drafter (often the builder).
2. **Business Common Sense** – Preference for commercially rational outcomes.
3. **Hierarchy Principle** – Main contract prevails unless otherwise stated.

Implication:

Clarity protects both parties. Tribunals will not "fill in the blanks" for sloppy drafting.

9. Practical Integration Tools

1. Joint Legal–Technical Review

- Convene cross-functional workshops before signing.

> *Ambiguous terminology like good marine practice lacks objective legal meaning*

- Ensure engineers understand legal implications; lawyers confirm technical feasibility.

2. Document Control System

- Use a master-controlled specification with revision tracking.
- Avoid multiple "working versions" circulated via email.

3. Structured Change-Order Workflow

- Define authority levels and sign-off sequence (technical → contract → commercial).
- Document all site-level changes formally.

4. Site Team Training

- Educate engineers on contract boundaries and communication discipline.
- Prevent "informal instructions" from becoming binding commitments.

Training Note:

Provide site teams with a one-page "Do's and Don'ts" card listing:

- Authorised signatories
- Change-order channels
- Rules for variation documentation
- Protocol for trial acceptance and signing "under protest"

10. Integration of Digital and Regulatory Agility

- Use digital platforms linking **3D design data** to **contract clauses**.
- Track rule editions, approval dates, and revision logs automatically.
- Enable version history for all specification changes.

Example:

If MARPOL or IMO code updates occur, the system flags affected clauses for cost/time impact review.

Result:

- Reduced human error
- Transparent audit trail
- Evidence protection in case of arbitration

11. Collaborative Contracting Mindset

Traditional shipbuilding relationships have been adversarial—owners vs. yards, lawyers vs. engineers.

A modern approach treats contracts as **living documents** and disputes as **shared problems**.

Collaborative Practices Include:

- Joint risk registers and review meetings
- Open communication between site teams
- Regular specification–contract alignment audits
- Early resolution panels before escalation to arbitration

Quote for Reflection:

"A well-drafted contract is not a weapon—it is a life jacket that keeps both parties afloat when the seas turn rough."

12. Checklists for Drafting Clarity

Before Signing:

- Confirm hierarchy of documents
- Freeze regulatory editions
- Define guarantees vs design criteria
- Include change-order procedure
- Verify refund guarantee language
- Align schedule, spec, and price structure
- Review translations and units

During Construction:

- Keep revision log for all drawings/specs
- Issue formal change orders only through authorised channels
- Record all site instructions in writing

- Cross-check class comments with contractual obligations

After Delivery:

- Document warranty claims formally
- Maintain defect log linked to contract article references
- Clarify whether issue is "defect" or "performance shortfall"

13. Standard Forms: Comparative Insights

SAJ Form

- **Strength:** Familiarity and wide adoption in Asia
- **Weakness:** Builder-friendly; lacks strong hierarchy and refund clarity
- **Recommendation:** Amend to specify hierarchy and rule-freeze clauses

NEWBUILDCON (BIMCO)

- **Strength:** Balanced drafting, detailed variation mechanism
- **Best Practice:** Use Annex A (specification) as the "living document"
- **Caution:** Customise to match local legal environment

Local Yard Forms (China, Korea)

- Often contain **home jurisdiction bias**
- Always review **governing law and arbitration clause** before technical negotiation

14. Summary Box – Persistent Lessons

Observation	Lesson Learned
Most disputes are preventable	Integrate legal and technical reviews early
Ambiguity breeds litigation	Use measurable standards and dated references
Hierarchy clause absent	Adds months to arbitration
Poor change control	Leads to unpriced variations
Site team untrained	Creates contractual exposure

15. Conclusion – Aligning Law and Engineering

The relationship between contract and specification is the central tension in shipbuilding.

When these documents align, a shipyard can manage risk, meet schedules, and preserve profitability. When they diverge, even a world-class design office cannot rescue the project.

Core Takeaways:

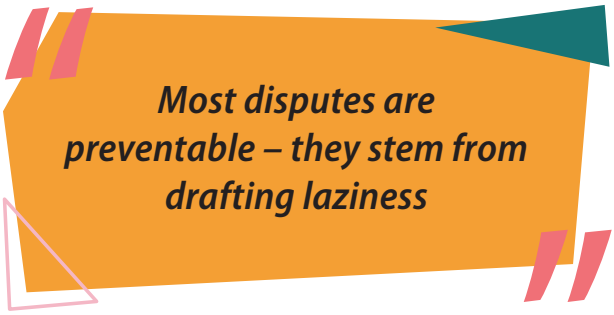
- Treat specifications as **legally binding instruments**, not engineering notes.
- Remove ambiguity: quantify, date, and define.
- Institutionalise **joint drafting** between lawyers and engineers.
- Train site teams to understand the contractual framework they operate within.
- Adopt **digital traceability** to manage specification revisions.

Ultimately, shipbuilding contracts succeed not through perfect clauses but through disciplined communication and mutual understanding. The ship's keel may rest on blocks of steel, but the project's stability rests on the alignment between law and engineering.

Clarity, once embedded, becomes the shipyard's strongest form of insurance.

Abbreviations

- BIMCO – Baltic and International Maritime Council: an international shipping association that publishes standard contract forms, including NEWBUILDCON.
- EWCA Civ – England and Wales Court of Appeal (Civil Division): used in neutral citations; e.g., [2002] EWCA Civ 1147, where "1147" is the sequential judgment number for that year. (Civ denotes the Civil Division, as opposed to Crim for the Criminal Division).
- FM – Force Majeure: a contractual clause excusing parties from liability for non-performance due to extraordinary events beyond their control (e.g., natural disasters, war, pandemics).
- HKIAC – Hong Kong International Arbitration Centre: an arbitration institution for resolving commercial and maritime disputes in the Asia-Pacific region.
- IMO – International Maritime Organization: a UN specialised agency responsible for regulating international shipping.
- LD – Liquidated Damages: a pre-agreed sum payable for failure to perform contractual obligations, typically delayed delivery of a vessel.
- LDs – Liquidated Damages (plural): commonly used shorthand for multiple claims or cumulative sums under LD clauses.
- LMAA – London Maritime Arbitrators Association: a London-based body providing arbitration services



for maritime disputes, including shipbuilding and charterparty contracts.

- MARPOL – International Convention for the Prevention of Pollution from Ships: an IMO convention addressing ship-sourced pollution, including oil, chemicals, sewage, and garbage.
- NEWBUILDCON – Newbuilding Contract: a BIMCO standard form used for shipbuilding contracts, covering delivery, payment, warranties, and dispute resolution.
- SAJ Form – Shipbuilders' Association of Japan Standard Form Shipbuilding Contract: a widely used standard form contract in Asia, especially for Japanese and Korean shipyards.
- SIAC – Singapore International Arbitration Centre: a Singapore-based arbitration institution for international commercial disputes, widely used in shipbuilding contracts.
- SOLAS – International Convention for the Safety of Life at Sea: an IMO convention establishing minimum standards for ship construction, equipment, and operation to ensure safety at sea.
- URDG 758 – Uniform Rules for Demand Guarantees, ICC Publication No. 758 (2010): internationally recognised rules governing demand guarantees and counter-guarantees, often applied to refund guarantees in shipbuilding contracts.

References

[1] BIMCO (2007) NEWBUILDCON Standard Newbuilding Contract. Copenhagen: BIMCO.
[2] Indian owner vs. Korean Shipyard (2015) LMAA Arbitration Award (unpublished, anonymized).
[3] ICC Arbitration Award (2019), Dispute between European Owner and Chinese Shipyard (unpublished).
[4] London Maritime Arbitrators Association "Bulk Carrier Delay Case", LMAA Award (anonymised, unpublished).
[5] Shipbuilders' Association of Japan (1999) Standard Shipbuilding Contract (SAJ Form), Tokyo: SAJ.
[6] Chinese shipyard v. investment company [2021] EWCA Civ 1147.
[7] European shipyard vs. Danish owner [2009] EWCA Civ 75.
[8] International Chamber of Commerce (2010) URDG 758: Uniform Rules for Demand Guarantees. Paris: ICC
[9] Law of Shipbuilding Contract by Simon Curtis

About the Author

Narayana Prakash is a shipbuilding consultant who advises a wide range of shipowners, with a particular emphasis on micro-level details to optimise shipbuilding contracts. With over 17 years of professional experience in shipbuilding, contract review, and arbitration proceedings, he has cultivated extensive expertise and a comprehensive understanding of shipbuilding contracts from both operational and legal perspectives.

Email: prakasini18@gmail.com

Historical Pursuit of the Elusive Magnetohydrodynamic (MHD) Marine Propulsion System – (Part 1)

Saptarshi Basu
Bhaskar M. Bhandarkar
Vipul Mohan Sethi
B.K. Singh

Abstract

Magnetohydrodynamic (MHD) propulsion has remained one of the most intriguing technological pursuits in marine engineering, offering the prospect of silent, vibration-free thrust generation using electromagnetic forces applied directly to seawater. This article provides a comprehensive and integrative historical narrative of MHD propulsion from early theory in the 1960s to the landmark Japanese experimental ship *Yamato-1*, and examines the parallel tracks of American, Soviet, and Russian research in both marine and plasma-based propulsion domains.

Emphasis is placed on the underlying physics of Lorentz-force-based propulsion, the engineering architecture of experimental thrusters, cryogenic systems, thrust modelling, hydrodynamic integration, and the broader strategic motivations—especially acoustic stealth and mechanical simplicity. The Japanese *Yamato-1* remains the only full-scale superconducting MHD vessel demonstrated at sea, and its successes and limitations provide invaluable insights into the challenges of scaling MHD systems for practical use. These include low seawater conductivity, Joule heating, complex cryogenic requirements, and high-power demands. Parallel Russian magnetoplasmadynamic research provides further context for potential cross-domain knowledge transfer.

Drawing together technical, historical, operational, and strategic dimensions, this article evaluates the contemporary viability of MHD propulsion, identifies barriers to commercialisation, and outlines forward-looking research priorities based on advances in high-temperature superconductors, hybrid systems, and nuclear power technologies. Despite the current practical constraints, the scientific clarity and historical persistence of MHD research signal long-term relevance for specialised future vessel types.

> *MHD propulsion promises silent thrust where physics, seawater and superconductors intersect*

1. Introduction

The search for alternative propulsion systems capable of eliminating mechanical vibrations, reducing noise, and enhancing long-term reliability has shaped several of the most ambitious engineering initiatives of the twentieth century. Among these, magnetohydrodynamic (MHD) propulsion stands out because it offers a fundamentally different means of generating thrust. By applying electromagnetic forces directly to

seawater, MHD propulsion bypasses propellers, shafts, bearings, and other rotating machinery, instead accelerating conductive fluid through sealed ducts embedded within the vessel structure. This theoretically allows propulsion that is nearly silent, mechanically simple, and exceptionally smooth in operation.

The appeal of MHD propulsion is especially strong in naval contexts, where acoustic stealth directly influences survivability. Conventional screw propellers generate broadband noise through blade passage, vibration, and cavitation. Although modern propeller designs have reduced noise signatures significantly, they remain detectable. MHD propulsion, by contrast, can eliminate cavitation entirely at low to moderate speeds and produces only the hydrodynamic noise of moving fluid. For strategic submarines or research vessels performing sensitive marine measurements, such acoustic benefits represent a substantial motivation for continued research.

Public imagination encountered MHD propulsion most famously through the 1990 film *The Hunt for Red October*, which portrayed a fictional Soviet submarine equipped with a "caterpillar drive." The film depicted a propulsion system so quiet that it rendered the submarine nearly undetectable. This fictional portrayal coincided with real developments: as the movie was released, Japan was completing the construction of *Yamato-1*, which would become the world's first and only operational superconducting MHD ship. The juxtaposition of fiction and engineering reality highlighted both the imaginative allure and the practical difficulty of making MHD propulsion viable.

The scientific principle underpinning MHD propulsion is the Lorentz force. When an electric current passes through a conductive fluid under the influence of a magnetic field, a perpendicular force is generated. The reaction to the accelerated fluid provides propulsive thrust. Although the physics are straightforward, the engineering execution is complex. Strong magnetic fields are required, typically achieved through superconducting magnets that demand cryogenic cooling systems. Seawater, while conductive, is orders of magnitude less conductive than metallic fluids used in terrestrial MHD generators, meaning that large currents must be applied to achieve measurable thrust.

Despite these challenges, MHD propulsion continues to receive intermittent bursts of research interest as materials science advances. The history of this pursuit—its experiments, disappointments, breakthroughs, and lessons—forms the central narrative of this article. By examining the development trajectory from the 1960s to the present, we can understand why MHD propulsion has proven so difficult to implement, what has been learned, and what emerging technologies may yet allow a practical future for this elegant but demanding concept.

2. Principles of Magnetohydrodynamic Propulsion

2.1 Lorentz Force and its Application

MHD propulsion is rooted in classical electromagnetism. The Lorentz force equation, expresses the force exerted on a moving charge within a magnetic field. When applied to seawater, the current density **J** is established through electrodes placed on opposite sides of a duct, and the magnetic field **B** is produced by superconducting coils surrounding the thruster. The resulting force pushes seawater through the duct, generating thrust.

In marine applications, the magnetic field is typically perpendicular to both the direction of current and the intended thrust direction, forming a right-handed orthogonal system. Fleming's left-hand rule provides an intuitive way to visualize the force orientation. Because seawater contains ions (primarily sodium and chloride), it serves as a conductive medium capable of carrying electric current. However, its conductivity is relatively low—generally around 3–6 S/m—so large currents and fields are required.

2.2 Thruster Construction

A typical MHD thruster consists of:

1. **Ducts or channels** through which seawater flows.
2. **Electrodes** forming an anode and cathode pair.
3. **Superconducting magnets** creating a transverse magnetic field.
4. **Power conversion systems** delivering high DC currents.
5. **Cooling systems** maintaining magnets at cryogenic temperatures.

The duct must be constructed from electrically insulating material to prevent current leakage. In addition, flow geometry must be configured to minimize turbulence, electrolysis bubble entrapment, and boundary layer interference.

2.3 Performance Constraints

Several key challenges limit practical MHD efficiency:

- **Low seawater conductivity**, reducing thrust per unit current.
- **Electrolysis**, producing hydrogen, chlorine, and oxygen bubbles that disrupt flow.
- **Electrical losses**, especially Joule heating.
- **Magnet requirements**, as superconducting fields above 4 T are required for adequate thrust.
- **Hydrodynamic interference**, including boundary layer thickening.

Typical efficiencies demonstrated in experimental systems have been less than 10%, although small laboratory thrusters using liquid metals exhibit higher values. Seawater, however, imposes strict physical constraints that cannot be circumvented easily.

3. Early MHD Developments (1960–1980)

The theoretical foundation for MHD propulsion emerged in the early 1960s. W.A. Rice published one of the first discussions on the feasibility of using electromagnetic forces to propel vessels. Phillips (1962) and Doragh (1963) expanded on the hydrodynamic and electromagnetic interactions required. Their analyses showed that, although the basic force mechanism was sound, the low conductivity of seawater would require extremely strong magnetic fields.

The first significant experimental demonstration occurred in 1966 when S. Way at Westinghouse built the EMS-1 model submersible. Using wire-wound electromagnets, the EMS-1 achieved speeds of approximately 1.5 knots. Although the thruster suffered from efficiency limitations, it proved the fundamental concept.

In 1976, Iwata and colleagues at the Kobe University of Mercantile Marine produced the first superconducting MHD model, SEMD-1. This represented a major leap forward, as superconducting magnets could generate magnetic

> *In the quiet pulse of Lorentz forces lies tomorrow's marine stealth*

fields several times stronger than those achievable with resistive electromagnets. The follow-on ST-500 model—a 3.6-meter craft with a 2-T superconducting magnet—attained speeds of 1.2 knots in tank tests. These small-scale experiments laid the groundwork for larger demonstrators.

During this period, the United States also initiated the Argonne–Newport MHD feasibility investigations. These studies explored scaling relations, electrode performance, and the behaviour of seawater under strong magnetic fields. Argonne's large 2-Tesla loop thruster became a cornerstone testbed for model validation. One of the most significant findings was that electrolysis bubbles formed rapidly at high current densities, reducing effective conductivity and causing thrust fluctuations. These experiments foreshadowed the challenges that later full-scale systems would face.

4. Japanese Breakthrough: The YAMATO-1 Project

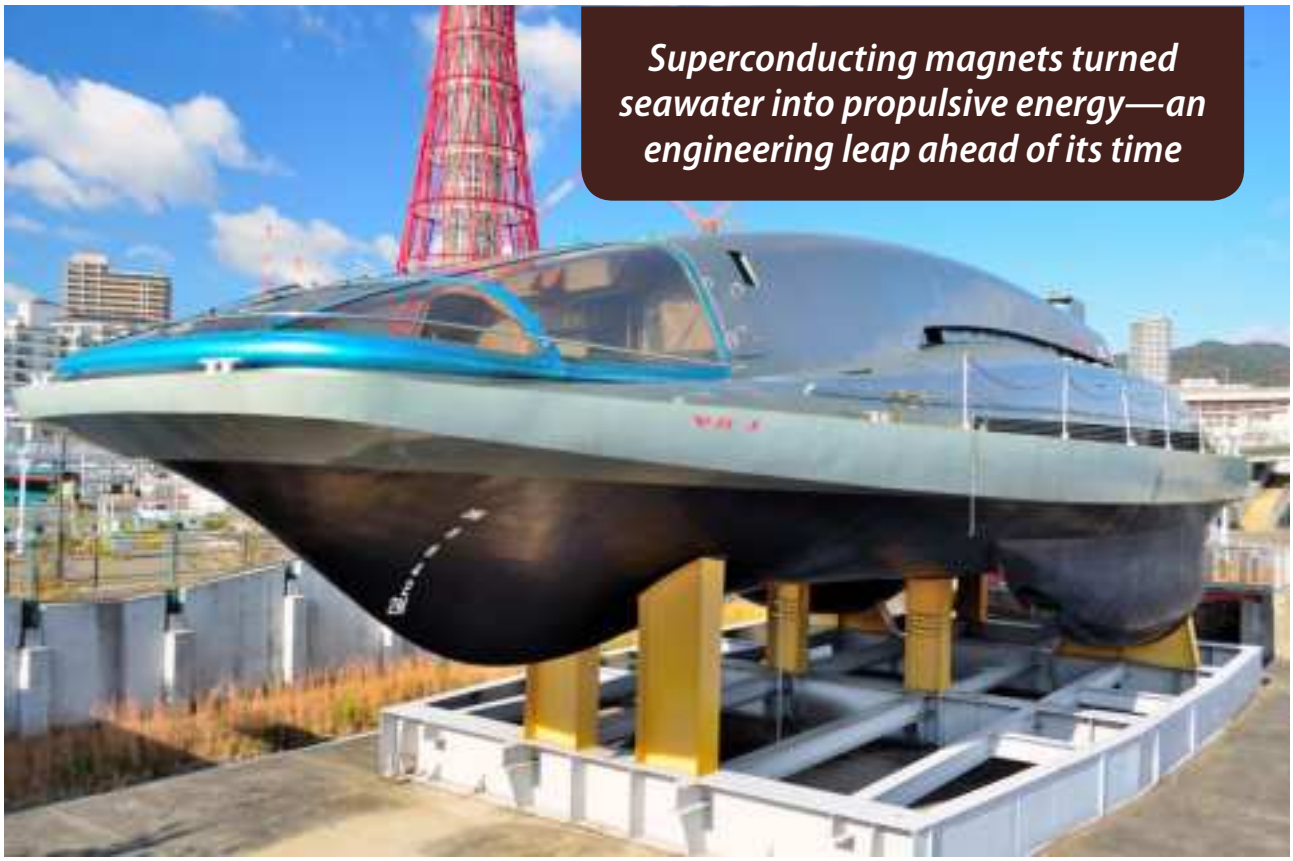
4.1 Programme Origins

In 1985, the Ship & Ocean Foundation of Japan launched the world's most ambitious MHD ship development program. Driven by a national desire to pioneer advanced marine technology, Japan invested heavily in design studies, magnet manufacturing, cryogenic engineering, and full-scale integration. The objective was clear: build a vessel that could demonstrate sustained MHD propulsion in open water.

Construction of *Yamato-1* began in 1988, and the ship was completed in late 1991. Sea trials in 1992 at Kobe harbour marked the first time a superconducting MHD propulsion system propelled a full-scale vessel.

4.2 Propulsion Architecture

Each of the two thruster units aboard *Yamato-1* contained six 10-inch parallel tubes arranged radially like rocket cluster nozzles. Superconducting magnets formed a toroidal configuration around each tube, using niobium–titanium alloy coils cooled to 4.2 K by liquid helium. These coils generated magnetic fields sufficiently strong to accelerate seawater efficiently through the ducts.



Superconducting magnets turned seawater into propulsive energy—an engineering leap ahead of its time

Electrodes supporting the current paths were constructed from titanium-niobium alloys, with dimensionally stable anode material and platinum plating used on the cathodes to resist corrosion. The thruster ducts were fabricated from glass-reinforced epoxy to ensure electrical insulation.

Two onboard AC generators fed DC power conditioning panels that supplied current to each electrode pair. Reversing current polarity enabled astern thrust without mechanical intervention. A bucket-type deflector provided additional manoeuvring capability for low-speed operations.

4.3 Cryogenic Engineering

One of the most complex aspects of *Yamato-1* was its cryogenic system. Because the vessel did not carry the equipment required for initial cool-down, the magnets were precooled ashore before being transferred to the vessel. Once aboard, gaseous helium maintained the coils at operating temperature.

Strict thermal gradient control was necessary to prevent structural damage. The maximum allowable temperature differential was limited to 40 K between inner and outer cryostat structures. Sensors continuously monitored these values, and cooling proceeded gradually from ambient temperature to approximately 20 K, at which point liquid helium was introduced. The magnetization process involved heating and cooling a persistent current switch to establish a closed superconducting loop.

4.4 Thruster Modelling and Thrust Measurements

Thrust measurement relied on a combination of Bernoulli's equation and duct flow analysis. Because seawater flow interacted with both internal pressure fields and external hull dynamics, precise calculations were required. The key thrust equation was:

where and are exit and inlet velocities, and and are nozzle and inlet pressures, respectively.

Experimental results indicated that thrust increased linearly with current, as expected. However, interference between ship motion and jet flow was minimal, validating the simplified modelling assumptions. Bollard pull tests revealed that static forces were sometimes greater than underway thrust due to favourable pressure distribution patterns.

4.5 Operational Outcomes

Yamato-1 ultimately reached speeds of around 8 knots during trials. This result represented a significant milestone: a functional full-scale superconducting MHD system capable of sustained operation. The ship drew worldwide attention from researchers and naval architects, confirming that MHD propulsion was technically feasible.

However, limitations emerged. Power requirements were enormous, overall efficiency remained low, and the complexity of the cryogenic system presented reliability concerns. These findings mirrored the challenges previously identified by Argonne and other researchers.

Despite these obstacles, *Yamato-1* remains a major engineering achievement and the most advanced public demonstration of MHD propulsion to date.

5. Russian and Soviet Efforts in Electromagnetic Propulsion

5.1 Keldysh Research Center

The Soviet Union had long invested in high-power electromagnetic technologies. The Keldysh Research Center, originally the Scientific Research Institute of Thermal Processes, spearheaded many of the USSR's most advanced propulsion programs, especially in magnetoplasmadynamic (MPD) thrusters for space applications.

During the 1960s and 1970s, Soviet researchers developed MPD thrusters operating at power levels up to 500 kW using lithium propellants. These demonstrated efficiencies near 60% and specific impulses around 4,000 seconds—figures far superior to seawater MHD propulsion, but achievable only with plasma exhausts.

5.2 Marine Application Exploration

Although much Soviet work was oriented toward spacecraft, there are indications that MHD marine propulsion was explored theoretically. Soviet research into high-temperature superconductors, liquid-metal cooled reactors, and large MHD generators suggests competence in the key technologies required for seawater MHD propulsion.

Western analysts speculated that the distinctive pod on Soviet Victor III-class submarines might house an MHD thruster, but later events confirmed that the pod contained a towed sonar array, not a propulsion device. This episode nonetheless demonstrated the persistent perception that the USSR might pursue such technologies.

5.3 Contemporary Russian Research

Modern Russian efforts continue to focus on advanced electric propulsion, including Hall effect thrusters and megawatt-class nuclear electric propulsion systems. Some of these programs explore MHD energy conversion concepts, potentially informing future maritime applications if high-temperature superconductors become practical.

6. Technical Challenges and Thrust Efficiency Limits

6.1 Seawater Conductivity

The most fundamental barrier to efficient MHD propulsion is seawater's low conductivity. Unlike liquid metals used in terrestrial MHD generators, seawater's ionic mobility is limited. As a result, very large currents are required to produce meaningful Lorentz forces, which leads to increased Joule heating and electrolysis effects.

6.2 Electrolysis and Gas Bubble Formation

Electrolysis produces hydrogen, oxygen, and chlorine gases, forming bubbles that significantly reduce effective conductivity and disrupt flow. Bubble suppression using modified electrode designs has been attempted, but no fully effective solution has been demonstrated.

6.3 Magnetic Field Requirements

Achieving adequate thrust requires magnetic fields of at least 4 T. Only superconducting magnets can produce such fields efficiently. Niobium–titanium, the most widely used superconducting material, must be cooled to 4.2 K, creating operational complications.

High-temperature superconductors (HTS), such as YBCO, offer promise by operating at 70–77 K, but HTS coils capable of marine-scale fields remain under development.

6.4 Hydrodynamic and Thermal Considerations

Boundary layer thickening and duct losses reduce efficiency further. Joule heating increases local water temperature, changing conductivity and density locally. Managing these coupled effects makes modelling and experimentation difficult.

7. Assessment of Feasibility for Marine Deployment

7.1 Advantages

MHD propulsion offers several compelling benefits:

- **Near-silent operation**, desirable for submarines and oceanographic research.
- **Absence of moving parts**, reducing mechanical wear.
- **Simplified hull integration**, enabling new vessel design architectures.
- **Linear and precise thrust control**, ideal for dynamic positioning or station-keeping.

7.2 Disadvantages

Practical barriers remain significant:

- Low efficiency at marine scales.
- Heavy and expensive superconducting systems.
- Cryogenic cooling demands.
- Large power requirements, often in megawatt ranges.
- Environmental concerns related to chlorine generation from electrolysis.

7.3 Suitable Applications

Given current constraints, MHD propulsion is best suited for:

- **Nuclear-powered submarines** requiring stealth over efficiency.

- **Oceanographic research vessels** that benefit from silent manoeuvring.
- **Specialised military platforms** where acoustic signature is critical.
- **Auxiliary thrusters** augmenting conventional systems.

8. Future Directions and Research Pathways

8.1 High-Temperature Superconductors

Rapid advancements in HTS materials could dramatically improve feasibility. HTS magnets operating at liquid-nitrogen temperatures offer:

- Reduced cooling complexity.
- Lower system weight.
- Higher achievable magnetic fields.

If HTS coils can be manufactured at scale, large MHD thrusters may become practical.

8.2 Hybrid Propulsion Systems

Combining MHD thrusters with traditional propulsion may allow:

- Silent low-speed manoeuvring.
- Enhanced dynamic positioning.
- Reduced acoustic signatures during surveillance missions.

8.3 Nuclear Electric Power Systems

Nuclear reactors provide continuous megawatt-scale electricity, making them ideal for powering MHD systems. Future nuclear-electric ships may incorporate MHD propulsion for silent operation phases.

8.4 Electrically Conductive Seawater Modification

Although adding electrolytes to seawater is not feasible environmentally, techniques such as:

- Enhanced electrode geometries,
- Microbubble control strategies, and
- Magnetic field shaping,

may improve effective conductivity locally within the thruster.

8.5 AI-Enhanced CFD and Multiphysics Modelling

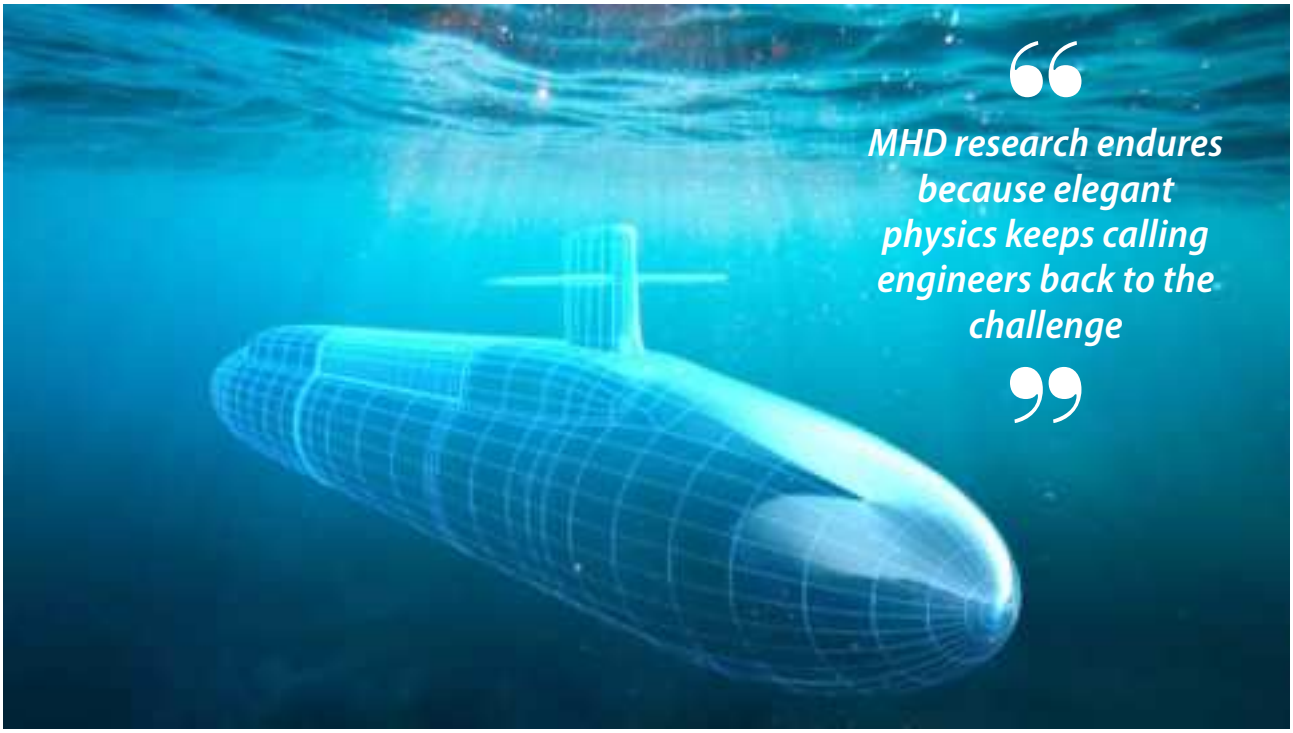
Emerging computational tools enable simulation of complex interactions between:

- Electromagnetics,
- Fluid flow,
- Heat transfer, and
- Bubble dynamics.

These tools may allow optimisation of geometries previously considered impractical.

9. Conclusion

The historical pursuit of MHD propulsion reveals a technology grounded in sound physical principles but constrained by materials science and practical engineering limitations. From early theoretical analyses in the 1960s to the construction and successful sea trials of *Yamato-1*, researchers have repeatedly demonstrated that MHD



propulsion is feasible, but difficult to scale efficiently for general marine use.

Japan's *Yamato-1* provided crucial validation: a full-scale vessel propelled entirely by superconducting MHD thrusters in open water. Despite this achievement, efficiency limitations, cryogenic challenges, and high power requirements prevented commercialisation. Russian and Soviet research contributed valuable insights through parallel development of MPD thrusters and advanced superconducting technologies, though no operational marine systems emerged.

Looking forward, breakthroughs in high-temperature superconductors, nuclear electric propulsion, and hybrid architectures may eventually revive practical interest. MHD propulsion may not replace propellers for commercial shipping, but it remains a promising candidate for highly specialised vessels requiring extreme stealth, minimal vibration, or silent low-speed operation.

Overall, MHD propulsion stands as a testament to the intersection of elegant physics and challenging engineering. Its historical trajectory highlights the perseverance of researchers across nations and decades, and emerging technologies suggest that its future may yet hold new possibilities for advanced marine propulsion.

References

1. Hartmann, J., Lazarus, F. *Studies on Hartmann Flow*. Publication details not available.
2. Sasakawa, Y., Takezawa, S., Sugawara, Y., Kyotani, Y. *The Superconducting MHD-Propelled Ship YAMATO-I*. Technical monograph.
3. Moesner, F.M., Bühler, P.S., Politano, D.C., Prati, P.V. *Electrohydrodynamic Propulsion for Miniature Ships*. ETH Zürich Technical Report.
4. Vasiliyev, L.G., Khozainov. *Magnetohydrodynamics in Marine Engineering*. Publication details not available.
5. Doragh, R.A., 1963. *Theoretical Feasibility of MHD Propulsion*. Journal details not available.
6. Iwata, K., et al., 1976. *Superconducting MHD Model SEMD-1: Experimental Results*. Publication details not available.
7. Phillips, O.M., 1962. *Feasibility of Magnetohydrodynamic Propulsion in Conducting Fluids*. Journal details not available.
8. Rice, W.A., 1961. *Conceptual Foundations of Marine MHD Propulsion*. Publication details not available.
9. Way, S., 1966. *Experimental Investigation of the EMS-1 MHD Submersible*. Westinghouse Electric Report.
10. Argonne National Laboratory & Newport News Shipbuilding. *U.S. Feasibility Study on Marine MHD Propulsion*. Technical Report.
11. Japan Ship & Ocean Foundation, 1992. *Technical Documentation of the YAMATO-1 Propulsion System*. Internal Report.
12. Keldysh Research Center. *Reports on MPD and Electromagnetic Propulsion Development*. Publication details not available.

About the Authors

Dr. Saptarshi Basu is a Marine engineer and former Chief Engineer with 25 years' sailing experience. Served in technical superintendent and QHSE leadership roles and taught at IMU and maritime institutes. Award-winning technical author and frequent IMEI speaker on advanced marine engineering topics.

Email: tigermariner@gmail.com

Capt. Dr. Bhaskar M. Bhandarkar a Former MRDB Chairman and IMEI Vice President. Served on INS Chakra, participated in IPKF operations, and led the Kursura Submarine Museum project. Award-winning academic, author and international industrial engineering fellow with extensive naval, managerial, and research credentials.

Email: bhandarkar.marine@gmail.com

Vipul Mohan Sethi is a Marine consultant and former Chief Engineer with expertise in vessel inspections, audits, offshore fleet management and newbuilding supervision. Held senior roles at Samson Maritime, Adani Shipping and Essar Shipping. Certified ISM/ISPS/MLC auditor and experienced technical assessor.

Dr. B.K. Singh, a Marine engineer with 29+ years' experience in ship operations, technical management, dry-dock supervision, and marine consultancy. Served with SCI, MSC, Eurasia, and Rolv Berg Drive. Currently Director at Caspia Ship Management and a Fellow of the Institute of Marine Engineers.

THE INSTITUTE OF MARINE ENGINEERS (INDIA), GOA

IMEI House, House No.11, Plot No.- D-27, Ranghavi Estate, Post Office, Dabolim, Goa 403 801
Tel: 0832- 2538500, Mobile: 9923102071, E-mail: trainninggoa@imare.com

DG APPROVED MODULAR COURSES

Sr. No.	Course Name	Course Fee	Course Duration	Course Schedule
1	Basic Training for Oil and Chemical Tanker Cargo Operations (OCTF)	₹6,950/-	6 Days	15th January, 2026, 03rd February, 2026
2	Basic Training for Liquefied Gas Tanker Cargo Operations (LGTF)	₹6,950/-	5 Days	08th January, 2026, 17th February, 2026
3	Basic Training for Ships using Fuels covered within IGF Code (IGFB)	₹12,550/-	5 Days	27th January, 2026, 16th February, 2026
4	Security Training for Seafarers with Designated Security Duties (STSDSD)	₹4,050/-	2 Days	22nd January, 2026, 23rd February, 2026
5	Ship Security Officer (SSO)	₹4,950/-	3 Days	05th January, 2026, 25th February, 2026

- **Course Fee includes** lunch, two tea breaks, and one examination fee**.**
- 5% discount **on group bookings of more than 6 candidates.**
- 7% discount **on group bookings for** combo courses **(OCTF + LGTF) with more than 6 candidates.**
- *Note:* ***Course dates are subject to change.***

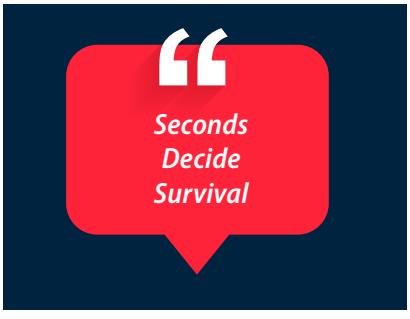
Progress in Tsunami Early Warning Technologies: Part B

Sundar Ranganathan
M Arul Muthiah
N. Vedachalam
B Ajay Kumar & R Balaji

Abstract

Tsunamis pose an ever-present threat to coastal nations bordering the Pacific, Atlantic, and Indian Oceans, as well as the Caribbean and Mediterranean seas. Since its inception in 2007, the **Indian Tsunami Early Warning System (ITEWS)** has undergone significant technological advancements. Since 2011, ITEWS has been serving as a **Tsunami Service Provider (TSP)** for the entire Indian Ocean Region, alongside Indonesia and Australia.

High on-demand reliability is a critical requirement for offshore-moored tsunami monitoring buoys, which continuously measure and transmit sea-level variations to Tsunami Early Warning Centres during tsunamigenic earthquakes. This article is presented in two parts. **Part A** discussed the fundamental principles and technologies of tsunami early warning, tsunami propagation modelling, and coastal impact assessment. **This part** focuses on the technological initiatives undertaken to improve the **Mean Time Between Failure (MTBF)** of offshore-moored buoys from **0.3 years in 2007 to 0.9 years at present**, optimisation of the offshore buoy network, demonstration of submerged tsunami buoys and hybrid satellite telemetry systems, challenges in accurate tsunami impact forecasting, and the protocols adopted for effective tsunami warning dissemination



Performance of the Indian tsunami buoy network

NIOT-developed and -operated Indian Tsunami Buoy System (ITBS) comprises four offshore nodes in the Bay of Bengal and one node in the Arabian Sea. These nodes communicate with the NIOT's Mission Control Center (MCC) at Chennai and INCOIS-Indian Tsunami Early Warning Center (ITEWC) in Hyderabad through INMARSAT telemetry link through a Land Earth Station (LES) and public networks. The data that are received at the NIOT-MCC is retransmitted to the ITEWC through VSAT and public networks. The operation and maintenance of a deep-ocean buoy network is challenging, as the system has to perform reliably in the unattended and hostile marine environment.The design architecture needs simultaneous consideration of technological maturity (reliability), availability (maintainability/quick restorability) and the demand rate on the ITBS.

The demand rate on the deep-ocean moored ITBS depends on the frequency of tsunami occurrence that could have a catastrophic impact on the Indian coastline. Based on scientific studies carried out from the confirmed tsunami events in the past 4000 years, ~9% are in the Indian Ocean region. The tsunami returns periods for magnitude 8, 8.5,9 in the Sumatra subduction zone are estimated to be 100,300 and 1000 years, respectively. Based on the stratigraphic records over 74 centuries, the average time period between dangerous Indian Ocean tsunamis is ~450 years. The results of the probabilistic reliability/ availability analysis of the ITBS network (comprising up to 4 buoys) with field-failure data (from ~1 million

offshore tsunami buoy-hours) as input is shown in the **Table.1.** Details on the methodology of computations and the actual field-failure data can be read from the references provided.

Table.1. Reliability/availability of the ITBS network

Configuration	Probability of failure	MTBF
Bay of Bengal		
1 buoy	68.3%	0.87 Years
2 buoys	54.55%	1.27 Years
3 buoys	48.59%	1.50 Years
4 buoys	46.01%	1.62 Years
Arabian Sea		
1 buoy	50.28%	1.43 Years

Availability is the prime requirement for the offshore-moored tsunami buoys, and hence early restoration of outages is essential. The availability of the tsunami buoy network comprising up to 4 buoys for a range of Mean-Time-To-Restore (MTTR) periods (computed based on their field-reported reliability **(Table.1)** are computed summarised in **Figure.1.**

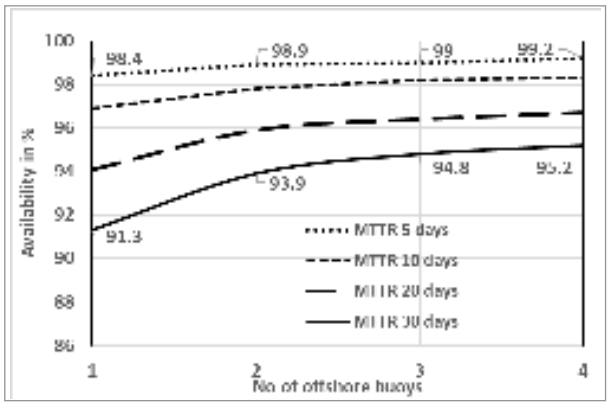


Figure.1. Availability analysis of the buoys in the Bay of Bengal

Table.2 shows the number of buoys that formed part of the Bay of Bengal (BoB) network since its inception, number of outages and MTTR. It is evident that the implemented offshore buoy network maintenance program helped to reduce the MTTR, thus ensuring maximum availability of the ITBS network over the years. Based on the identified results, the tsunami buoy maintenance program is formulated. Based on the IEC 61508 HSE standards, taking into consideration the risk consequence, alternate Safety Instrumented Function (SIF) in place, human occupancy and the demand rate for the system, the buoys are set to report its healthiness to the MCC at NIOT every 3h.

Table.2. MTTR for buoy network in Bay of Bengal

Period	No of buoys	No of outages	Mean time to restore (days)
2010-2015	10	22	6.6
2016-2020	6	13	9.6
2021-2025	4	8	7.3

> *Engineering Against Extinction*

Continuous efforts for improving offshore system reliability

In order to increase the availability of the offshore moored tsunami buoys, systematic evaluation of the failures, understanding its root cause and continous improvements to overcome the failures is being undertaken. The on-demand reliability/safety reliability analysis using numerical methods/ published failure models based on IEC 61508 HSE standards with field-reported failure-in-time data is used as an yardstick for comparing alternate technologies, continuousimprovements, and maintenance planning of the time-critical ITBS.

Based on the field-failure data (collected during 2007-2014) as inputs, probabilistic reliabilty assessment results **(Figure.2)** carried out using TOTAL_GRIF software shows the surface buoy had a failure rate of 63.8% in 1 year, in which the failure contribution of data acquistion, data transmission and position mooring were 30%, 46% and 24%, respectively. In case of data acquistion system, the failures are reduced through redundant configuration, firmware improvements, three-level software-based watchdog timer enabling reboot during prolonged handups, and two-way communication facility to restart the processor from NIOT's MCC. The reliability of the position mooring is improved by adopting stringent quality control in realising mooring components, providing adequate scope for the mooring for ensuring structural integrity during extreme sea states (cyclonic conditions) based on dynamic simulations vaidated through field data, corrosion management, following standard deployment procedures and maintenenace planning.

Based on field-failure data obtained from moored buoys that have clocked ~114 mooring-years, the present MTBF of the mooring is ~6 years, compared to an MTBF of ~1 year during 2010. In the data transmission system **(Figure.3),** during the same period, energy storage-cum-power systems (represented Evt45), and antenna mast/ sensor arm (Evt47), each contributed to 50% of the failure. The power systems were ruggesied by incorporating Lithium-Ion battery back which shall serve as a back-up for the solar-powered lead-acid battery system, and its energy capacity is sized to cater the needs until the next periodic maintenace (1 year), along with a configuration that ensures lowest failure rate (0.87% in 1 year). The failure of the solarpanel charging system and the mast antenna weremainly caused by the act of external elements (vandalism) prevailingin the deployed locations. Damage to thesolar panels led to charging failure of the lead-acidbattery, and damage to the INMARSAT mast

antenna resulted in the loss of communication between the offshore node and MCC, which needed appropriate attention.

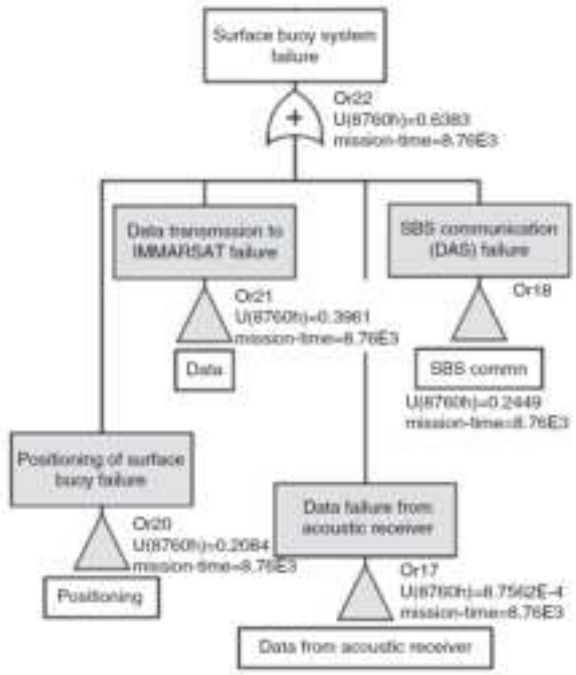


Figure.2. Factors contributing to failure of surface buoy systems

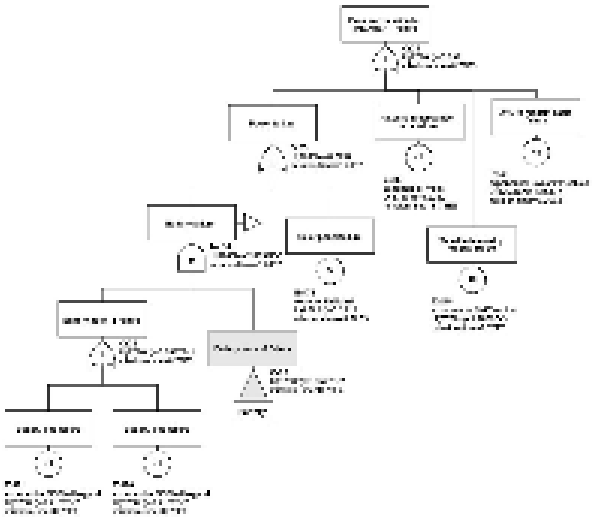


Figure.3. Factors contributing to data transmission system failure

At present efforts are underway to realise ITBS with reduced CAPEX and OPEX, without compromising on-demand reliability of the network. As buoy unavailability due to vandalism reduces the cost-benefit proposition of the buoy network, awareness camps are regularly conducted to the sea-going community,insisting the importance of moored surface buoys involved in tsunami monitoring. In addition to this, a Continuously Homing Submerged Autonomous Tsunami Underwater System **(**CHATUR) in which the buoy is submerged at a depth of 300m, collecting sea-level data during normal conditionsand surfacing during a tsunami eventto transmit the event data, is in demonstration stages. This configuration helps to prevent vandalism, and realize a cost effective and environment-friendly design compared to the presently operating moored surface buoy that are continuously exposed to sea surface environmental stresses, particularly during extreme cyclonic events.

By on-demand reliability analysis, CHATUR is found have a theoritical probability of failure of 23% and requires a health monitoring at an interval of 13days. Its failure rate is half that of the present NIOT-operated tsunami buoys in the Indian Oceanbecause of the four key advantages including, vanalism-resistance, reduced mooring hydrodynmaic loads due to lower water currents (1/5th of velocity that in the sea surface, and 25 times lesser drag-induced load), reduced maintenance requirements due to reduced biofouling in the non-photic zone, and increased life of the electronics systemsdue to enhanced heat dissipation at relatively low ambient temperature of ~15°C. Based on these encouraging results from the numerical models and field experiments conducted in the Bay of Bengal location 16°31.63`N- 87°59.85`E in 2630m water depth **(Figure.4),** efforts are underway in deploying a pilot system in the Bay of Bengal for an extended period. This shall provide inputs on the system engineering and environment-specific failure modes and improve the design over a period of time.

Figure.4. Ocean qualification of CHATUR

As an effort to optimise the tsunami buoy network satellite communication OPEX, a novel hybrid satellite telemetry system with Indian National Satellite System (INSAT) as the primary link and INMARSAT as a redundant safety link is demonstrated in a tsunami buoy operating in location Lat 06° 20'54" Long 88° 35'36". Based on

the identified on-demand reliability demands, INMARSAT telemetry link is configured to transmit the water level data during the tsunami mode and INSAT telemetry is configured for transmitting normal mode data and to maintain the on-demand reliability of the INMARSAT telemetry link **(Figure.5).** Based on this, the buoy-located INMARSAT transmitter is powered every 1hr to get the buoy geo-location, and once in every 24hrs it sends the data to ensure the overall link in Level 4 of IEC61508 HSE Safety Integrity Level 4. The successful response of the cost-effective telemetry system to a seismic event has given confidence that the demonstrated hybrid telemetry system could offer reliable support to the ITEWS.

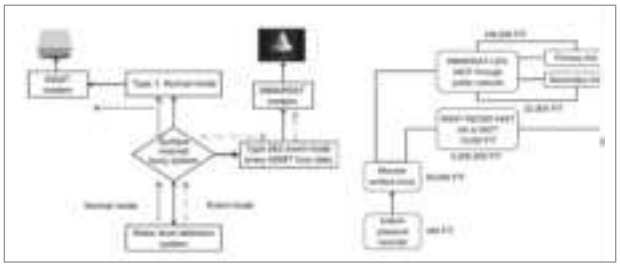


Figure.5. Implementation of hybrid telemetry system using INSAT and INMARSAT

Challengesin estimating energy in a tsunami wave

While the technologies for precisely localising the earthquake (EQ) and monitoring the changes in the water column in the deep-oceans, characterising tsunami amplitude, velocity and their travel durations are matured, quantifying the tsunami wave energy has not been much investigated. The strength of a tsunami depends on the type and characteristics of seismic energy source, where-in the energy is distributed all through the water column immediately after its generation. Tsunamis generated by shallow undersea EQ are usually stronger than submarine landslide-generated tsunamis. To calculate the tsunami wave energy, numerical tsunami modeling is performed using hydrodynamic models, where leap-frog time-differencing scheme (moving boundary) is used to solve both linear and non-linear shallow-water equations on both Cartesian and spherical coordinate systems. Analysis performed on tsunami generation potentials of Makran fault involving a width of 210km, dip angle of 7º, slip angle of 90º, dislocation of 10m, top depth of 10km,indicate 1% of the energy released in EQ transmitted to tsunami wave, which is a few 10^{15}J. Direct energy estimation of 2011 Japan Tohoku-Oki tsunami (originated from a 400 km long and 100 km wide area) using deep-ocean pressure measurements, based on the first wave recorded at the two closest tsunami buoys indicate tsunami wave energy of ~3x10^{15} J (10^{15}J= 1 Peta Joule, equals 278GWh, which is the energy in 0.2Million Tons of TNT). The interpretation of the global tsunamigenic EQ magnitude and its associated energy is shown in **Table.3.** Its relative strength in comparison to the energy in 8.1 Mw EQ is also provided to understand the significance of Mw.

Table.3. Tsunami wave energy for a range of seismic moments

Seismic moment Mw	8.1	8.7	9	9.2
Energy (J)	2 x 10^{13}	2 x 10^{14}	2 x 10^{15}	1 x 10^{16}
Effect Times 8.1 Mw EQ	-	10	100	500

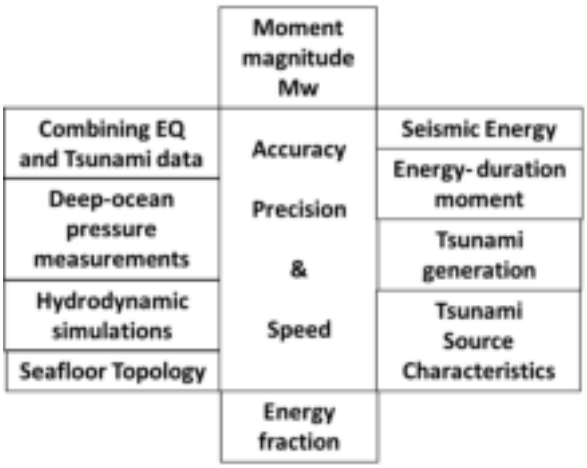


Figure.6. Factors to be considered for precise estimation of tsunami energy

Various factors involved in precisely estimating the energy in a tsunami wave is summarised **(Figure.6).** The tsunami wave energy estimation process starts right from the measurement of the magnitude of the seismic moment (Mw), which depends on the quantity of slip on a fault and fault area. Estimating the seismic energy (using methods like the E/M0 discriminant and real-time estimates of seismic moment) are done based on the below relationship, that however depends on the fault properties.

$$\log E = 5.24 + 1.44Mw$$

From the seismic energy estimated and duration, energy transferred as tsunami wave is determined, which generally varies from 0.1 to 1% of the total seismic energy. Factors such as rupture area, rupture rates, co-seismic slip, and the shape of the fault rupture influence the tsunami energy.Tsunami buoys and other instruments can measure deep-ocean pressure, which can be used to estimate tsunami energy. The seafloor topography (depth and shape of the ocean floor) plays a crucial role in how tsunami energy propagates and is affected by factors like speed and direction of the tsunami, which forms the basis of hydrodynamic simulations used to model tsunami generation and propagation.Thus, estimating tsunami energy accurately is complex and depends on the available data and the model's ability to capture the intricate details of tsunami generation and propagation, which is an area of future research.

Dissemination of tsunami warning

An effective early warning dissemination system must include not only the detection and tracking of the propagation of a tsunami wave, but also an efficient public notification system through which the population can be warned in time by the local government. According to the UN International Strategy for Disaster Reduction, among both the developed and developing nations, the weakest elements are warning dissemination and preparedness to act. In recent years, disaster management has changed from viewing a problem in isolation to a policy of sustainable hazard mitigation. Thus, an effective early warning dissemination system must be an integral part of disaster risk reduction strategies in national development frameworks and requires the cooperation of many partners at the local, regional, national, and international levels. Considering the critical importance of the warning dissemination, ITEWC has the SOP for generating and issuing tsunami information to national and international warning centres. At the national level, information is disseminated to designated agencies including the Ministry of Earth Sciences (MoES), Ministry of Home Affairs (MHA), National Disaster Management Authority (NDMA), National Crisis Management Committee (NCMC), National Disaster Response Force (NDRF) battalions, State Emergency Operations Centre (SEOC), District Emergency Operational Centres (DEOC), the public, and the media.

Table.4. Threat status and recommended action

Threat status	Recommended action
Warning (Red colour)	Public should be advised to move inland towards high grounds.Vessels should move into deep ocean
Alert (Orange colour)	Public should be advised to avoid beaches and low-lying coastalareas. Vessels should move into deep ocean
Watch (Yellow colour)	No immediate action is required
Threat passed (Green colour)	“All-clear” determination to be made by the local authorities

ITEWC services for an EQ event commence whenever EQ are recorded with magnitudes ≥6.5 within the Indian Ocean and magnitudes ≥8.0 outside the Indian Ocean. Upon detecting a tsunamigenic EQ, the duty officers in 24x7 ITEWC respond immediately and begin their analysis of the event. The analysis includes automatic and interactive processes for determining the EQ’s epicentre, depth, and origin time, as well as its magnitude. The criteria for the generation of different threat types (Warning/Alert/Watch) for a particular region of the coast arebased on the available warning time (i.e., time taken by the tsunami wave to reach the particular coast). The threat criteria are based on the premise that coastal areas falling within 60 minof travel time from a tsunamigenic EQ source need to be warnedbased solely on EQ information and pre-run numerical scenarios, since enough time will not be available for confirmation of the water levels from the tsunami buoys and tide gauges. Those coastal areas falling outside the 60 min of travel time from a tsunamigenic EQ source could be put under the Alert/Watch status and upgraded to Warning/Alert only upon confirmation from the water level data. The criteria for considering an area under different threat levels are shown in **Table.4.**

The Standard Operating Procedure (SOP) for information dissemination to national agencies is shown in **Figure .7.** As per the SOP, Type-1 bulletin will be issued within (T0 + 10)min from the earthquake occurrence. Based on the pre-run scenario results, Type-2 bulletin shall be issued within (T0 + 20) min, which contains Threat (Warning, Alert and Watch)/No threat information. Subsequently, based on the sea level information, Type-3 bulletin shall be issued which indicates the information on the wave amplitude and the likely coastal areas under threat. The final bulletin with “Threat passed” shall be issued within 120 min after last exceedance of threat threshold amplitude for the last Indian Ocean coastal forecast zone. As a TSP, the ITEWC has the responsibility to disseminate tsunami advisories to the National Tsunami Warning Centers (NTWCs) in the Indian Ocean rimcountries, as per the agreed SOP.

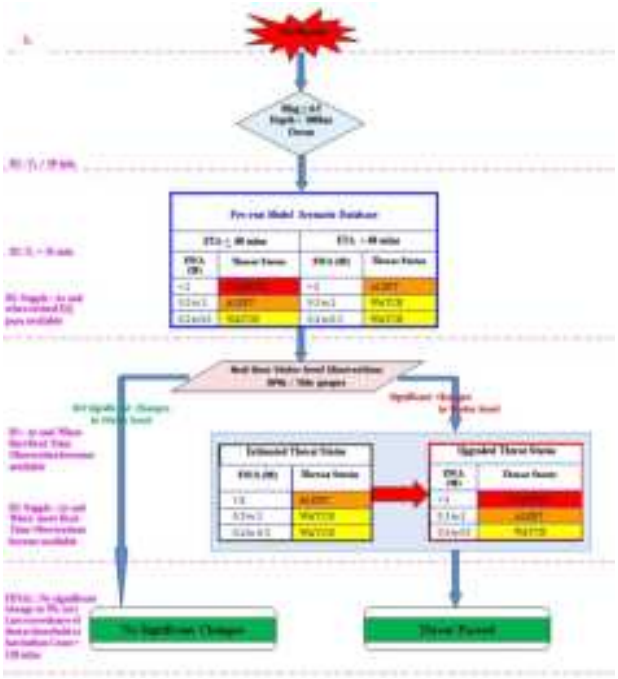


Figure.7. SOP for national tsunami warnings

Taking into account the requirement for rapid response due to near-field tsunamis in the Andaman and Nicobar Islands, a fail-safe satellite-based communication system “VSAT-aided Emergency Communication System (VECS)” is established at seven nodal Emergency Operation Centers (EOC) including Port Blair (State Control Room and EOC), Mayabunder, Hutbay, Nicobar, Kamorata, and Campbell Bay. The VECS, with operation based

on GSAT-12, is networked using an Internet-enabled telephone and fax and configured with a computer-based EQ alert and web-access system. The electronic display boards installed are capable of displaying ticker messages related to a recent tsunami event as well as triggering a built-in siren alert system that is audible upto a distance of 1km. Considering the importance of reliable warning information delivery to the stakeholders, the ITEWC utilises multiple modes of communication including Short Message Service(SMS), e-mail, fax, phone, website, File Transfer Protocol (FTP), electronic display boards, VECS, mobile APP (SAMUDRA) and NDMA's Sachet platform (utilising the Common Alert Protocol) for taking appropriate action. In addition to the periodic mock drills conducted, periodical communication tests are conducted by the ITEWC by sending tsunami test bulletins for pseudo-events through e-mail, Global Telecommunication System (GTS), SMS and fax to other NTWCs.

Acknowledgements

We thank the Ministry of Earth Sciences (MoES), Government of India for encouraging the submission of this article.

References

- Assessment of the reliability of the Indian tsunami early warning system, Marine Technology Society Journal, Vol.50, Issue 3, pp:92-108.
- Assessment of the reliability of Indian tsunami buoy system, Journal of Society for Underwater Technology, Vol.32, Issue 4, pp::255 – 270.
- Can submerged buoys be reliably used for monitoring tsunami in the Indian Ocean ? Marine Technology Society Journal, Jan/Feb 2021, pp. 127-136.
- Evolution of reliable and cost-effective power systems for buoys used in monitoring Indian seas, Marine Technology Society Journal, Vol. 49, Issue 1, pp:71 – 87.
- Reliability analysis and integrity management of instrumented buoy moorings for monitoring Indian seas, Society of underwater technology, Vol.33, Issue 2, pp:115-126.
- Reliability assessment of state-of-the-art real time data reception and analysis system for Indian seas, Marine Technology Society Journal, Vol. 9, Issue 3, pp:127-134(8).
- Development and performance assessment of a hybrid telemetry system for Indian tsunami buoy system", Society of Underwater technology, Vol.33, Issue 2, pp:105-113.
- Study of the algorithms for the detection of tsunami using an ocean bottom pressure recorder, Marine Technology Society Journal, Vol.48, Issue 1, pp:76-83(8).
- Direct energy estimation of the 2011 Japan tsunami using
- deep-ocean pressure measurements, JGR, Vol. 117, doi:10.1029/2011JC007635, 2012.
- Evaluation of tsunami wave energy generated by earthquakes in the Makran subduction zone. Elsevier Ocean Engineering, Vol165, 2018
- Websites of MOES-INCOIS, MoES-NIOT, NDBC-NOAA.

About the Authors

Sundar Ranganathan is a Scientist–E in the Ocean Observation Systems Group at the National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. With over 20 years of experience, he specialises in the design, development, and end-to-end management of ocean observational systems and data. He holds a B.E. in Computer Science & Engineering and an M.Tech in Ocean Technology from IIT Madras. He has authored over 20 indexed journal publications, holds two national patents, and serves as an Ambassador for Ocean Best Practices in India. He is a professional member of IEI, IEEE, and MTS.

M. Arul Muthiah is Scientist-F and Head of the Ocean Observation Systems Group at NIOT, Chennai, with over 20 years of experience in the design, development, and maintenance of offshore autonomous data acquisition platforms. He led the indigenous development of a moored buoy system transmitting over 200 real-time parameters and contributed to India's first underwater ocean observatory near the North Pole. A recipient of the National Geosciences Award (2016) and Meritorious Scientist Award (2008), he holds a B.E. in Electrical Engineering and an M.E. in VLSI, has authored over 28 publications, holds five patents, and is an active member of IEEE and MTS India.

Dr. N. Vedachalam is Scientist-G and Director of the DeepSea Technologies Group at the National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, India. He has over 30 years of experience across industrial power, process, offshore, and subsea domains, including roles with the Aditya Birla Group, General Electric, and Alstom Power Conversion (France). His technical expertise spans multi-megawatt subsea power and control systems, offshore renewable energy, manned and unmanned underwater vehicles, ocean observation technologies, and industrial systems. His research interests include energy systems, subsea robotics, and reliability. He has authored over 100 indexed publications, holds one international and two national patents, and serves on several national committees and review boards.

Email: veda1973@gmail.com

Dr. B. Ajay Kumar is Scientist-E in Operational Ocean Services at the Indian National Centre for Ocean Information Services (INCOIS), Ministry of Earth Sciences. He holds an M.Sc. (Tech) and Ph.D. in Geophysics and has over 18 years of experience in tsunami early warning, sea-level monitoring, and operational ocean services. He played a key role in establishing the Indian Tsunami Early Warning System (ITEWS) and has been instrumental in issuing timely tsunami advisories to stakeholders. In recognition of his contributions, he received the National Geoscience Award in the Disaster Management category. His research interests include earthquakes, tsunamis, and disaster management, and he has authored over 15 publications. He actively contributes as an expert member to UNESCO-IOC, SAHF, and other international forums.

Prof. R. Balaji is the Director of the National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, and is on deputation from IIT Bombay, where he has been a Professor in the Department of Civil Engineering since 2011. Prior to academia, he served as Senior Coastal and Port Engineer at Sogreah Consultants, Dubai. He obtained his Master's and Ph.D. degrees in Ocean Engineering from IIT Madras. Prof. Balaji has authored over 80 peer-reviewed journal papers and 82 conference publications, and has received multiple excellence awards, including the Professor S. P. Sukhatme Excellence in Teaching Award (2024). His professional experience includes major waterfront development projects in India and abroad, with core expertise in port, harbour, marina, and coastal infrastructure planning and design. He serves on several national committees and review boards.

Marine Engineering Accident Investigation Series

From Microcrack to Mayday: Forensic Analysis of Fatigue Failures in Marine Structures

Gajanan Karanjikar

Abstract

This article presents a practical framework for forensic analysis of fatigue failures in marine structures. It covers metallurgical examination, non-destructive testing (NDT) methods, the use of S–N curves and cumulative damage concepts, and life-cycle assessment after incidents. Relevant codes and conventions are referenced, and the potential legal and financial consequences for shipowners are discussed. The aim is to help marine engineers turn each fatigue incident into a learning opportunity rather than a repeatable pattern.

Keywords: fatigue failure, forensic metallurgy, S–N curves, NDT, IACS CSR, SOLAS, accident investigation, life-cycle assessment

Introduction:

Forensic analysis of fatigue failures in marine structures involves a multi-faceted approach using material testing, advanced imaging, and computer modeling to determine the cause and history of a failure. This analysis includes identifying the failure's origin (crack initiation), how it propagated (crack propagation), and its final fracture point through methods like scanning electron microscopy (SEM) and finite element analysis (FEA). The goal is to understand the failure mechanism to prevent future incidents in similar structures.

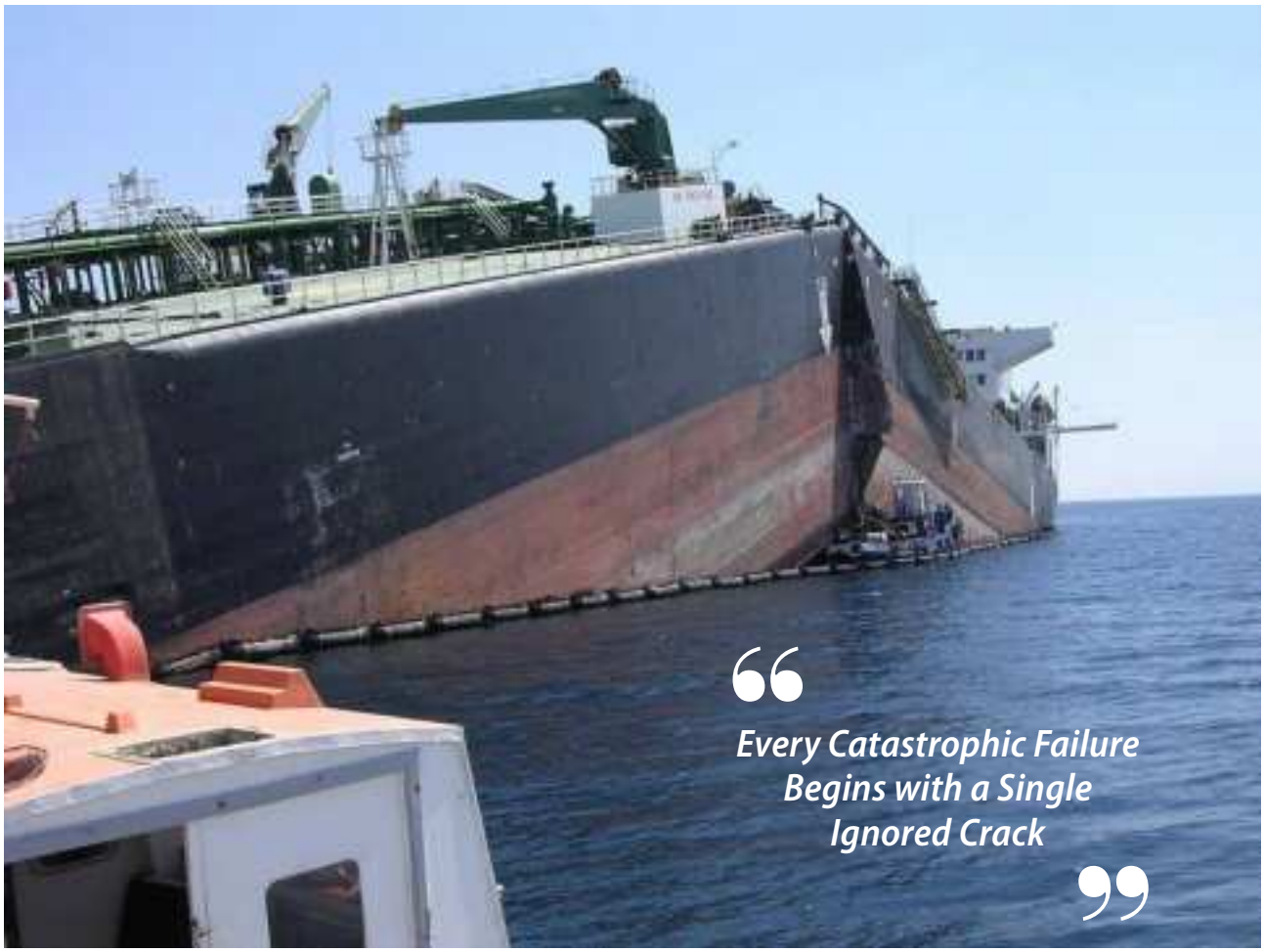
> *"Fatigue Writes the Accident Long Before It Happens*

1. From hairline crack to structural casualty

Every major fatigue failure starts as a microscopic discontinuity – a machining mark, a weld toe notch, a local hardness change, or a tiny inclusion. Under repeated cyclic loading from waves, cargo, vibration, or pressure pulsations, this tiny imperfection becomes a short crack, then a dominant crack, and ultimately an unstable fracture.

On board, the first visible sign might be something apparently trivial: a rust streak on deck, a hairline crack in the way of a scallop, a recurring oil mist alarm, or a vibration pattern that "does not feel right" to the experienced engineer. Suppose this is treated as mere housekeeping rather than a symptom of structural fatigue. In that case, the next step may be a flooding incident, a machinery breakdown, or, in the worst case, a mayday call.

As a marine engineer or investigator, your role is crucial. You are tasked with walking this path backwards, from the catastrophic event to the microcrack, and to reconstruct the full technical, operational and organisational story.



2. Understanding fatigue in the marine context

Marine structures are exposed to a particularly harsh fatigue environment:

- **Wave-induced hull girder loads** producing global bending and local hot-spot stresses in deck, bottom and side shell.
- **Cargo- and ballast-induced loads**, including sloshing, cargo movement and repeated loading cycles on bulkheads and inner bottoms.
- **Machinery vibration and torsional oscillations** in shafts, gears and engine components.
- **Pressure pulsations and flow-induced vibration** in piping systems and turbomachinery.

Design rules for fatigue in ship structures are chiefly contained in:

- **IACS Common Structural Rules (CSR)** for Bulk Carriers and Oil Tankers, which specify hot-spot stress assessment, S–N curve selection and safety factors for defined design fatigue lives.
- **IACS Unified Requirements** (e.g., UR S11 series on longitudinal strength and UR S34 on functional requirements), which indirectly govern fatigue strength by controlling scantling and stress levels.
- **SOLAS Chapter II-1**, which, though not a fatigue code per se, imposes structural integrity requirements and damage tolerance expectations on key watertight boundaries and machinery spaces.
- Relevant **classification society rules** for hull and machinery, including specific requirements for propeller shafts, crankshafts, connecting rods and critical welded structures.

Accident investigation aims to determine not only *how* fatigue failure occurred, but also whether the structure, as built, maintained and operated, complied with these design and operational expectations. The potential legal and financial consequences for shipowners are significant, underscoring the importance of thorough investigation and compliance.

3. Metallurgical examination: the fracture tells the story

Metallurgical examination is the heart of forensic fatigue analysis. A typical investigation includes:

3.1 Macroscopic fracture examination

- Identifying **fatigue beach marks** or “clam shell” patterns that show crack growth over time.

- Differentiating between **initiating zones** (often at weld toes, bolt holes, or sudden changes of section) and final fast-fracture zones.
- Assessing secondary damage (impact, abrasion, plastic deformation) that may have occurred during the casualty and must not be mistaken for primary crack features.

3.2 Microscopic examination

Using optical and scanning electron microscopy (SEM), the investigator looks for:

- **Fatigue striations**, marking the advance of the crack front with each load cycle.
- **Inclusions, porosity, or micro-shrinkage** in weld metal or parent metal that act as stress raisers.
- Local **microstructural changes** (e.g., over-hardening, tempering, sensitisation) caused by poor welding, improper heat treatment, or overheating in service.

3.3 Mechanical and chemical testing

- **Hardness testing** across welds, heat-affected zones and base material to identify over-hard regions susceptible to brittle cracking.
- **Tensile and Charpy impact testing**, where representative specimens are available, to verify that actual properties match those assumed in design.
- **Chemical analysis** to check conformity to the specified grade (yield strength, alloying content, Sulphur and phosphorus limits, etc.).

This combination allows the investigator to determine whether the failure was primarily due to design stress levels, material deficiencies, manufacturing defects, improper repair, or abusive service conditions.

When Housekeeping Neglect Turns Steel Into a Distress Call

4. Non-destructive testing: mapping the unseen

NDT bridges the gap between a single failed component and the rest of the structure. After a fatigue-related incident, systematic NDT helps answer two critical questions: *Where else might similar cracks exist?* And what *should be done to keep the vessel safe in the interim?*

Common techniques include:

- **Ultrasonic testing (UT) and phased-array UT** for detecting internal cracks in welded joints, shafting, thick plates, and critical nodes. Phased-array UT can also provide a detailed picture of crack size, orientation and depth for engineering assessment.
- **Magnetic particle inspection (MPI)** for surface and near-surface cracking in ferromagnetic components such as crane structures, rudder stocks, anchors and chain links.
- **Dye penetrant testing (DPT)** for surface cracks in non-magnetic materials, including stainless steel and aluminum alloy components.
- **Eddy current testing** for localised surface cracking, particularly around fastener holes and weld toes in aluminum gangways, superstructure elements and certain machinery parts.
- **Radiography** (where practicable) for volumetric defects in welds that may have acted as crack initiators.

Standards such as **ISO 17635**, **EN ISO 5817** and class-specific NDT procedures provide acceptance criteria and testing methodologies. However, for an incident investigation, the objective is often more conservative: find everything that could be a threat, even if some indications would have been acceptable in a new building inspection. This underscores the gravity of your responsibility in ensuring the safety and integrity of marine structures.

5. S–N curves and life-cycle damage: putting numbers to the story

A forensic investigation that stops at "there was a crack" is incomplete. The marine engineer must ask: *Was the crack predictable from the original fatigue design?*

Using **S–N curves** (stress range versus number of cycles to failure) and **cumulative damage concepts** (such as Miner's Rule), investigators can:

1. **Reconstruct stress histories** – using design calculations, class records, sea state data, loading computer histories and, where available, strain gauge or vibration logs.
2. **Estimate stress ranges** at the crack location – employing finite element analysis (FEA), simplified beam and plate models, or hot-spot stress methods as in IACS CSR.

3. **Calculate fatigue damage** – comparing the expected cycles at given stress ranges to the relevant S–N curve for the detail type (e.g., welded attachment, cut-out, free plate edge).
4. **Compare design life and actual life** – identifying whether the failure occurred within, at, or beyond the intended initially fatigue life.

Suppose the analysis shows that the detail operated well beyond its design fatigue life. In that case, the question becomes one of **life-cycle management**: why was the detail not identified as a "fatigue critical location" for enhanced inspection or reinforcement?

If the analysis shows drastically shorter life than expected, attention turns to:

- Incorrect as-built geometry (poor detailing, sharp notches).
- Unapproved modifications (brackets, doublers, cut-outs).
- Unforeseen operating patterns (harsher routes, higher average speed, increased loading cycles).

This quantitative assessment is central to demonstrating whether the owner exercised due diligence in design, maintenance and operation, which in turn has legal implications.

6. Codes, conventions and the investigator

Several international instruments form the backdrop against which fatigue-related casualties are judged:

- The **International Safety Management (ISM) Code** requires companies to establish procedures for critical equipment maintenance, defect reporting and corrective actions. Repeated crack repairs without root-cause analysis may indicate ISM failures.
- The **IMO Casualty Investigation Code** (Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident), which frames how flag States investigate and report serious structural or machinery failures.
- The **Hague–Visby Rules**, especially Article III, require carriers to exercise due diligence to make the ship seaworthy before and at the beginning of the voyage. A fatigue crack that a reasonable inspection should have discovered may undermine a cargo owner's defence.
- **SOLAS** requirements for surveys, enhanced inspections of older bulk carriers and oil tankers and maintenance of class. Failure to comply with thickness measurements and structural surveys can point to systemic shortcomings.

Investigators, therefore, operate at the intersection of **engineering evidence** and **regulatory expectations**, translating the condition of the metal into questions of compliance, due diligence and seaworthiness.

7. Legal and financial consequences for owners

When fatigue failure leads to a casualty, the financial implications can be severe and multi-layered:

- **Direct repair costs** – renewal of damaged structure, temporary repairs at a remote port, specialist welding, dry-docking and class survey fees.
- **Off-hire and loss of earnings** – time lost during deviation, repairs and subsequent surveys. Under many time charterparties, structural or machinery failures that cause a loss of performance place the vessel off-hire.
- **Cargo damage and delay claims** – if water ingress or machinery breakdown affects cargo condition or delivery schedule, cargo interests may pursue substantial claims.
- **Salvage and general average** – where a failure leads to loss of propulsion, grounding, or risk of sinking, salvage remuneration and GA contributions can be significant.
- **Pollution liability** – if the failure contributes to an oil spill (e.g., structural failure of a tank boundary), MARPOL and civil liability regimes may expose owners and insurers to large claims.
- **Reputational damage and increased insurance premiums** – repeated fatigue-related incidents or a major casualty often lead to stricter scrutiny by P&I clubs, hull underwriters and port State control.

Legally, the owner may face allegations of:

- **Failure to maintain class** or to follow up on the surveyor's recommendations.
- **Inadequate planned maintenance system**, if recurring cracks were "patched" but never properly investigated.
- **Failure to provide a seaworthy ship** at the commencement of the voyage, potentially affecting limitation rights and insurance coverage.

A thorough, technically sound fatigue investigation can be decisive in demonstrating that the owner acted

responsibly, or conversely, can expose long-standing neglect.

8. Life-cycle assessment after the incident

Once the immediate repair is planned, the marine engineer must help the owner answer: *What does this mean for the rest of the vessel's life?*

A post-incident **life-cycle assessment** typically includes:

- **Re-evaluation of critical details** – identifying similar structural or machinery details exposed to comparable stress spectra and bringing them into an enhanced inspection regime.
- **Modification of design** – adding brackets, softening stress raisers, grinding and profiling weld toes, or replacing specific details entirely.
- **Updating inspection and NDT plans** – incorporating higher frequency inspections at known hot-spots, perhaps aligned with class survey windows but not limited by them.
- **Operational changes** – limiting certain loading conditions, speed profiles, or routes that exacerbate fatigue damage.
- **Risk-based maintenance planning** – ranking components by consequence of failure and their measured fatigue damage to prioritise resources.

For older ships, a severe fatigue failure may be the trigger for deciding whether further operation is economically justified, especially where extensive steel renewals, life-extension studies and upgraded monitoring systems would be required.

9. Turning lessons into prevention

For marine engineers, surveyors and accident investigators, "From microcrack to mayday" is not just a catchy title; it is a reminder that most catastrophic fatigue failures are, in principle, preventable. The tools are available: sound design rules, robust metallurgical techniques, sophisticated NDT, S-N-based assessment and well-developed codes of practice.

What is often missing is the **discipline to treat every crack as a story to be understood, not merely a defect to be ground out and re-welded**. Suppose every incident investigation strengthens the feedback loop into design, class rules, maintenance practices and crew awareness. In that case, the cost in repair bills, claims and potential loss of life can be dramatically reduced.

In that sense, the true success of a fatigue investigation is not simply in explaining why one structure failed, but in ensuring that a hundred similar structures do not forget in the future – so that the next microcrack never has the chance to become a mayday.

*(Excerpts from the forthcoming book – **Marine Investigation techniques authored by Capt Gajanan Karanjikar**)*

References

1. British Standards Institution (2014) *BS 7608: Guide to fatigue design and assessment of steel products.* London: BSI.
2. Det Norske Veritas (n.d.) *Fatigue design of offshore steel structures, DNV-RP-C203.* Høvik: Det Norske Veritas.
3. Hobbacher, A. (2016) *Recommendations for fatigue design of welded joints and components.* IIW Collection. Cham: Springer.
4. IACS (n.d.) *Common Structural Rules for Bulk Carriers and Oil Tankers.* London: International Association of Classification Societies.
5. IACS (n.d.) *Unified Requirements for Hull Structure (UR S11, UR S34 and related URs).* London: International Association of Classification Societies.
6. IMO (1974) *International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended.* London: International Maritime Organization.
7. IMO (2008) *Code of the International Standards and Recommended Practices for a Safety Investigation into a Marine Casualty or Marine Incident (Casualty Investigation Code).* London: International Maritime Organization.
8. Paik, J.K. and Thayamballi, A.K. (2003) *Ultimate limit state design of steel-plated structures.* Chichester: John Wiley & Sons.
9. Radaj, D., Sonsino, C.M. and Fricke, W. (2006) *Fatigue assessment of welded joints by local approaches.* 2nd edn. Cambridge: Woodhead Publishing.

About the Author

Capt. Gajanan Karanjikar is a Master Mariner, marine surveyor and US-based casualty investigator with decades of sea and shore experience. He advises owners, insurers, and regulators on technical surveys, class and flag compliance and post-casualty investigations, blending professional seamanship with modern forensic analysis.

Email: captgajanan@gmail.com

ANGLO EASTERN
MARITIME TRAINING CENTRE

AEMTC MUMBAI : 401, Fourth Floor, Leela Business Park, Marol, Andheri-Kurla Road, Andheri (East), Mumbai-400 059.
T. +91 22 6720 5600 / 611 / 612 |
A.O.H. +91 8657408962 / +91 9820917656
aetr.bom@angloeastern.com
Mr. Francis Akkara, Capt. Liston Pereira, Mr. Ivor Wilson

AEMTC DELHI : A-43, Ground Floor, Mohan Co-Operative Industrial Estate, Mathura Road, Delhi-110044, India.
T. +91 11 6817 0800, 0801 / +91 9811249849 / 9850
aetr.del@angloeastern.com
Capt. Prashant Gour, Ms. Sukhjeet Kaur, Mr. Suresh Kumar

Anglo Eastern Maritime Training Centre | aemaritimetrg | For more details visit website: **www.maritimetraining.in**

For Pre Sea Training Courses kindly contact **Anglo-Eastern Maritime Academy** (A Division of Anglo-Eastern Institute) **DNS Course :** 011 68170837 | **GME / ETO Course :** 011 68170831 | aema.edu.in

MAN | PrimeServ Man Energy Solution is now **Everllence**

Everllence | PrimeServ Academy Partner, Mumbai
(OEM Approved Courses)

ME-C Control System Standard Operation

Jan 2026: 26 - 30 | Feb 2026: 23 - 27

ME-GI Control System Standard Operation

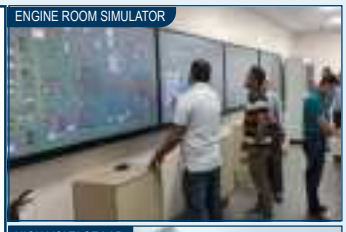
Feb 2026: 02 - 06 | Mar 2026: 02 - 06

For bookings: aetr.bom@angloeastern.com | primeserv.academy-cph@everllence.com

WIN GD (OEM Approved Course)

Operation Advanced Course WECS 9520-Controlled X Engines — Jan 2026: 05 - 09

Operation Advanced Course UNIC-Controlled X Engines — Feb 2026: 02 - 06



For bookings: +91 8657408962 / +91 9820917656

WÄRTSILÄ

Wartsila RT Flex Engine

Conducted by Wartsila Switzerland

Jan 2026 : 05 - 09

Feb 2026 : 16 - 20

VACANCY Faculty position

Apply Now!
talentsourcing@angloeastern.com/
aemt.bom@angloeastern.com

Training Faculty – Engineering

Qualifications and Experience

- Marine Engineer Officer Class 1 – COC from India / UK.
- With min. 1 year rank experience as Chief Engineer (Preference for experience on LNG/ LPG/ Tanker vessels).
- Experience in Ship operation, ship repair, teaching, auditing, inspections preferred.
- Training for Trainers and Assessors (TOTA) or Vertical Integration Course for Trainers (VICT).
- Other ISO / ISM / Technical Value-added courses.
- Excellent verbal and written communication skills. Should be interested in modern teaching methodologies.
- Candidate must have a passion for learning continuously and a desire to be in the teaching profession.
- Proficient in use of computers and savvy with use of various software.

1st in India & 2nd in the world to receive distinction by DNV SeaSkill Benchmarking

DNV

https://imare.in/

COMARSEM '26

COCHIN MARINE SEMINAR

29 - 30 JANUARY 2026 | VIVANTA, MARINE DRIVE, KOCHI

Organized by

Institute of Marine Engineers (India)

In Association with

A Global conclave with **Technical Seminars & Exhibitions bringing together Policy makers, Maritime Professionals, Industry Leaders** and **Technology experts** Two days of knowledge sharing and Networking.

COMARSEM '26
COCHIN MARINE SEMINAR
29 - 30 JANUARY 2026 | VIVANTA, MARINE DRIVE, KOCHI

Organised by

In Association with

ADVISORY BOARD

Mr. Madhu S Nair, CMD, Cochin Shipyard Ltd.
Mr. B Kasiviswanathan, Chairperson, Cochin Port Authority
Mr. J Senthil Kumar, P.O – MMD, Cochin
Mr. Loknath Behra, IPS (Retd), MD, Kochi Water Metro Ltd
Mr. Arun Sharma, CMD, Indian Registrar of Shipping
Mr. Antony Prince, President & CEO, SEDS, Cochin
Mr. Dipin Kayyath, CEO, IGTPL – DP World, Cochin
Mr. Kaushik Kumar Seal, President, IME (I)
Mr. Rajeev Nayyer, Immediate Past President, IME (I)

About Cochin – The Marine and Commercial Capital of Kerala

Cochin, known as the Queen of the Arabian Sea, is a vibrant city located on the south west cost of India, star of God's Own Country, Kerala. From time immemorial, Arabs, British, Chinese, Dutch, and Portuguese traders have left an indelible mark on the history and development of this beautiful coastal town.

Cochin has preserved many of its historic landmarks and monuments, which continue to add to its charm and glory. The city is the Maritime and Commercial capital of Kerala, boasting of major infrastructure such as seaports, container terminals, modern shipyard, maritime educational and training centres, airport, an efficient Metro and Water Metro network.

Cochin enjoys excellent connectivity to Kerala's major tourist destinations through rail, road, and inland waterways. A wide range of hotels and restaurants offering delicious cuisine at affordable prices make it a destination for both business and leisure travellers.

The Institute of Marine Engineers (India)

The Institute of Marine Engineers (India) is a premier professional body representing marine engineering professionals across the country. With a membership strength of over 13,000, the Institute members include professionals serving both in India and abroad in key positions across the maritime industry.

Headquartered in Mumbai, the Institute operates eight regional branches located in different parts of the country. It actively provides various facilities to enhance the knowledge and professional competence of its members, while extending a wide range of services aimed at their professional growth and welfare.

The primary objectives of the Institute are to promote the scientific and technological advancement of marine engineering, facilitate the exchange of ideas and information among marine engineers, uphold the professional status of its members, foster cooperation with other professional institutions, classification societies, and the maritime industry, and contribute to the advancement of engineering education in the country.

About the event, COMARSEM 2026

COMARSEM (Cochin Marine Seminar) is a flagship event periodically organised by the Cochin Branch of The Institute of Marine Engineers (India). The upcoming COMARSEM 2026, scheduled for January 2026, will be an international seminar bringing together eminent stakeholders from across the global maritime industry under one roof.

COMARSEM 2026 organized by **IMEI Kochi** branch in association with **DG Shipping**

Themed "**Maritime India – Innovations and Collaborations**," this mega event will feature panel discussions, technical presentations, and interactive sessions that deliberate on the progress of India's maritime sector and explore strategies to realise the nation's vision of becoming a maritime superpower.

The event will host focused panel discussions and paper presentation on key topics such as:

- Policy framework and new legislations to accelerate Indian Shipping and Inland Waterways.
- Infrastructure growth for enhancing shipping, shipbuilding & repair and ship recycling.
- Accelerating the adoption of greener technologies to meet decarbonisation goals
- Innovate training methodologies for skill development focused on alternate fuel, digital. autonomous, AI technology etc.
- Developing maritime clusters to address emerging challenges indigenously
- Improvements in logistics and supply chain systems for sustained growth.

These discussions aim to foster cross-industry collaboration, drawing valuable insights from both Indian and international participants, while exploring the financial and technological pathways essential for achieving these ambitious goals.

This event will feature:

TECHNICAL PRESENTATIONS, PANEL DISCUSSIONS & NETWORKING

- Inauguration Session attended by Industry Leaders.
- Four (4) Sessions of Paper presentation of 4 papers each
- Four (4) sessions of Panel discussions
- Industry Exhibits
- Kochi back water networking cruise.
- Valedictory function.

COMARSEM '26
COCHIN MARINE SEMINAR

SPONSORSHIPS AND BENEFITS

MAIN SPONSORSHIP

- **PLATINUM** SPONSOR - **INR 10,00,000**
- **GOLD** SPONSOR - **INR 7,00,000**
- **SILVER** SPONSOR - **INR 5,00,000**
- **ASSOCIATE** SPONSOR - **INR 2,00,000**
- **KNOWLEDGE** SPONSOR - **INR 6,00,000**
- **DINNER & COCKTAIL** SPONSOR - **INR 3,00,000**
- **GIFT HAMPER/ BAG** SPONSOR - **INR 2,00,000**
- **NAME BADGE/ LANYARD** SPONSOR - **INR 2,00,000**
- **STALL** SPONSOR 3M X 2M - **INR 90,000**
- **STALL** SPONSOR 2M X 2M - **INR 70,000**

DELEGATE FEE

- **DELEGATE FEE - INR 3,500**
- **DELEGATE FEE (INEI MEMBERS) - INR 2,500**
- **STUDENT DELEGATES - INR 1,000**

ADVERTISEMENT

- **SOUVENIR** [BACK COVER] - **INR 1,00,000**
- **SOUVENIR** [FRONT COVER FOOTER LOGO] - **INR 1,00,000**
- **SOUVENIR** [FRONT COVER INSIDE] - **INR 80,000**
- **SOUVENIR** [BACK COVER INSIDE] - **INR 60,000**
- **SOUVENIR** [FULL PAGE] - **INR 50,000**
- **SOUVENIR** [HALF PAGE] - **INR 30,000**

BENEFITS OF **SPONSORSHIP**

	Platinum	Gold	Knowledge Partner	Silver	Associate Sponsors	Stall- 1(3x2)	Stall- 2(2x2)	Chair Branding	Gift Sponsor
Official Status as Partner/Sponsor	✓	✓	✓	✓	✓	✓	✓	✓	✓
Company Logo on main Backdrop	✓	✓	✓	✓	✓				
Company Logo on side panels and welcome panel	✓	✓	✓	✓	✓				
Complimentary Registration	10	7	5	3	2	2	2	2	
AV (60 seconds) to be played during session breaks	✓	✓	✓						
Company Logo in all conference material	✓	✓	✓	✓	✓	✓	✓	✓	✓
Company Logo on our website	✓	✓	✓	✓	✓	✓	✓	✓	✓
Corporate literature to be included in the Delegate kit	✓	✓	✓	✓	✓	✓	✓	✓	✓
Special acknowledgment at the event inaugural and concluding session	✓	✓	✓	✓	✓	✓	✓	✓	✓
Company Logo, brief profile and contact details to be carried to be event coverage	✓	✓	✓	✓	✓	✓	✓	✓	✓
Company Logo on the Chair Cover								✓	
Company Logo/Name on the Pen & Notepad	For the Sponsoror of the item								
Company Logo/Name on the Lanyard									✓
Company Logo will carry in post-event coverage	✓	✓	✓	✓	✓	✓	✓	✓	✓
Airport Pick Up and drop	✓	✓	✓	✓					

For **COMARSEM- 2026:**

S Krishnankutty
Chairman, Organising Committee

For further details, **please contact:**

N Rajan: +91 **8129852288** (Convener)
rajun1953@yahoo.co.in

BANK DETAILS

Account Name: **THE INSTITUTE OF MARINE ENGINEERS INDIA**
Bank Name: **YES Bank**, Account No. **009694600000450**
IFSC Code: **YESB0000096**
Branch: **Kochi, Kerala**
Company's PAN: **AAATI3254B**

Institute of Marine Engineers (India)
Promoting Knowledge, Building Relationships

OFFICE
CC NO 48/200 B1 NARAYANASSAN ROAD,
PONNURUNNI VYTTILA KOCHI, ERNAKULAM KERALA 682019 INDIA
https://imare.in/ +91 70251 59111

Going Astern into MER Archives...

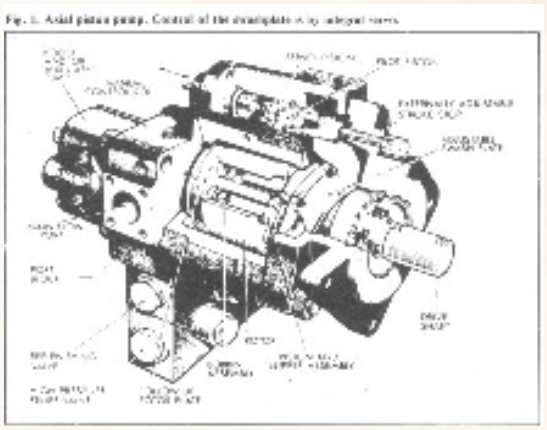
The IMEI was formally started in 1980 so that financial reporting structure can perform wrt statutory reporting. The editor calls for cooperation between IMEI branch offices and the governing council at IMEI. He emphasizes the needs for teamwork to further the cause IMEI.

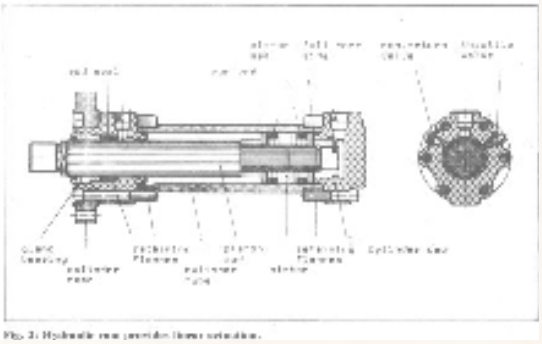
This edition focuses first on **hydraulic machinery**, with the opening articles addressing shipboard hydraulic systems, maintenance, and specialised applications. This is followed by articles on **heavy-lift equipment**, covering the development and operation of mast derricks and high-capacity lifting arrangements. The later sections move into **offshore developments**, particularly vessels and technologies supporting subsea maintenance. I have sampled selected articles that remain highly relevant to the maritime and offshore industry even today, reflecting enduring engineering principles and proven operational practices.

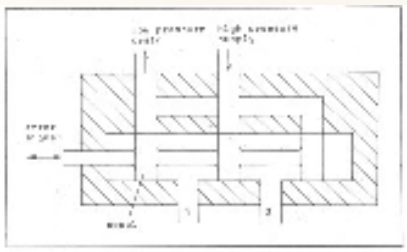
The latter part of the edition contains detailed discussions on the **need for a dedicated maritime university** to build a **self-sustaining maritime training and education ecosystem**. These papers analyse gaps in fragmented training models and argue for integrated academic, technical, and research frameworks aligned with industry needs. Notably, the **first conceptual seeds of what later became the Indian Maritime University (IMU)** were already being sown as early as **1986**, through discussion papers and policy-level deliberations advocating a unified national maritime institution.

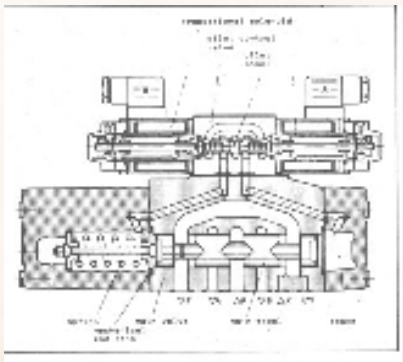
Hydraulic control systems by D A Taylor, MIMar Eng,

The Feb 1986 gives some basic information and applications of hydraulics systems onboard. This article describes the Hydraulic machinery onboard ships uses pressurised oil to transmit power. High-pressure systems (200–300 bar) operate steering gear, deck cranes and offshore equipment. Medium-pressure systems (100–160 bar) serve winches, hatch covers and stabilisers. Low-pressure systems (<100 bar) handle lubrication, cooling and control circuits. Main components include pumps, reservoirs, filters, valves, accumulators, actuators, piping, seals and control units ensuring smooth, reliable operation with redundancy, safety reliefs, monitoring and routine maintenance practices onboard.



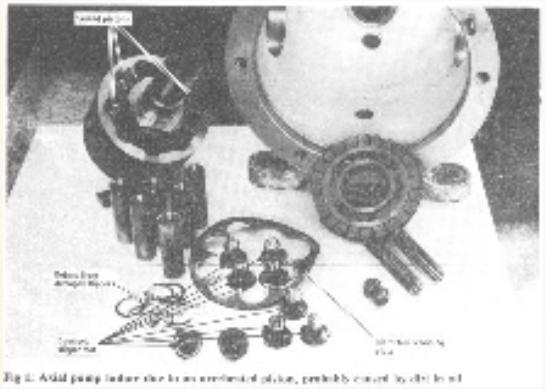


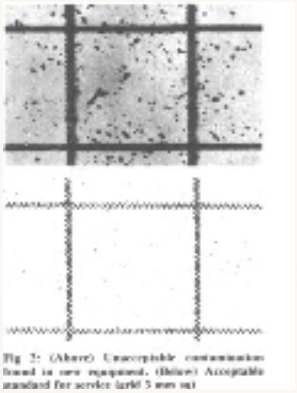


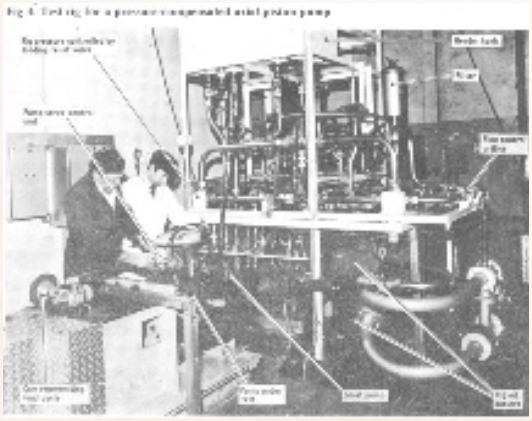


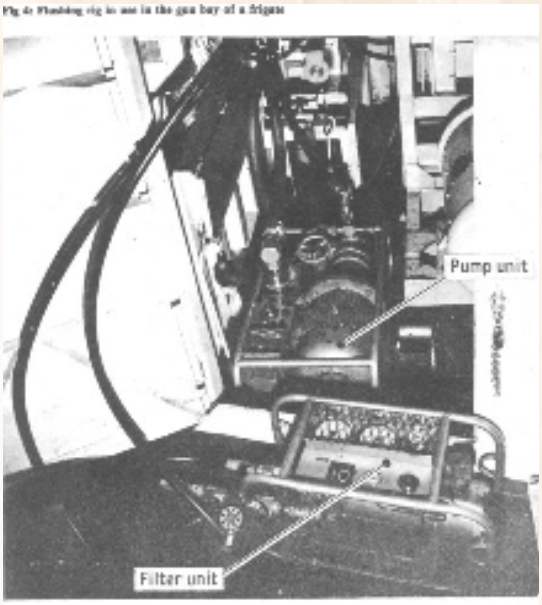
Next article is on **Repairing and refitting of hydraulic machinery onboard** by R J Corless, FIMarE, MIMechE, RCNC, HM Shipyard Devonport.

The paper presents a practical shipyard-oriented approach to the repair, overhaul, and refitting of shipboard hydraulic machinery. It covers safe system isolation, pressure release, dismantling procedures, cleanliness standards, inspection of pumps, valves, cylinders, and pipework, and assessment of wear, tolerances, and seals. Emphasis is placed on correct reassembly, alignment, flushing, pressure testing, fault diagnosis, commissioning trials, and proper documentation, reflecting established best practices to ensure reliability, safety, and extended service life of hydraulic systems on naval and merchant ships.



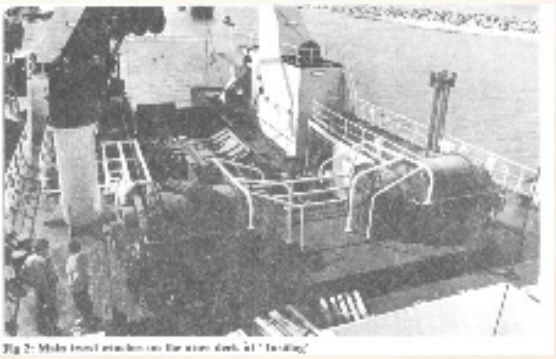






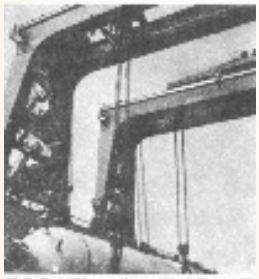
Winches for Specialised Applications" – Ingemar Borg, AB Hägglunds & Söner, Hydraulics Division

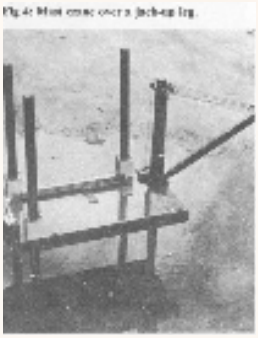
The paper discusses the design and operation of hydraulic winches for specialised marine applications requiring high torque, precise speed control, and continuous duty. It explains the use of hydraulic motors, braking systems, gear arrangements, and control valves to achieve smooth, shock-free performance. Emphasis is placed on reliability, overload protection, redundancy, and adaptability for offshore, towing, anchoring, and heavy-lift operations in demanding marine environments.



"The Development of Heavy-Lift Mast Derricks" – Richard Krabenham

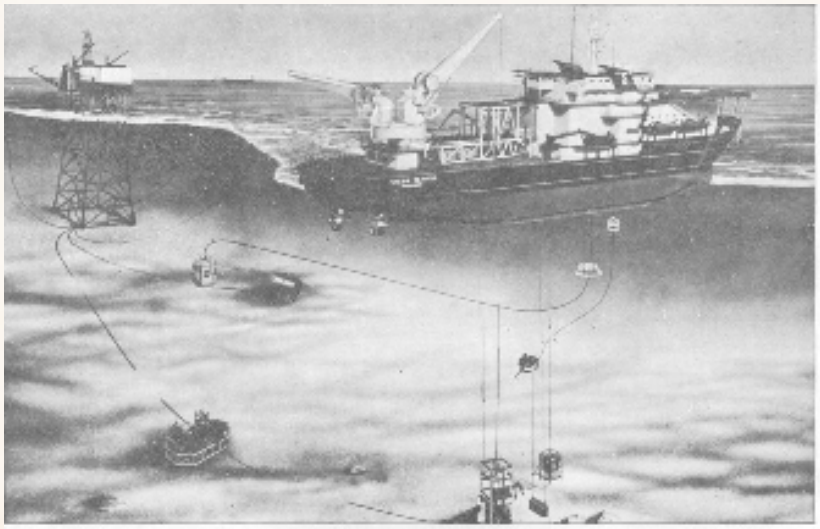
The paper describes the evolution of heavy-lift mast derricks to meet increasing marine cargo and offshore lifting demands. It explains improvements in mast design, load distribution, rigging arrangements, and high-capacity winches. Emphasis is placed on structural strength, stability, redundancy, and precise control systems, highlighting how modern heavy-lift derricks achieve safer, more efficient handling of exceptionally large and heavy loads at sea.

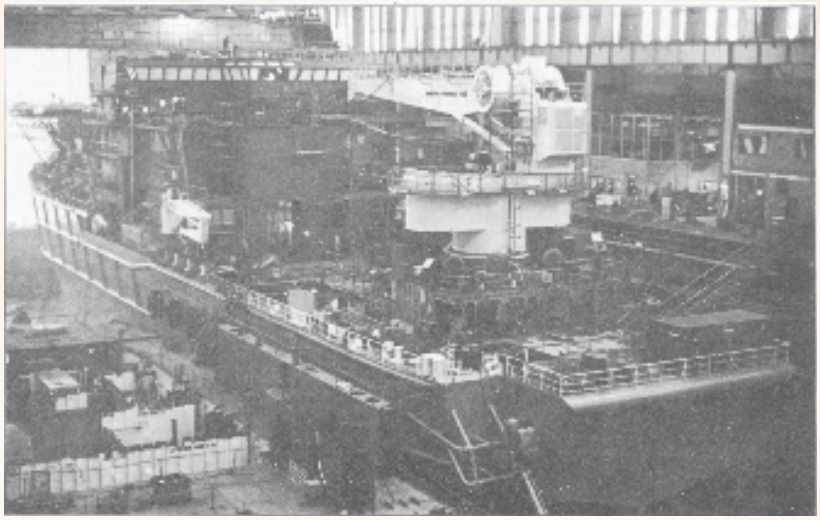


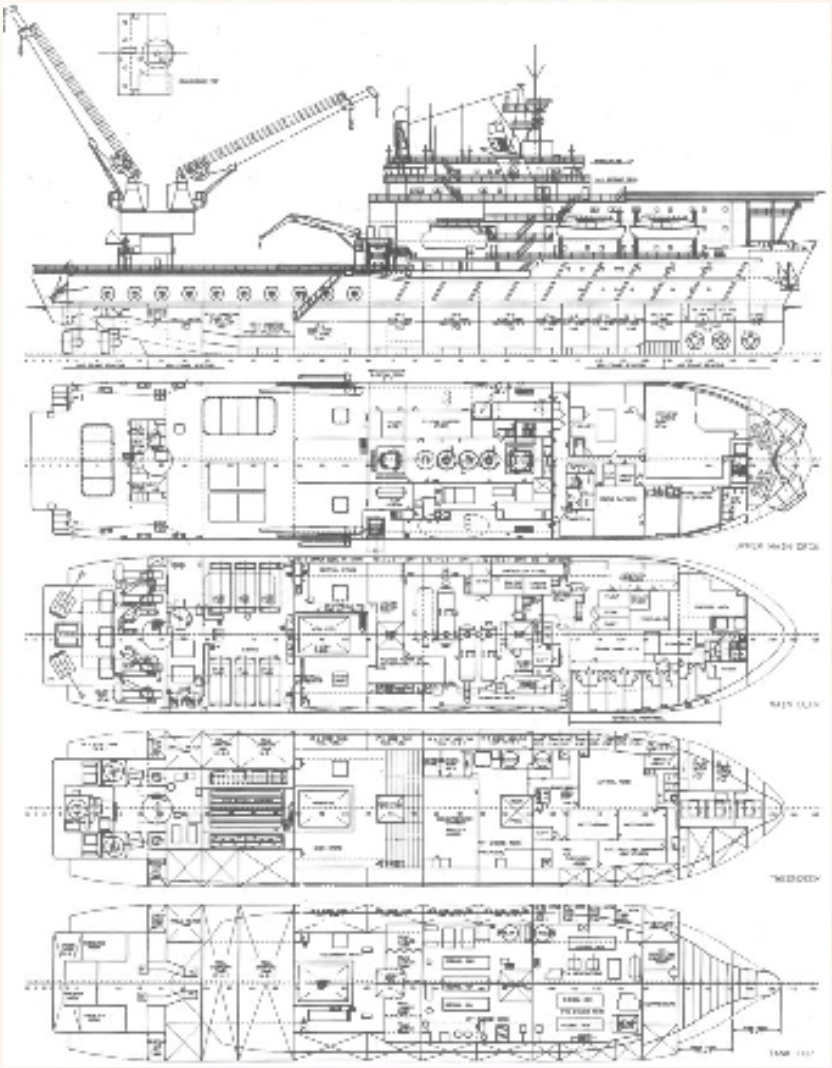


"Subsea Maintenance & Vessel Service Vessels" – A. Hell, MSc, MRINA, Stena AB & FC Tubbett, BSc, C Eng, Sunderland shipbuilders

The paper outlines the role and design of vessels dedicated to subsea maintenance and support operations. It covers vessel capabilities such as dynamic positioning, heavy-lift cranes, ROV systems, dive support facilities, and specialised deck machinery. Emphasis is placed on operational flexibility, safety, redundancy, and integration of subsea systems, highlighting how modern service vessels support inspection, repair, and maintenance of offshore and subsea infrastructure.







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

The Institute of Marine Engineers (India)

MUMBAI BRANCH ALONG WITH NAVI MUMBAI & GUJARAT CHAPTERS

CORDIALLY INVITE YOU FOR THE

Technical Seminar and Annual Meet 2026

SAVE THE DATE
27 FEBRUARY 2026

Venue:
Mumbai Cricket Association, MCA Club Lawns BKC, Mumbai

For any queries or sponsorship details,
Pls contact: Mr. Suraj : 9967481448; mumbai@imare.in

"Reg. No. MCS/090/2018-20"
RNI No. MAHENG/2006/19917
W.P.P. Licence No.:
MR/Tech/WPP-336/ South/2018-20

IME(I) House, Nerul, Navi Mumbai