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# Nation Building through SHIP BUILDING

**July 25 - 26, 2019**

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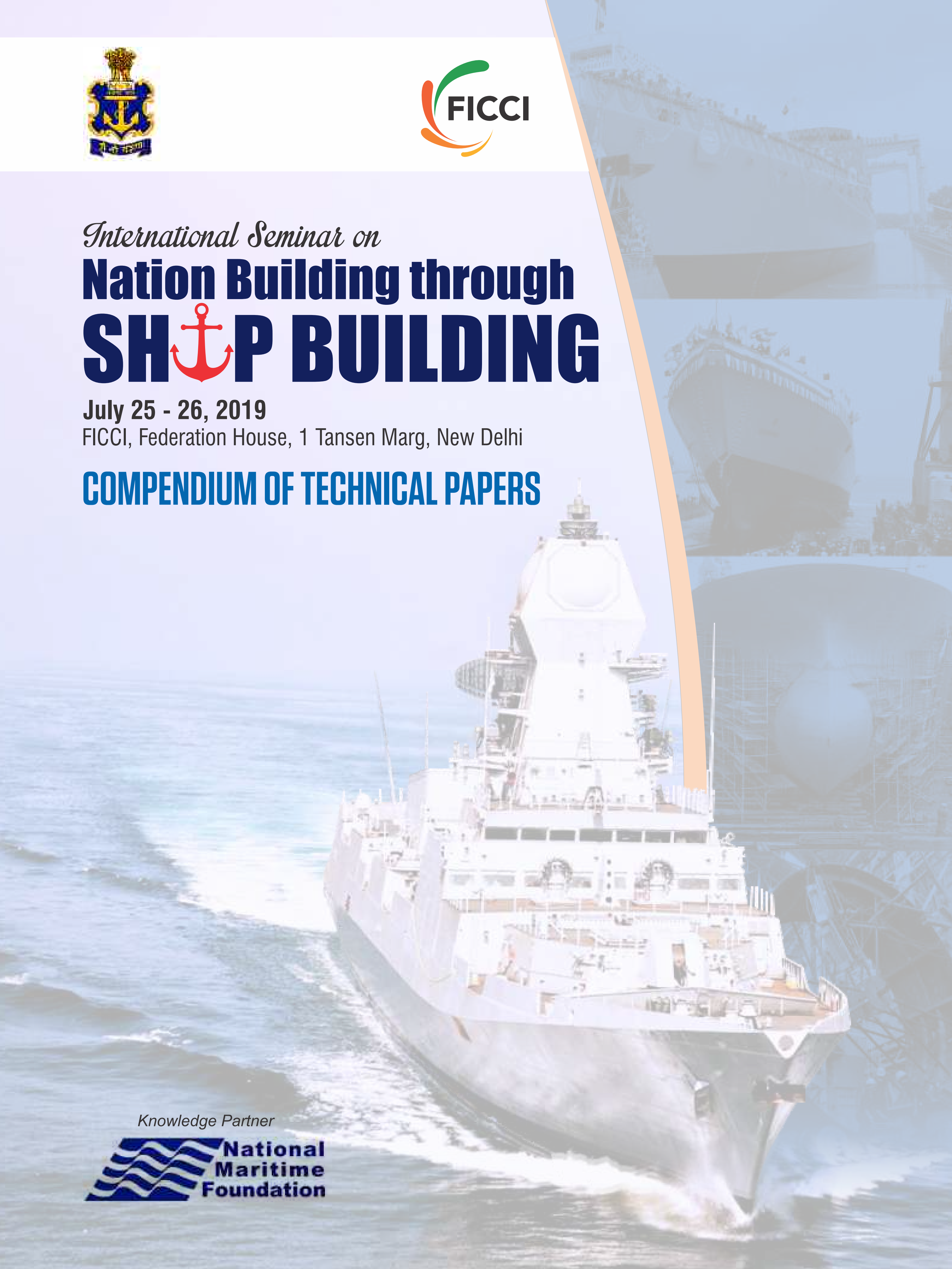

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# TECHNOLOGIES OF THE 4TH INDUSTRIAL REVOLUTION: EFFICIENCY ENABLERS IN SHIP DESIGN AND CONSTRUCTION

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**1. Abstract**

1.1 Symbiotic relation between shipbuilding and society predisposes the shipyards towards implementing the emerging technologies of the 4th Industrial Revolution (IR) as efficiency enablers. This paper examines the increased use of virtual/ augmented reality, Artificial Intelligence, Internet Of Things, computational and simulation software, Blockchain, cyber physical systems and 3D printing in Shipyard 4.0. Some of the examples of implementation of new technologies have been illustrated. An essential commonality of these efficiency enablers of the 4th IR is that they are built on a digital backbone and this underlines the growing importance of cyber security. Significance of cyber security infrastructure as a framework for assured productivity enhancement of Shipyard 4.0 has been highlighted in the conclusion.

**2. Keywords**

2.1 Technology; shipbuilding; 3D printing; computational electromagnetic simulation, artificial intelligence, augmented/ virtual reality

**3. Introduction**

3.1 Since early history, shipbuilding and societies have shared a symbiotic relationship. This relationship has evolved over centuries from the early days of boats like paddling and sailing canoes, galleys with oars, wooden sail ships, engine propelled steel ships to the modern day autonomous unmanned vessels. New technologies, systems and processes that evolve in society always have a direct impact on shipbuilding industry enabling it to grow in-step. Two facets of civilization have been the main couplers between the ships and society – trade and warfare.

3.2 Ships can carry large volumes of cargo and have therefore been a preferred primary mode of transportation.[1] Humans have used various types of boats even before the wheel was invented.[2] Nearly 80 per cent of world's population lives within 60 miles of the coastline and two-thirds of the global economy is derived from activities that involve seas in some form.[3] Shipbuilding has therefore been instrumental in the overall growth story of society and it involves multi-trade industrial complex that employs large numbers of people of different specialties. In the era of wooden ships with sails, shipbuilding involved designers, carpenters, dubbers, caulkers, joiners, riggers and other craftsmen in large numbers to construct a vessel.[4] Over the centuries, use of iron, new design techniques, construction processes, modern machinery, electronics and data processing systems have added to the complexity of shipbuilding.[5]

3.3 Shipping forms the backbone of the world trade and has also been the earliest vehicle and facilitator of globalisation and continues to be a principal component of the modern world system.[6] Even in the current times, there is a ninety per cent chance that a product ordered on the click of a mouse has travelled in part or whole, at least some of its journey on a ship. Unlike commercial ships, warships and submarines are basic building blocks of sea power[7] which is an extension of military power on the seas.

3.4 During the 14th and the 15th centuries, commercial rivalry between the Italian city-states Genoa and Venice, erupted into open naval conflicts, and the Venetian encounters between the Christian and the Muslim fleets fused together the interests of the merchants and the States. The Italian experience was reproduced later in Seville, Lisbon, Amsterdam and London. Its transplanted seedlings were to be found everywhere in the Indian Ocean by the beginning of the 16th century. This was made possible once the Iberians developed long-distance armed merchant shipping, floating fortresses and warehouses, making it possible to extend the area of oceanic control from the home bases and establish new bases in remote places. Advances in technology of shipbuilding was an important factor.[8] Ever since, shipbuilding has continued to hold its position of primacy because of its intrinsic value in world trade and warfare.

3.5 Shipbuilding mirrors the developments in the society. Emerging technologies trigger clusters of innovations introducing newer products in the global market. These products stimulate demand, increasing the volumes of international trade. Sea-trade and shipbuilding follow the growth trajectory since they are major constituents of the 'modern world economy' and a 'globalized world order'. Whilst increased demand on shipping translates to growth of the shipbuilding industry, the contemporary technologies also modify and modernize shipbuilding itself. This pattern has been more pronounced in the post-industrial revolution era which will be examined next. The technological transformation impacts both the merchant shipbuilding and warship-building. These two branches of shipbuilding industry share technological antecedents and many common factors in production and maintenance through life cycle. However, impact of emerging technologies in each of these branches differ. A plausible explanation of this difference is that the dynamics of shipbuilding in the mercantile marine is market driven whereas the warship building is state controlled.

**4. Classification and Periods of the Industrial Revolution**

4.1 Some scholars classify distinct periods when a group of technologies substantially changed the way of life, as 1st, 2nd or 3rd Industrial Revolution (IR). These classifications have been varied and diverse, depending on the criteria chosen for the study and hence there is no standard frame of reference. Some historians used terms like 'industrial revolution of the thirteenth century', an 'early industrial revolution' etc. to refer to major changes in that period.[9] Another classification refers to the period from 1750 to about 1960s as the industrial age and the period after that as the second machine age. However, in this paper, the period from 1750 to 1830s will be referred to as the 1st IR, 1850s to 1950s as the 2nd IR, 1960s to 2000 as the 3rd IR and from 2000 to the present as the 4th IR.

4.2 The 1st IR was characterised by replacement of human skills by mechanical devices, human and animal power by inanimate power – in particular, steam. The core industries of this revolution were textiles, iron and steel, heavy chemicals, steam engineering and railway transport.[10] Iron was introduced for shipbuilding and there was a changeover from paddle to screw propulsion. Surface condensers and steam engine were used in propulsion.[11] Britain played a leading part in diffusing and financing new technology in the railways and in shipbuilding.[12]

4.3 The 2nd IR was characterised by use of electricity, petroleum and steel.[13] A cheaper method of steel production was invented[14] and steel replaced iron in construction, machines, railroads and shipbuilding. There was an increase in number of Iron armoured and then Iron clad ships; subsequently steel replaced iron. Compound steam engines with superheated steam were used in new designs. New applications included use of steam turbines, diesel engines, changeover from rivets to welding, wireless telegraphs, radars, submarines and launch of aircraft from ship. The demand was also propelled by the 1st and the 2nd World Wars.

4.4 The 3rd IR began in 1960s and is characterised by the digital revolution. It was built around advances in semiconductors, integrated circuits (IC), computers, internet and communication technologies. Innovations in semiconductors helped improve communication and data processing and successful demonstration of IC in 1958 enabled higher complexity of digital circuits.[15] This ushered-in an era of greater automation in ship systems.

4.5 The 4th IR, encompasses technologies such as Artificial Intelligence (AI), Machine Learning (ML), Virtual/ Augmented Reality (V/AR), 3D Printing, Blockchain, Autonomous Vehicles, advanced materials, Digital Twinning, Internet of Things (IoT) and Cyber Physical Systems (CPS) and has made inroads into diverse applications in the maritime world. It is the fusion of diverse technologies and their interaction across the physical, digital and biological domains that makes the 4th IR fundamentally different from the previous revolutions.[16] These technologies have found generic applications in diverse fields and have also had an impact on mercantile marine and warship building. The 4th IR facilitates 'Industry 4.0'; more specifically 'Shipyard 4.0' or 'smart shipyards'. Against this backdrop, it is important to examine some of the new technologies that have been implemented as enablers in ship design and construction.

**5. Enablers in Ship Design-I: Virtual reality / Augmented Virtual Reality**

5.1 **Technology**. VR is an application where a virtual location is digitally created and the physical presence of the viewer is simulated in a manner that the viewer can use headsets, gloves etc. to move around and interact with the virtual environment. In AR, physical objects are identified in a location and information related to them is augmented by computer generated inputs using devices such as smart phones, tablets and head-mounted displays that detects its position relative to the real-world environment around it.[17] Features of AR and VR are also combined in a single application referred to as 'mixed reality'.

5.2 **Implementation**. Virtual Reality (VR) and Augmented Reality (AR) are rapidly emerging technologies that are revolutionising design, maintenance and training in shipbuilding. One such application is being developed for shipbuilding and maintenance, by a Norwegian company using Microsoft 'HoloLens' technology in a headset that makes it possible to see reality with an overlay of digital information, move around on the ship, talk on phone and cooperate with colleagues at any remote location sharing the same picture.[18]

5.3 Many AR/VR enabled software applications are now available as open source, free or commercial-off-the-shelf and are supported by different platforms like Windows, Linux, Android or iOS. Shipyards choose their preferred software, compatible hardware like the tablets or hand-held or head-up displays, advanced game engine etc. and develop an integrated system which has features of geo-location, localisation and mapping to map an environment, track movements and aid navigation.

5.4 A common architecture of an integrated enterprise-wide solution for a Shipyard 4.0, common to warships and merchant ship building, consists of a Visualization and Interaction (VIS) layer of hand

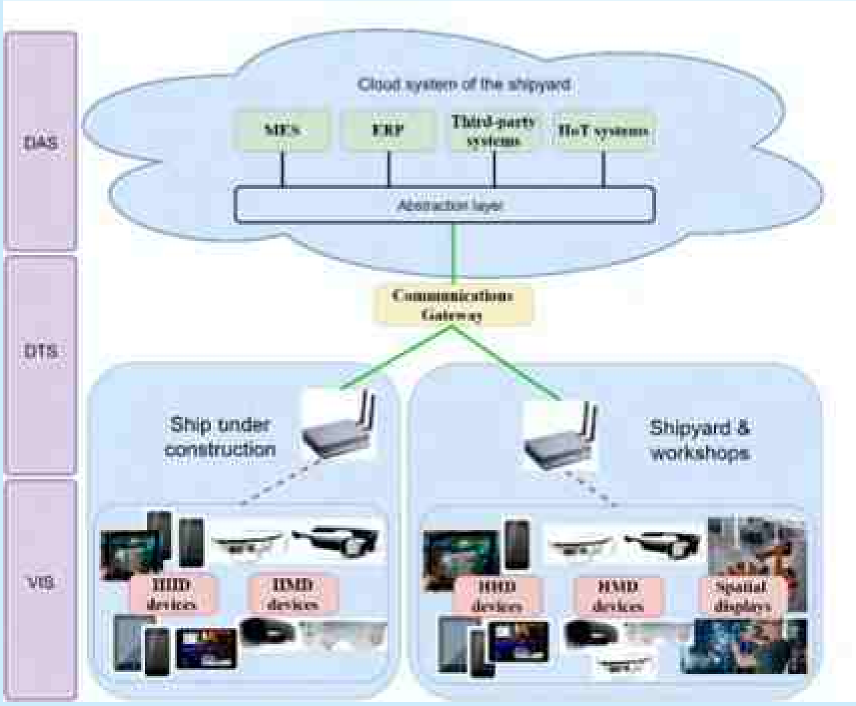
**Fig. 1: Example of video-mixed display**

**Fig. 2: Localisation of products inside a workshop using an Industrial Augmented Reality ( IAR) system**

held and head mounted devices used by the workers onboard ship under construction or on the shop floor, a Data Transport System (DTS) which is a combination of wireless and fibre optic networks to transport the data to the Data Abstraction System (DAS) integrated in the cloud with the ERP, third party software, Industrial Internet of Things (IIoT) and mobile edge computing systems *(see Fig. 1 and Fig. 2)*. Many shipyards are investing in development of such VR/AR intensive technologies to enhance productivity. Navantia shipbuilders created a joint research unit Navantia-UDC (University of A Coruna) in end 2015 to study application of different Industry 4.0 technologies to shipyards with one of the verticals as 'Plant Information and Augmented Reality'.[19]

5.5 3D virtual reality models are replacing erstwhile wood or cardboard mock-ups and stakeholders

**Fig. 3: Traditional IAR Architecture**




can now walk-through the ship before it even gets off the drawing board to indicate any changes required. Unlike the 2D CAD drawings which required engineering skills and knowledge, the 3D models are used by stakeholders to immerse themselves and contribute to refine the design evaluating piping layout and cable routing, unshipping route and access for maintenance of a fitted equipment etc.; this obviates re-work and optimises overall cost and build period. BAE Systems has used Oculus Rift, a VR headset that presents video or computer graphics in 3D for video game industry to build 3D full scale model of the OPVs under construction and to design Type 26 Frigate for the Royal Navy.[20]

5.6 AR is replacing drawings, bringing cameras into the shipyards and putting computers in the hands of everybody. It builds on the inputs from the 3D models and is extensively used for training, knowledge management and to add value in construction activities such as welding, painting, quality control etc. During construction of very large ships like aircraft carriers, temporary steel is installed at various locations in the initial stage and removed later. Newport News Shipbuilding (NNS) employed AR to locate and remove temporary steel while constructing USS Gerald R. Ford by providing step-by-step instructions to workers using visual overlays which showed temporary steel in a different colour on the hand held devices. NNS started exploring AR in shipbuilding in 2011 and is developing commercial AR applications in collaboration with Index AR Solutions. It aims to make CVN-80, the future USS Enterprise as the first paperless aircraft carrier.[21] Such applications are attracting large investments and the AR/VR is expected to create a global market of US $80 bn by 2025.[22]

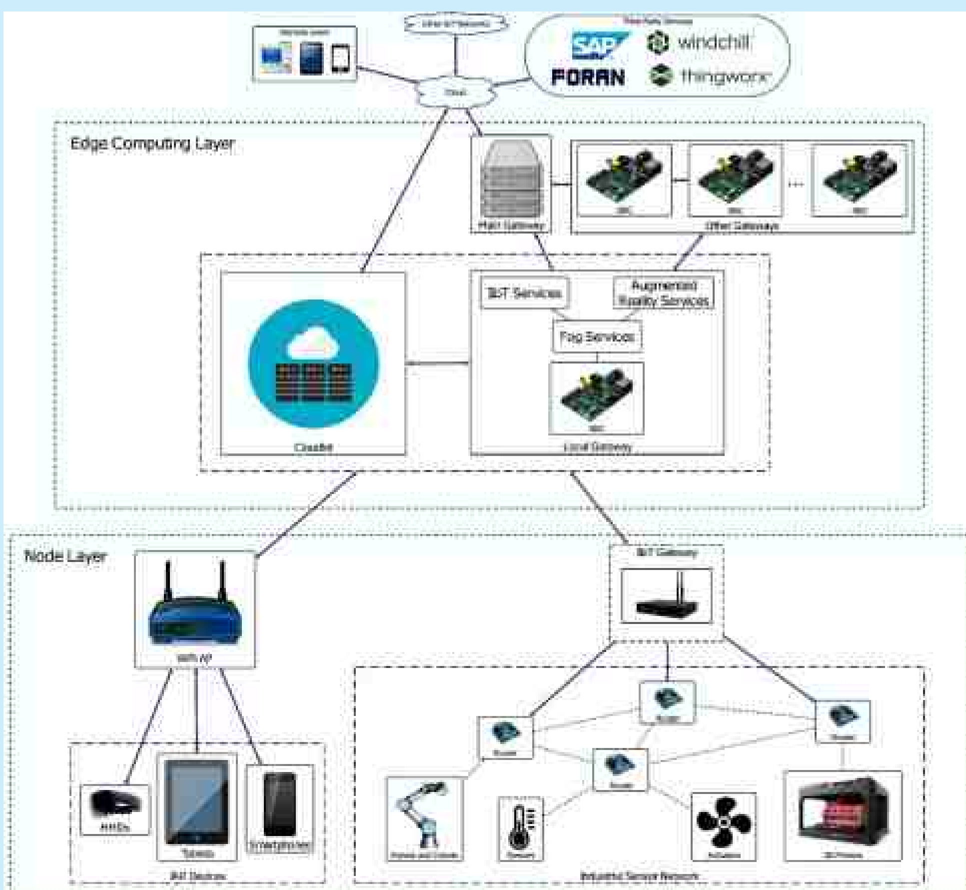
5.7 A typical Shipyard 4.0 can implement applications of the IAR across the departments as efficiency enablers as listed in *Table 1*. A proposed architecture of the IAR system is shown in *Fig.3 and Fig.4.*

## 6. Enablers in Ship Design-II: Artificial Intelligence

**Table 1: Applications of IAR Across Shipyard 4.0**

| Service | Manufacturing | Sales and Marketing | Design | Operations | Training |
|---|---|---|---|---|---|
| Manuals and Instructions | Quality Assurance | Product analysis and Demos | Collaborative engineering | Head-up displays | Job specific training |
| Inspections and verifications | Maintenance Work Instructions | Logistics, retail space optimization | Inspection and digital prototypes | Digital product controls | Safety and security training |
| Remote expert guidance | Performance dashboards | Augmented brand experience | Augmented interface | Augmented operator manuals | Expert coaching |
| Improved service and self-service | Assembly work instructions | Augmented advertise-ment | Error diagnosis | Augmented interface | |

**Fig. 4: Architecture of the IAR system proposed.**



6.1 **Technology**. Artificial Intelligence (AI) started as the branch of computer science that aimed to make computers follow logical steps to do some of the basic functions that the humans performed using common sense and evolved from imitation, extension, augmentation and finally reached human-level AI. In 1956 John McCarthy used the coinage 'Artificial Intelligence' and proposed a summer research project on the subject at the Dartmouth college involving scientists of psychology, mathematics, computer science and information theory; marking the beginning of AI as a science and engineering of making intelligent machines and recognising it as a field of research.[23] Technologies driving AI have since evolved from conventional programming using logical steps, heuristics using neural networks, machine learning using big data analytics to the ability of self-evolution. As a part of AI, machines simulate human intelligence processes like learning (acquire information and the rules for using that information), reasoning (using rules to reach approximate or definite conclusions) and self-correction to find application in expert systems, speech recognition and machine vision.[24]

6.2 **Implementation**. AI enabled advanced robotics are increasingly used in the workflow of shipbuilding where robotics process automation (RPA) are programmed to perform high volume repeatable tasks. Hyundai heavy Industries Co. has completed testing of a 670-Kilogram industrial robot which automatically shapes a vessels' 3D curved surface *(see Fig. 5[25])*. It can be used to curve and weld steel pieces for the ship by connecting remotely to the computers on which the design software is running.[26]

**Fig. 5: courtesy of Yonhap News Agency**

6.3 Artificial intelligence methods are used in the preliminary ship design of cargo ships to optimize performance and achieve minimum of propulsions power and maximum of deadweight simultaneously.[27]

### 7. Enablers in Ship Design-III: Internet of Things

7.1 Technology: Internet of Things (IoT) is network of physical objects that are embedded with electronics, software, sensors and connectivity in which various sensors and actuators are interfaced with computers on the network. The IoT has been widely adopted in many fields such as connected cars and homes, smart factories, wearable devices, intelligent infrastructure and manufacturing industries.[28] New applications are transforming common objects to connected devices over the internet making ubiquitous computing[29] a reality and grow beyond consumer applications to provide framework for industries in the form of Industrial IoT.[30] Internet of Everything (IoE) is the networked connection of people, process, data and the IoT.

7.2 **Implementation:** Shipyards are making smart ships by fitting hull monitors, equipment sensors, machinery diagnostics devices and CCTVs etc., during the construction and integrating them with compatible software platforms provided by global mobile satellite operators to implement IoT for real time expert systems support from remote location. Inmarsat and Samsung Heavy Industries (SHI) of South Korea have concluded a strategic agreement under which SHI is fitting Inmarsat approved hardware which can then be used with FleetXpress platform of Inmarsat using a dedicated bandwidth provided to certified owners.[31] Large volumes of data available from ships at sea are transforming maintenance as well as accurate planning of next sorties. These are also the building blocks towards improving design of the follow-ons and will help in evolution of the autonomous ships.

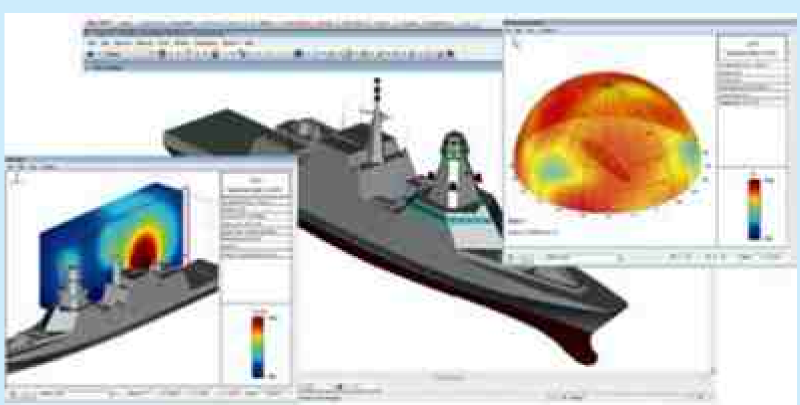
## 8. Enablers in Ship Design-IV: Computational Electromagnetic Simulation Tools and Quadcopter based Validation

8.1 **Technology**. Computational Electromagnetic (CEM) simulation software such as *Ship Electromagnetic Design Framework (ShipEDF)* provides detailed models and simulations of the electromagnetic environment, **infrared signature** and **radar cross section** of a new ship's design and makes use of advanced electromagnetic solvers as well as analytical, computational and design procedures spanning across conceptual design phase to construction and final acceptance stages of a ship. This adds a new chapter in ship design which traditionally relied primarily on hydrodynamic design at the initial stages.

8.2 **Implementation of CEM Framework.** Till the recent past, top deck design of naval platforms has followed conventional wisdom and frameworks animated by empirical measurements in real-time, often on completion of ship construction, at various stages of acceptance trials by customer. At this stage the scope and scale of any modifications to the ship's design were constrained, expensive and time consuming thereby leading to operational limitations on exploitation of the critical EM suite. Computational Electromagnetic (CEM) simulation software such as *ShipEDF* is now used to provide detailed model and simulation of the electromagnetic environment, **infrared signature** and **radar cross section** of a new ship's design for analysis and early course correction. This has had a multiplier effect on optimal top deck designs of ships resulting in efficient utilization of plethora of complex equipment suite onboard platforms.

8.3 **Quadcopter Based Validation**. In a further fillip to CEM based simulation, customized interfaces of quadcopter with electromagnetic and photogrammetry payloads has elevated the protocol of real-time validation of CEM results to a new paradigm, the first known instance of which has been

**Fig. 6: CEM simulation in shipEDF environment (courtesy IDS Italy)**



successfully tested in the Indian Navy very recently. In contrast to the physical measurements onboard ships using man-held instruments, use of quadcopter has enabled real-time aerial 3D EM mapping of platforms and their photogrammetry to validate simulation results with consummate ease and amortized costs in the long run. It also paves way for revolutionizing use of quadcopters with specific payloads towards enhanced efficiency of life cycle management of ships. Clearly, use of shipEDF framework in conjunction with quadcopter based validation arrangement can be touted as a paradigm shift in the overarching scheme of ship construction testing and life cycle operation.

**Fig. 7: Quadcopter make- Irbis, used as part of measurement setup (picture courtesy IDS Italy)**

## 9. Enablers in Ship Design-V: 3D printing - the 'Additive Manufacturing' process

9.1 **Technology**. 3D printing or additive manufacturing is a method in which an item is manufactured by building up layers of two dimension (2D) repeatedly to add up to the final product. The basic requirement of this process is to prepare a three-dimensional (3D) digital model of the product and then extrude specified material in a controlled environment to mould up layer by layer to manufacture the desired product. 3D printing was initially used for 'Rapid Prototyping'.[32] This manufacturing process has rapidly grown to connect the digital and the real world and is now being used to manufacture the product itself.

9.2 The shipbuilding industry uses 3D printers to print the models of ships during design, unlike the other industries the printed models are used as functional models and subjected to mechanical loads for optimising the design specially of appendages like rudders etc. A German hydrodynamics research organisation Hamburg Ship Model Basin (HSVA) reported a 70 per cent slash in lead production times and an overall cost reduction of around 30 per cent after using 3D printers for two years.[33] Use of 3D printed models makes it possible to have more iterations for early finalisation of design, present the promotional models for better appreciation of the customer. This technology compliments lean and 'just in time' processes and one-piece flow in Naval and Maritime constructions. 3D printing is being increasingly used to manufacture micro panel profiles, non-standard brackets and outfitting equipment like double bottoms, side shells – single and double skins, decks and longitudinal bulkheads. A major advantage is that it provides capability to manufacture 'one of a kind' steel part or smaller and complex parts without having to machine it or outsource it to a third party, thus reducing the cost substantially.

## 10. Enablers in Ship Design-VI: Blockchain

10.1 **Technology**. The global financial crisis of 2008 was caused by the deregulation of the financial sector and fuelled the idea of an entirely new form of currency which could be transparent and global. A white paper published under the pseudo-name of Satoshi Nakamato in October 2008 presented a blueprint of a peer to peer electronic cash system.[34] First release of the blockchain based digital encrypted currency with a distributed ledger system was released in January 2009 and was managed by bitcoin.org. Although the overall value of global cryptocurrency market is presently estimated to be over $700 billion[35] the underlying blockchain technology has been employed in diverse fields including shipbuilding.

10.2 Implementation: In shipbuilding industry, blockchain technology can integrate the entire supply chain of designers, financers, sub-contractors of services, suppliers of equipment and construction material, quality control inspectors, auditors and customers. The transparent and secure transactions inherent to the blockchain technology will ensure that the multiple agencies involved at each stage of construction are on the same page ensuring trust and removing bottlenecks caused by communication gaps. Maritime Digital Supply Space (MDSS) is a joint project started in 2017 by Lapeenranta University of Technology (LUT), Finland, to develop a blockchain based solution for shipbuilding and involves academia, shipyards and industries like Rolls Royce and Wartsila.[36]

## 11. Enablers in Ship Design-VII: Cyber Physical Systems

11.1 **Technology**. A real world or physical system that has an embedded computer integrated with a communication network, can govern actuators and receive inputs from sensors is broadly defined as a Cyber Physical System (CPS). Such systems effectively form a smart control loop capable of adaptation and autonomy.[37] A system that combines the capabilities of computing, communications and data storage, in order to monitor or control the entities that exist in the physical world are referred to as CPS.[38]

11.2 **Implementation**. The concept of CPS has the potential to transform the production logistics in Shipyard 4.0 by integrating CPS into products, parts and logistics resources. Implementation of CPS can facilitate demand-oriented production supply like in Milk run 4.0[39] and holistically synchronise materials and information flows. It can also automate Kanban approach[40] of the traditional mass-production environments to achieve much higher efficiencies. Logistics processes can be optimized by using CPS based solutions like tracking and tracing heavy load carriers in harbour with RFID positioning systems, complimentary inventory strategies like expediting the required carrier on request, optimising the traffic flow and magnetic traverse of steel products.[41]

## 12. Conclusion

12.1 The technologies under the 4th IR examined are at various stages of development or being already implemented and are built on digital technologies. Any phenomena that gets digitised experiences rapid growth in steps of 'Six Ds of exponentials: digitalisation, deception, disruption, demonetization, dematerialization and democratization'.[42] Once digitized, the growth pattern of that product begins to follow a trend similar to that of information technology which has largely grown as per the Moore's law. An indicator of the impact of expansion of the digitized world is that the processing power has increased one trillion-fold from 1956 to 2015.[43]

12.2 Since most of the emerging applications have high content of digitisation and networking, the issue of cybersecurity is becoming central to provide assured service. During the 3rd IR, in the information age, cyber security industry focussed on protecting the confidentiality of data of an individual. However, the technologies of the 4th IR are getting more integral to human functioning from health to artificial intelligence and autonomous operations, thus transcending the scope of cyber security from mere data protection to ensuring digital integrity and availability.[44] As more technologies of the 4th IR get implemented as efficiency enablers in the shipyards 4.0, cyber security infrastructure must evolve in-step for assured productivity enhancement.

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# INTEGRATED CAD-PLM ENVIRONMENT (ICDE) FOR DESIGN, CONSTRUCTION AND LIFE CYCLE MANAGEMENT OF WARSHIPS / SUBMARINES

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**Nomenclature**

| | |
|---|---|
| CAD | Computer Aided Design |
| CAE | Computer Aided Engineering |
| CAM | Computer Aided Manufacturing |
| PLM | Product Lifecycle Management |
| ICDE | Integrated CAD-PLM Environment |
| IDP | Integrated Data Package |
| BOM | Bill of Material |
| System Owner | Team / Group responsible for development of respective systems |
| Compartment Owner | Team / Group responsible for configuration management of respective compartments / zones in the vessel. |

**1. Introduction**

1.1 Design, construction and maintenance of warships and submarines is one of the most complex engineering challenge requiring harmonic interfacing and synchronizing of large number of engineering disciplines for the vessel to meet its desired intent. The intensity of complexity varies with ship type, requiring interfacing 100 to over 200 systems comprising of various types of structures subjected to different types of loadings, mechanical systems comprising of propulsion, steering and stabilizing, ballasting – deballasting, hydraulics, compressed air, HVAC and air purification, fresh water, fire fighting and damage control etc., Living spaces, electrical systems comprising of power generation and distribution networks, controls, EMI / EMC, navigation, communication etc. and the weapon systems.

1.2 With such large number of systems are required to be configured towards meeting the operational requirement of a vessel, the design activity needs to encompass generation of thousands of design drawings and documents towards manufacturing / assembling / integration of tens of thousands of individual parts comprising of structures, equipment, fittings, piping, cabling, sensors etc. The vast amount of data generated and its management requires a strict configuration management and control.

1.3 The last few decades have seen development of various digital design and construction solutions relating to 2D CAD and progressing to 3D CAD, Naval Architecture studies, Finite Element Analysis, Flow Analysis, Computational Fluid Dynamics, Digital manufacturing etc. While, the solutions were being developed to address specific areas of design and construction, "Product Data Management (PDM)" and later "Product Lifecycle Management (PLM)" software separately emerged as a solution for managing industry processes related to management of lifecycle of a product from its conception, through design and manufacturing, to service and disposal. Interfacing of CAD and PLM started with a humble beginning with management of documents generated in the various design solutions and management of workflows related to approvals and release of data.

1.4 However, with the potential for advanced bi-directional integration of 3D CAD with PLM, and integration of CAD with other Naval Architecture and CAE applications, new horizons have opened up not only for design and construction of vessels but also for life time management and maintenance / upgrades of the vessels.

1.5 In an environment of not having an inherent robust R&D and material / equipment developer base that is commensurate with the technological requirement of the platform, dependency on foreign OEMs / ToT becomes inevitable. This invariably leads to the stretching of the cycle time for vessel design and construction, resulting into a concurrent design and construction scenario. A strict configuration control over the vessel design and construction is therefore required to address any consequent situation of suboptimal designs / redesigns, extended construction periods, cost overruns and impact on force level availability.

1.6 An Integrated CAD-PLM Environment (ICDE) has emerged as the only logical solution today to address this requirement. Whereas such digital design and manufacturing environments have been successfully implemented in automobile, aerospace and energy sector, use of such an environment for warship design and construction is still at a nascent stage in India.

1.7 This paper presents the concept and architecture of ICDE addressing the needs of the Indian Navy for efficient development and management of design, construction and life cycle of vessel. The paper covers the ICDE architecture in following sequence:-

(a) Concept Design.

(b) Sketch Design.

(c) PLM Classification Structure for Classification Parts

(d) Technical to Detailed design.

(e) ICDE for Construction Applications.

(f) Crew Module encompassing Exploitation documents, Training capsules, SFD, Maintops, D787, Spares management etc.

(g) Repair / Refit Module encompassing As-Built drawings, Repair documents / norms, OEM documents and part list etc.

(h) Integrated Data Package.

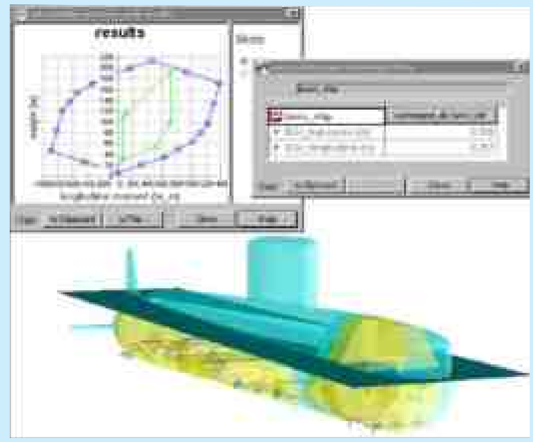
**2. Concept Design**

2.1 Once the draft Staff Requirements (SRs) have been formulated, the design exercise commences with the Concept Design. The concept design stage may lead to the development of multiple variants with an initial development of vessel architecture comprising of broad general arrangement, displacement calculations, main dimensions, powering requirements, speed and range and weapon package for each variant. The design studies also include application of new technologies, extent of automation, use of new materials etc. The variant selected results in finalization of the Staff Requirements.

2.2 Conventionally, the concept design studies are undertaken based on “type ship” data, building block method, graphical methods, design norms and parametric studies. Lately, CAE software have been developed based on 3D CAD platforms to undertake the concept design studies featuring geometric product modelling, hydrostatic and stability calculations, hydrodynamic calculations, structural calculations and broad general arrangement / sub-division of vessel in building blocks form (see Fig. 1 and Fig. 2). The studies undertaken in the concept design software can be migrated to ICDE along with 3D model and analysis / study reports / documents. Further, the interface between ICDE and software can be made bi-directional and 3D models / data further developed in ICDE can be ported back in preliminary design software for any design iterations, if required.

**Fig. 1: Concept Design – Naval Architecture and Engineering Analysis using Paramarine Software (Courtesy: M/s QinetiQ GRC, UK)**

**Fig. 2: Graphical Representation of Submarine Attitude and Trim Polygon & BG data using Paramarine Software (Courtesy: M/s QinetiQ GRC, UK)**

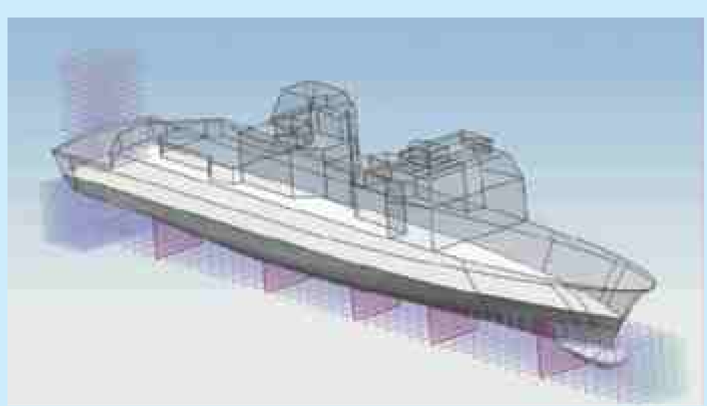



### 3. Sketch Design

3.1 With the Concept Design resulting in drawing up of final SRs, the Sketch Design phase commences with a view to confirm the technical feasibility of achieving the SRs. This phase includes the determination of displacement, speed, range, hydrostatics, hydrodynamics, selection of main machinery, development of major system schematics, and development of broad General Arrangement. It also includes the model tank tests.

3.2 **Reference Planes and Theoretical Surfaces**. As a first step, the reference planes and theoretical surfaces can be developed in ICDE with the geometry created in CAD and volumetric data related to full vessel / compartment / zone captured in PLM in synchronized mode. Any change made in the CAD w.r.t. vessel shape would result in corresponding change in volumetric parameters in PLM. The finalized 3D model can be utilized for generation of Lines Plan and for construction of model for model tank tests. Fig. 3 shows the development of theoretical surfaces of vessel with reference planes, frame stations, decks / compartment subdivision. Each theoretical surface generated can be

**Fig. 3: Seed Part - Development of Reference Planes and Theoretical Surfaces in CAD (Courtesy: M/s Siemens PLM Software Inc.)**



stored as a separate CAD and corresponding PLM part which can be developed / detailed further in next phase of design. The 3D model so generated is named as "seed part" with all deck / compartment subdivisions defined as separate parts in PLM for subsequent design development. Further, as part of ICDE customization, any item located in any one subdivision captures the location attributes of the area with frame numbers, port / starboard location etc.

3.3 **System Schematics**. The next important part of the sketch design is the development of major system schematics. The systems onboard can be broadly classified under two categories – feeder systems and consumer systems. Whereas, the consumer systems can be developed independently based on their respective technical requirements and norms, various components of these consumer systems would need power supply / cooling / controls and instrumentation / hydraulic supply / compressed air supply etc. and are therefore required to be interfaced with feeder systems such as power distribution networks, ship hydraulic system, compressed air systems, fresh water / sea water cooling systems, control systems, HVAC etc. The development of feeder system schematics is therefore dependent on defining the interface requirements with all consumer systems across the vessel. This network and interfacing of systems creates a web shaped network diagram at vessel level with strict requirement of interfacing protocol definition for optimum and accurate design of each interfacing system.

3.4 The ICDE configuration would include development of system schematics in 2D CAD module with synchronized parts creation in PLM. Each system schematic and each part created in the schematic is given a unique ID. The technical parameters of each system and component would reside in PLM in respective "design data sheet" along with required "Interface data sheets" which would be the conduit of technical information exchange through digital workflow in PLM for development of both feeder and consumer system schematics (see Fig. 4). All system schematics / interface requirements are initiated in PLM by respective system owners, routed to interfacing system owner and finally to compartment owner to check feasibility and allocate space in the compartment as per system requirement (see Fig. 5). Further, the ICDE would also facilitate defining structural subdivision requirements like compartments / enclosures / tanks etc. based on functional requirements of each system. Considering an example of a fuel system, the fuel tank forms part of fuel system schematic

**Fig. 4: Interfacing requirement definition leading to development of systems**

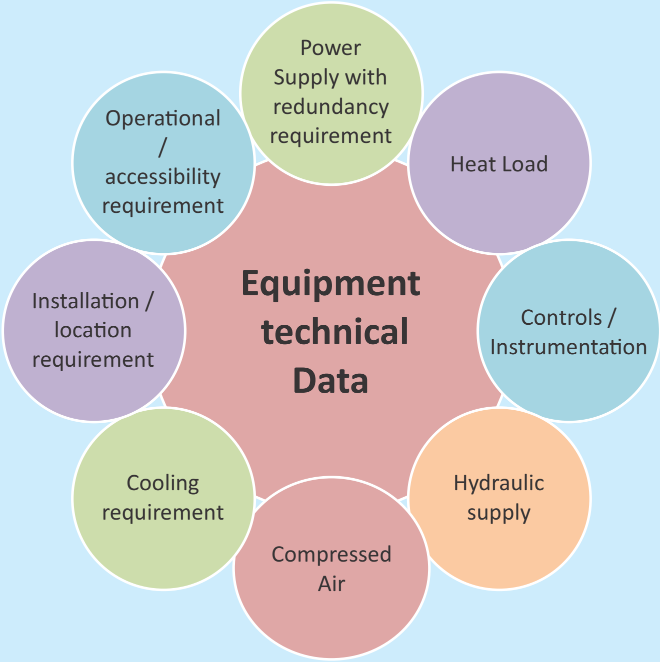
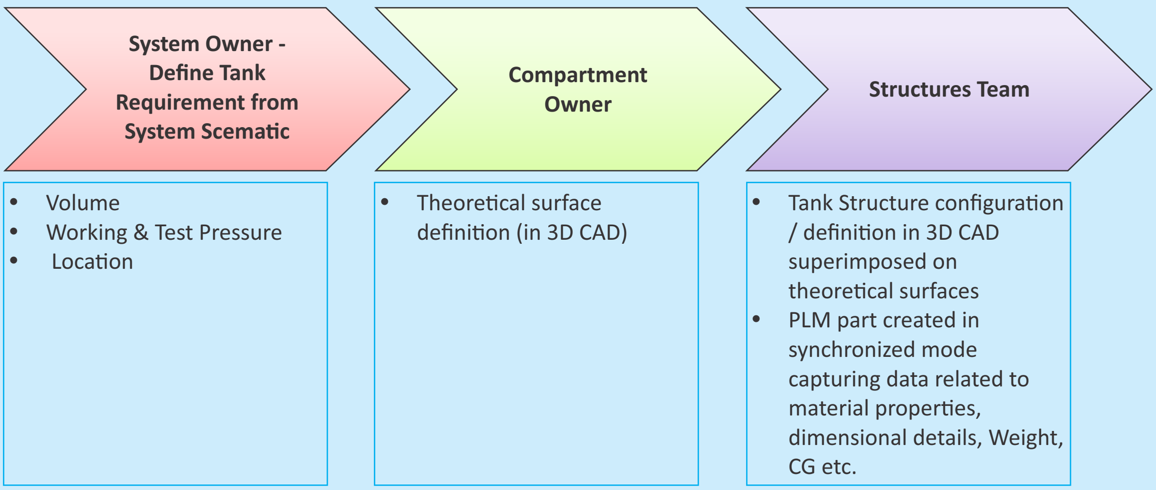


Fig. 5: Workflow for System Schematics development in ICDE


Figure 6: Structural Configuration Development linked to system schematics




defining tank volume, pressure, location requirement etc., and this data is exchanged with compartment owner team and Structural design team through digital workflow in PLM leading to development of structural design of tank (see Fig. 6). The technical / interface data defined at this stage of design could be tentative which could be refined on actual system / equipment development during further design iterations. In each case PLM would capture the complete design history of structures / systems / equipment development.

3.5 **Product Structure**. The vessel Product Structure plays a vital role in ICDE. It creates a 'tree shaped' structured relationship among the various components of the vessel and integrates all product related information enabling easy archival and retrieval. The product structure also indicates the release status / in-workflow status of each item in product structure. By default, the product structure displays the latest version of the items, however, the design history and earlier versions of respective items can be accessed through the product structure. The 3D CAD models are dynamically linked with respective PLM product structure parts and the vessel 3D model can be launched at any level in the Product Structure. Further, by virtue of bi-directional interface between CAD and PLM, CAD sessions can be launched from respective PLM parts and any updation / changes made in CAD generates next version of respective PLM part with updated attributes synchronized between CAD and PLM.

3.6 The Product Structure is configured in “System View”, “Design View” and “GA (General Arrangement) View” as seen in Fig. 7 to Fig. 10. The System View houses all the system schematics, calculation documents, line plan, naval architecture studies / calculations etc. The 2D system schematics are used for schematic driven 3D modelling of respective systems which are housed under the Design View in system-wise configuration. Schematic driven 3D modelling enables comparison run between 2D schematics and respective 3D models to check for mismatches, if any. The GA View houses the same 3D models as in Design View, however, the configuration is compartment-wise thereby giving compartment / zone general arrangement view. By virtue of structuring the 3D models in design or GA view, the Bill of Material can be extracted from the Product Structure either system-

**Fig. 7: Product Structure of vessel in three view with seed part attached as additional item at same level as three views**

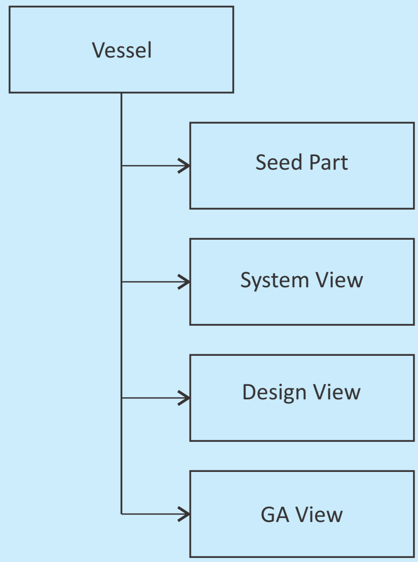



**Fig. 8: System View of Product Structure housing the 2D system schematics, calculation documents, Line Plan, Structural plan**

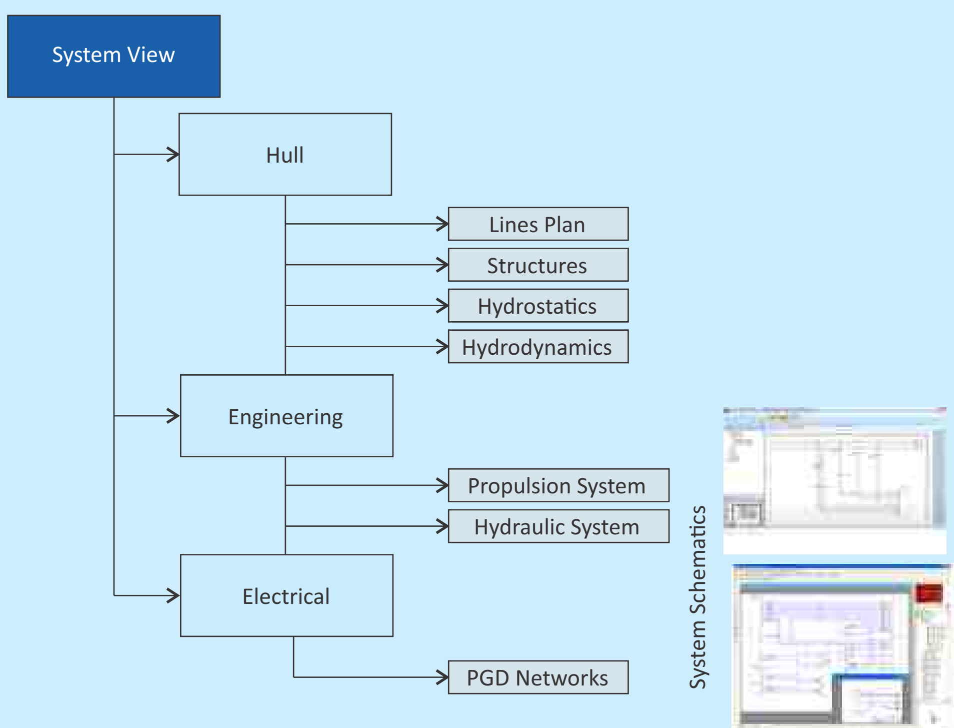


**Fig. 9: Design View of Product Structure housing the schematic driven 3D models**

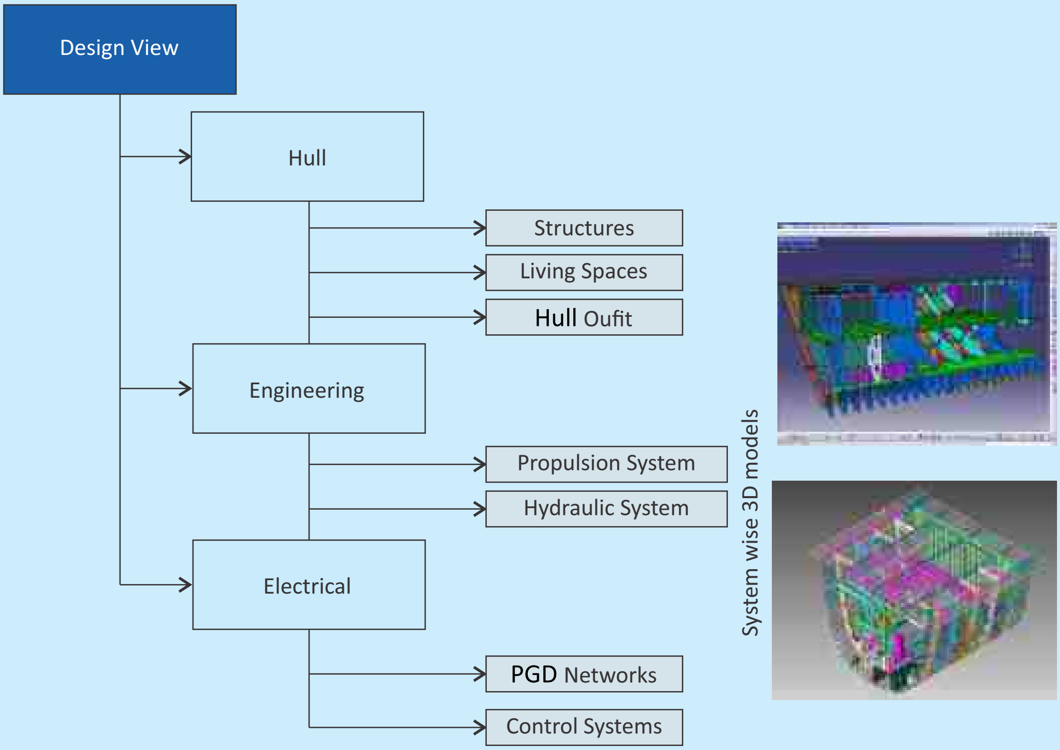
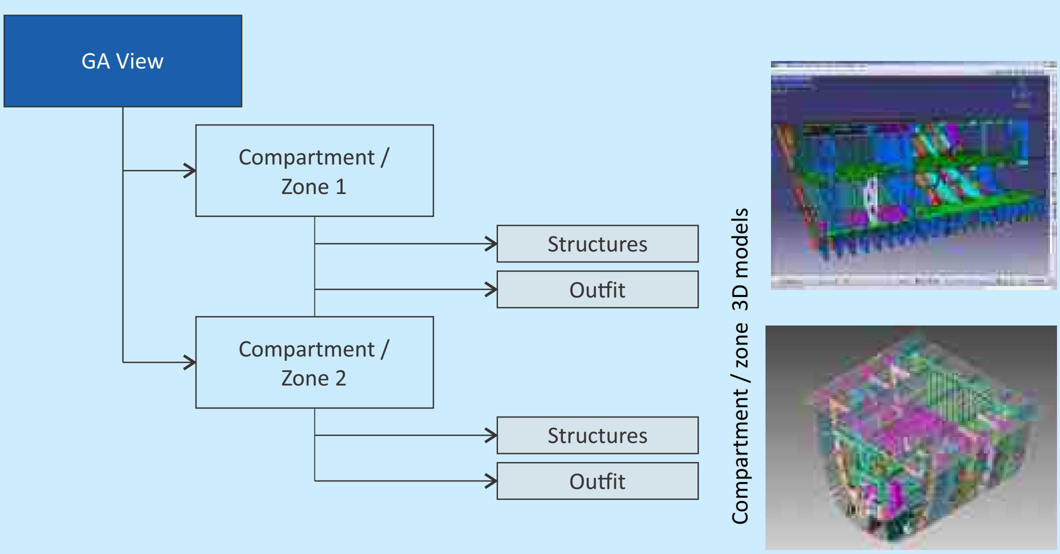



**Fig. 10: GA View of Product Structure housing the 3D models configured compartment / zone-wise**



wise or zone-wise. At the Sketch Design level, the main focus is on development of main system schematics and major structural configuration and hence the product structure in the three views is accordingly populated to the extent of maturity level of the design. On completion of Sketch Design phase, the “vessel” configuration in the Product Structure can be released marking the version definition of Sketch Design phase. For subsequent design stages, next version / revision of vessel and its systems would be generated.

3.7 The 3D model thus generated with structures, main equipment and systems can be used for generation of Bill of Material, weight / CG calculations, displacement, main dimensions in ICDE with generated data getting populated in PLM. The 3D model can also be used for hydrostatics studies and can be further interfaced with CAE applications such as CFD software for hydrodynamic studies in addition to the model tank tests.

**4. PLM Classification Structure for Standard parts (Equipment / Material)**

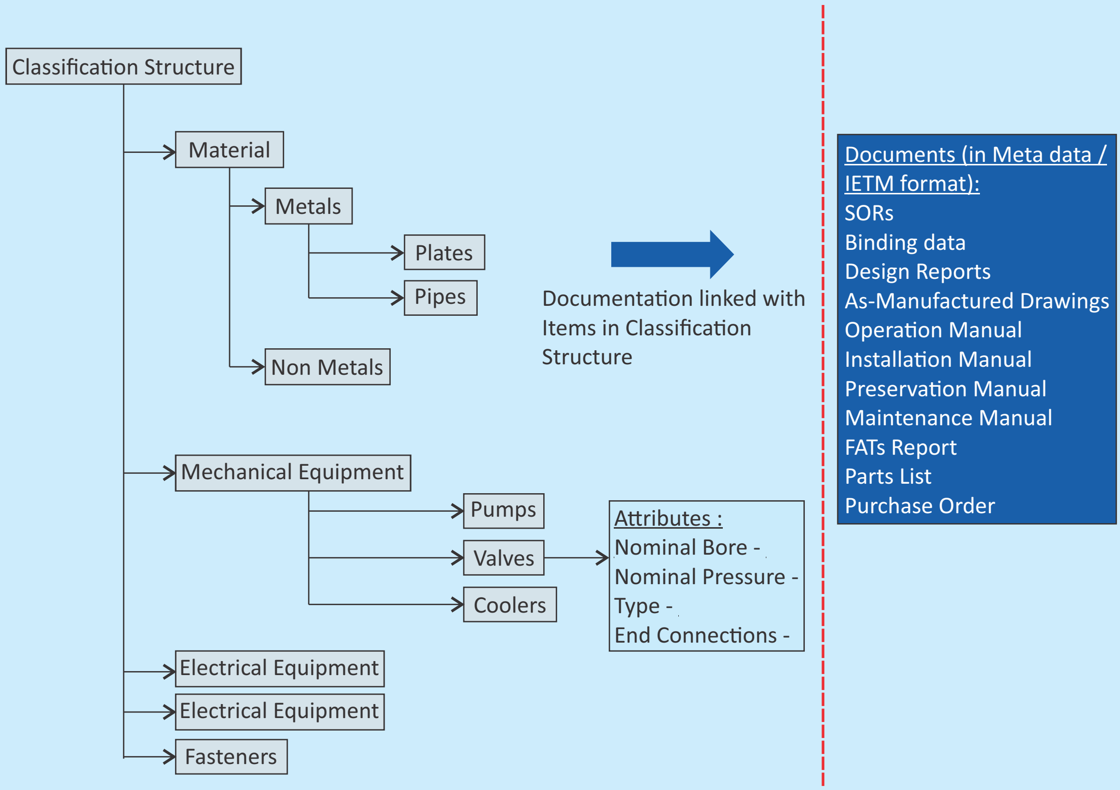
4.1 The PLM classification structure forms one of the main pillars of ICDE in creation of equipment and material catalogue or library. The standard parts used in the vessel are created and classified in the PLM classification structure with attributes and 3D models created / migrated to CAD, associated with the respective PLM parts. Attributes are synchronized between PLM and CAD, as required and finalized parts are released for use in the design of the vessel. All standard parts including materials, equipment, fittings, valves, cables, fasteners etc. are classified in PLM in a logical tree structure with unique IDs. Each branch of the tree forms a family / sub family with its own set of attributes common to the items being classified under the branch.

4.2 The PLM classification structure enables version and variant control of all standard parts, especially for developmental items. With completion of Sketch Design phase, the technical requirements of main equipment and systems are identified. Items already developed by the industry / readily available from previous projects can be incorporated in the classification structure and used in design. However, certain items would need to be developed based on the Sketch Design technical requirements. Accordingly, "Statement of Requirements (SORs)" for such items is generated and initial shape / dimensions are based on either maximum possible space allocation in vessel or extrapolation of similar category equipment. The provisional part with SOR data can be created in the Classification Structure as first version / revision. As the item progresses through the life cycle of development, design data at different stages is incorporated in Classification Structure as subsequent revisions. ICDE platform, shared between vessel designer and equipment developer with suitable “access rules” enables collaborative approach where design data can be shared and reviewed for acceptance in real time.

4.3 The various documents generated through the development lifecycle of the item would also be captured in PLM in "Metadata (pdf files)" or "IETM" format, as generated by the OEM. The documents envisaged to be linked include SORs, Binding data, design reports, final manufactured drawings, OEM documents, FATs reports, inspection reports, Part list, Purchase Order details etc. OEM data, if available in IETM level 4 or above would also enable easy creation of Equipment Product Structure with part list (analogous to vessel product structure) and component level 3D model.

4.4 Fig. 11 and Fig. 12 depict the concept of Classification Structure while Fig. 13 shows the flowchart of digital workflows between the vessel designer and equipment developer towards equipment development.

## Fig. 11: Typical Classification Structure for Standard parts




## Fig. 12: Snapshot of typical PLM Classification Structure (Courtesy: M/s Siemens PLM Software Inc.)

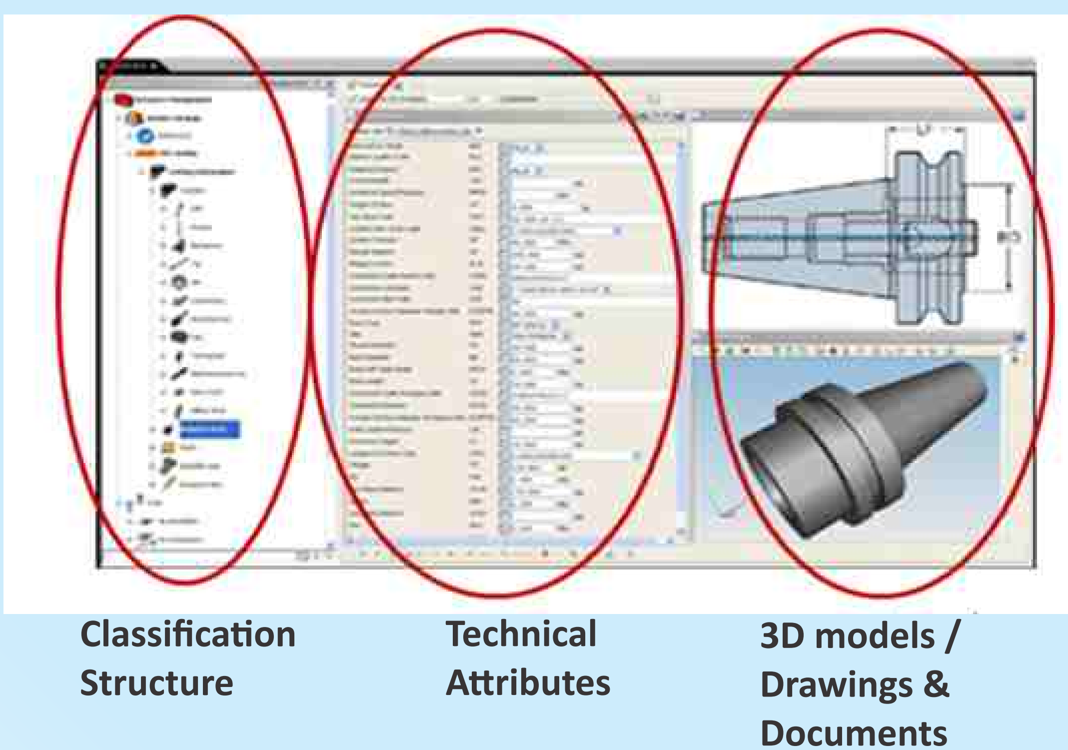
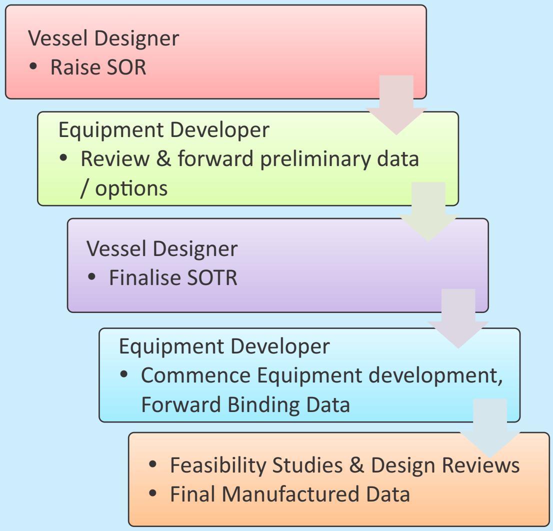


**Fig. 13: Typical equipment development workflow in ICDE**




4.5 As brought out earlier, during development of system schematics in 2D CAD, each component of the schematic is given a unique ID. To create corresponding 3D model of system, each 2D component corresponding 3D model is invoked from the Classification Structure and instantly created in the vessel product structure with same ID as defined in 2D schematic. The system 3D model thus created is linked with the 2D schematic and a comparison check can be run at any stage of design and essentially prior release to check trueness between the two. The Classification Structure also enables creation of multiple instances of one catalogued item in different systems as per design requirement.

## 5. Technical Design

5.1 As brought out earlier, during the Sketch Design phase the aim is to achieve a broad layout of the vessel with displacement, hydrostatics, hydrodynamics, speed, range etc. and development of major system schematics to meet the approved SRs. Another major part of the Sketch Design phase is to draw up SORs for development of new systems and equipment. The preliminary SORs may also be developed post Concept Design phase itself based on the maturity level of the design and the design requirements.

5.2 The Technical Design phase leads to the next level of design maturity with incorporation of binding data of newly developed items / systems, undertaking pipe routing of major systems and large bore diameter pipes of other systems, allocating space for main cable runs, defining all major and minor subdivisions and laying the major devices / components. The General Arrangement of the vessel is prepared to a fairly large detail indicating the architecture of the vessel. This phase also involves undertaking pipe flow analysis of major fluid systems based on pipe routing to establish technical acceptability of systems layouts. Space for systems under development is also reserved. Large number of drawings and calculations are undertaken to confirm to the technical and tactical requirements of the vessel.

5.3 ICDE provides an ideal platform to undertake the Technical Design encompassing the development of structural configuration, equipment layout and system routing in 3D CAD. Developing the equipment and system configuration and layout in 3D CAD ensures an ergonomic layout while studying for any physical and / or logical interferences / clashes. Passage and access routes are defined as soft spaces to ensure no equipment / piping / cabling clashes take place. As brought out earlier, the pipe routing is undertaken using schematic driven 3D modelling and 3D system layout checks can be undertaken with corresponding system schematics. The piping 3D models can be interfaced with CAE solutions to undertake flow analysis. Based on the analysis, the routing geometry can be modified to meet the desired results. Based on the GA development in 3D environment, volumetric and permeability calculations can be undertaken with a very high accuracy by the software.

5.4 While in the Sketch Design phase, technical information exchange is undertaken on 2D system schematics / components using electronic data sheets, the work flows in technical design stage are undertaken on 3D models of corresponding equipment / components. As brought out in the Classification Structure section, all equipment, materials and standard items are classified in the Classification Structure. During the development of a schematic driven 3D modelling, parts from the catalogue are invoked and instance with unique ID corresponding to 2D system schematic part is created. This becomes the initiation point of digital workflows on the instanced parts as illustrated at Fig. 4. The workflows on 3D components facilitate layout optimization, location finalization with orientation, seating / foundation development, piping / cabling interfacing and kinematic studies related to equipment operation / maintenance. In addition, workflows related to power supply requirements, control system interface, head load, hydraulics / compressed air requirements can be initiated on the instanced 3D CAD parts, in case of any change in design / interface data w.r.t Sketch Design phase.

5.5 The Product Structure in all three view gets further developed with detailing of systems and zones. All calculation documents are linked with respective PLM parts with system / equipment attributes (both technical and locational) residing in PLM and synchronized with CAD. The layout and system drawings are extracted from 3D models with accurate Bill of Material for each system / assembly.

5.6 The overall vessel layout with technical acceptance of systems layout and interface is reviewed critically in 3D CAD, towards the finalization of the Technical Design stage. The 3D CAD model can also be migrated to "Virtual Reality" software, both in external or immersive mode to review the layout in detail and also conduct walk-through simulations with mannequins. Further, the Product Structure created in ICDE generates an accurate Bill of Material to facilitate procurement action of materials and equipment. The 3D model can be also used to develop the construction philosophy and can be optimized using 3D simulation studies.

**6. Detailed Design**

6.1 Completion of the Technical Design phase evolves into the Detailed Design which is aimed to generate full set of workshop / production drawings for the construction of a vessel. The number of workshop drawings range in thousands giving detailed construction data, Bill of Material and specifications. Detailed General Arrangement layouts are developed including all structures, systems, gears and components. Detailed construction philosophy, construction / outfitting sequence and shipping-in routes of all equipment is also developed for drawing the Build Plan of the vessel.

6.2 The ICDE serves as the platform for further detailing the vessel design from the Technical Design stage to Detailed Design stage. All balance system schematics are developed along with creation of classification structure of balance standard parts and 3D modelling undertaken to the last detail for each structure fabrication, components and assemblies manufacturing, equipment installation, pipe routing, cable routing, living spaces installations, coatings etc. Detailed layout and systems configuration analysis is undertaken in the 3D CAD prior extraction of the workshop / production drawings.

6.3 Salient benefits accrued from use of ICDE for the vessel design from the Concept Design stage to Detailed Design stage can be summarized as follows:-

(a) Seamless bi-directional integration between CAD and PLM capturing all design data in a single environment, structured and interlinked in a logical manner.

(b) Classification Structure for all standard parts / equipment / assemblies / materials, capturing 3D geometry and attributes along with OEM documents and capturing the complete design history of equipment development.

(c) Creation of Reference Planes and theoretical surfaces defining the vessel subdivision in 3D CAD (Seed Part). The Seed part serves as the 3D space envelope in which the vessel configuration is further developed.

(d) Creation of all 2D system schematics.

(e) Digital workflows for defining unambiguous and seamless interface requirements between various systems. Creation of system schematics interface web.

(f) Generation of new systems / equipment SORs based on system requirement definitions.

(g) Feasibility studies for platform (vessel) integration of systems / equipment under development.

(h) Schematics driven 3D modelling, linking system schematics with 3D models.

(j) Design rules definition in CAD related to structural configuration, equipment layout, pipe routing and cable routing ensuring optimum design.

(k) Digital workflows to develop the vessel configuration between the system designers and the layout developers.

(l) Interfacing with CAE applications for various design analysis (e.g. naval architecture analysis, FEA, CFD, Pipe flow analysis, kinematics analysis etc.)

(m) Capturing the complete design history for each system from concept design onwards with robust revision control mechanism.

(n) Defining the Product Structure of the vessel in a logical manner and in multiple views.

(p) Optimized and ergonomic layouts.

(q) All passages and access routes are defined as soft spaces to ensure that they do not interfere with free routes.

(r) Ensuring operability / maintainability / accessibility requirement of systems and equipment.

(s) Build Technology studies and shipping-in routes definition.

(t) Extraction of error free drawings with respective Bill of Material.

(u) Extraction of detailed Bill of Material at any level in the Product Structure.

(v) Extraction of "Ship Fit Definition".

(w) Accurate weight & CG calculations.

(x) Surface area calculations for painting, insulation etc.

(y) Compartment / zones permeability calculations.

(z) Capturing / generating design drawings and documentation and logical linking of same with respective parts in ICDE.

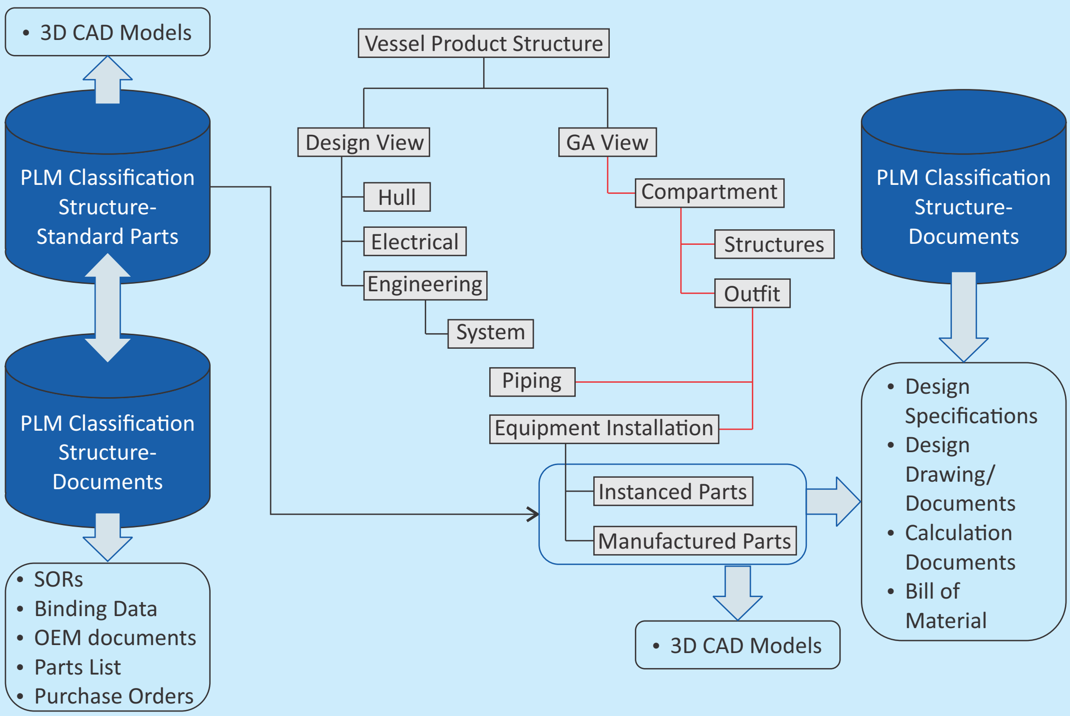
(aa) Logical archival and easy retrieval of design data.

6.4 The ICDE architecture for design activities is seen in Fig. 14.

## 7 ICDE for Construction Applications

7.1 While the ICDE facilitates the complete design and equipment / system development process from concept to detailed design, the design data takes shape of a virtual vessel in CAD with technical attributes in PLM. The virtual vessel shared with shipyard can be interfaced with "Digital

**Fig. 14: ICDE architecture for warship / submarine design**




Manufacturing Solutions" towards facilitating actual construction. Following benefits can be accrued using digital manufacturing:-

(a) Visualization of vessel to be constructed.

(b) Planning and sequencing of construction and development of production strategy.

(c) Design of jigs and fixtures for fabrication / outfitting activities.

(d) Simulation of welding processes, equipment shipping-in etc.

(e) Estimation of "Construction Bill of Material" over and above the design Bill of Material, including manpower / mandays, jigs and fixtures, consumables, building facilities / services etc.

(f) Just-in-time ordering of material and equipment.

(g) Development of "Overall Build Plan" and "Project Planning and Management".

7.2 Further, in a concurrent design and construction scenario, the design data can be released incrementally through ICDE and actual construction progressed can be mapped in the environment. This would facilitate optimum decision making while studying the impact of design changes necessitated due to progressive systems / equipment development towards arresting delays / cost overruns. Further, the design change management undertaken in ICDE, post release of design data, also ensures real-time updation of the 3D model and BOM from design version to as-built version.

7.3 In addition to the above, as in case of design, large amount of data is generated during construction. The ICDE can be shared with shipyard with necessary access rules for the shipyard to access relevant released design data and upload production data in the "Documents Classification Structure" in PLM and link with the corresponding parts in the Product Structure. Salient categories of data generated during construction that can be uploaded and linked in ICDE are as follows:-

(a) Production Drawings.

(b) Quality Assurance and inspection plans.

(c) Process and procedure documents.

(d) Material and equipment certificates / documents.

(e) Receipt inspection and pre-installation inspection reports.

(f) Structure fabrication inspection reports (including dimensional checks, NDT etc.)

(g) Parts / components / assemblies manufacturing inspection reports.

(h) Equipment installation inspection reports.

(j) Piping manufacturing and installation inspection reports.

(k) Structures and piping pressure testing reports.

(l) Piping flushing reports.

(m) Cabling preparation, laying and connectorisation inspection reports.

(n) Equipment preservations records.

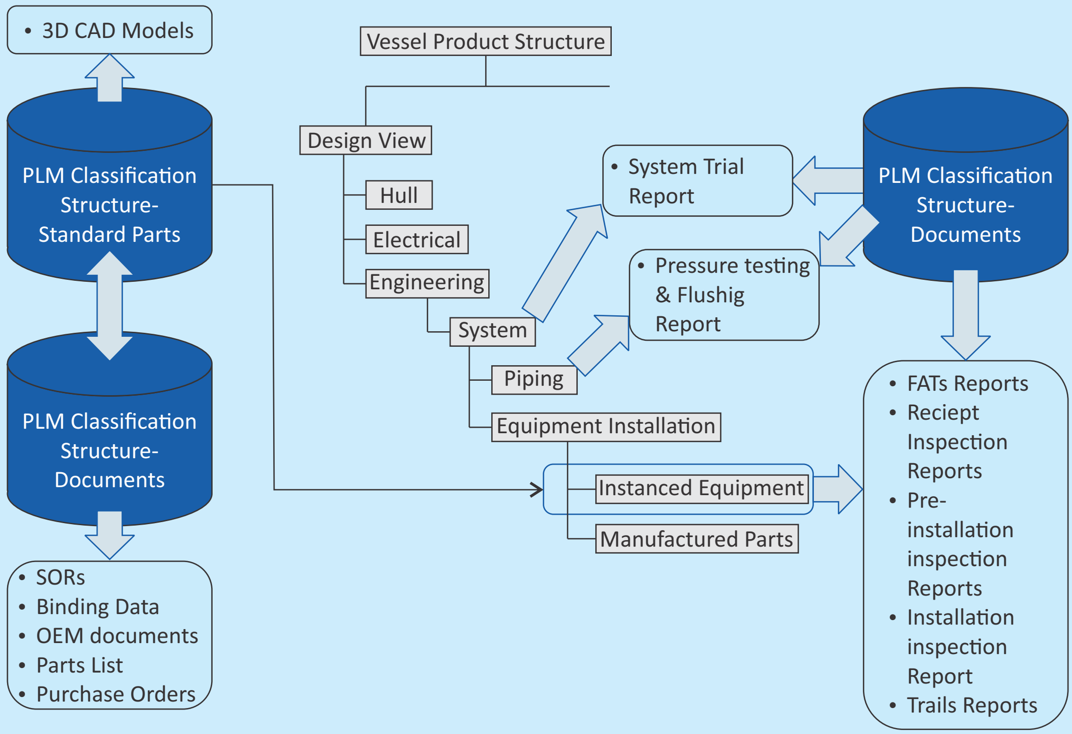
(p) Setting to Work, HATs and SATs reports.

(q) As-built weight and CG records.

(r) As-built drawings.

7.4 A sample ICDE architecture for construction related activities is shown in Fig. 15.

Fig. 15: ICDE Architecture for warship / submarine construction




**8. ICDE for Life Cycle Management – Crew Exploitation Module**

8.1 On completion of the vessel construction with all design and construction data configured and captured in the ICDE, the platform can be extended for the crew's applications. The ICDE being an open architecture platform with 'Product Structure' as the back bone of data configuration, additional data / documents can be generated and uploaded in the environment, linked with the corresponding parts in Product Structure. Salient data / document categories that can be effectively archived, accessed and managed through ICDE are as follows:-

(a) Training documents / modules using 3D animations, generated from 3D CAD models.

(b) Exploitation documents of systems and equipment in IETM format.

(c) OBS and B&D spares.

(d) SFD.

(e) D787.

(f) Maintops.

(g) Maintenance logs.

8.2 Illustration of a typical 3D based IETM that can be linked with Product Structure in ICDE is shown in Fig. 16.

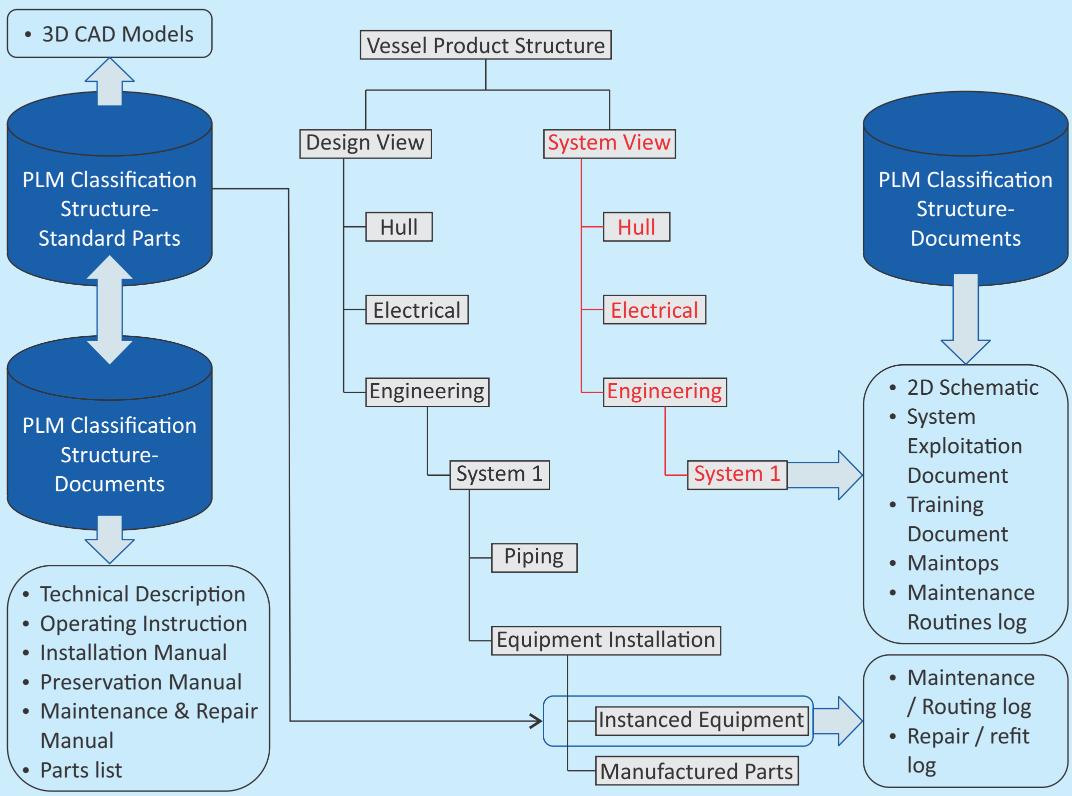
Fig. 16: Images of 3D based IETM and training manuals (Courtesy: M/s Dassault Systems)

## 9. ICDE for Life Cycle Management – Refit Agencies Module

9.1 As in the case of crew, the utility of the ICDE can be extended to repair and refit organizations by configuring and linking "Repair Technical Documents" and maintaining Repair / refit history.

9.2 The ICDE architecture for crew and refit agencies applications is shown in Fig. 17.Integrated **Data**

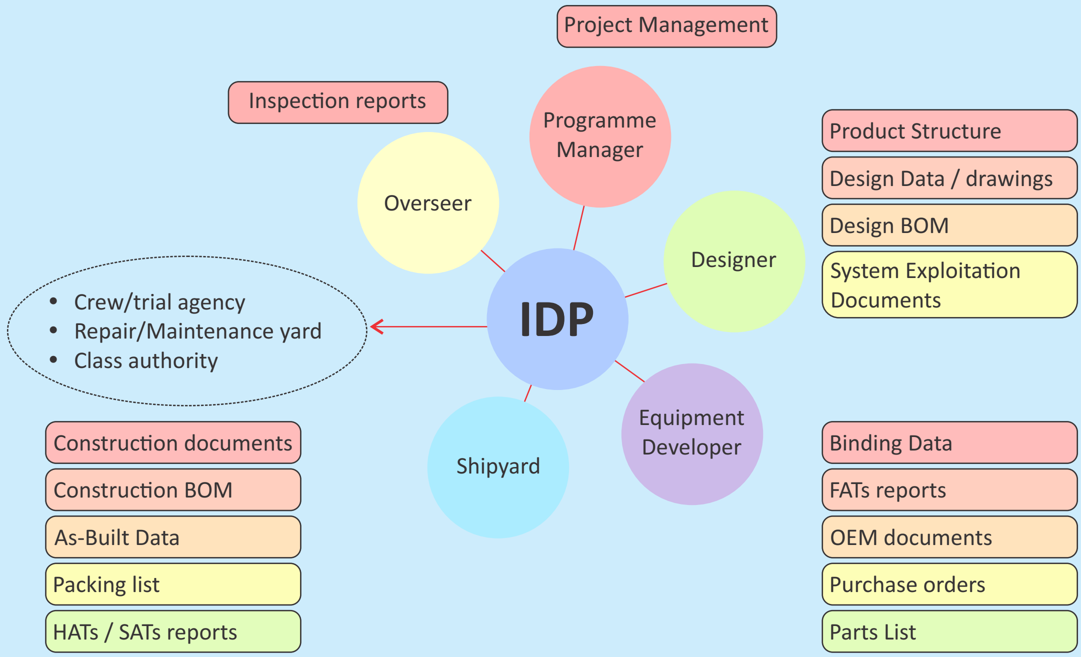
**Fig. 17: ICDE Architecture for crew and refitting agencies**




## 10. Package (IDP)

10.1 As demonstrated in the preceding paragraphs, the ICDE can be configured for undertaking and capturing all design and construction data which can be subsequently packaged with exploitation documents, repair documents, maintenance routines, OEM documents etc. for undertaking life time management of vessel by crew and refitting agencies. The package thus configured may be named as an "Integrated Data Package" which can be shared online and in real time with all stake holders with applicable user access rights. Such an IDP would then serve as a single window access to complete vessel details configured in a logical tree (product) structure, which would be an extremely efficient tool for life cycle management and exploitation of the vessel from womb to tomb. As brought out above, IETMs would also be encompassed within the IDP, linking the exploitation documents, OEM documents with 3D models. A diagrammatic representation of linking all stake holders with IDP ensuring real time data access is shown in Fig. 18.

Fig. 18: Integrated Data Package (IDP) configuration




## 11. Conclusion

11.1 This paper presents the concept and architecture of ICDE towards addressing the needs of the Indian Navy for efficient management of design, construction and life cycle of a vessel. As brought out in the preceding paragraphs, ICDE provides an ideal platform for ***"Womb to Tomb"*** management through the life cycle of vessel beginning from concept design till the decommissioning of the vessel. A list of salient and non-exhaustive benefits accrued from adoption of ICDE for design, construction and life cycle management of a warship or submarine is included below:-

(a) Seamless bi-directional integration between CAD and PLM capturing all design data in a single environment.

(b) Classification Structure for all standard parts and documents capturing 3D geometry and attributes with complete design history of equipment development, along with OEM documents, FATs reports etc.

(c) Creation of a vessel product structure in a logical manner and in multiple views.

(d) Digital workflows capturing the design and development history.

(e) Robust version control and management.

(f) Development of optimum design with ergonomic layouts.

(g) Extraction of error free workshop / production drawings and BOM.

(h) Creation of virtual vessel in 3D CAD with technical attributes mapped in PLM.

(j) Capturing construction data linked with Product Structure (Process documents, jigs and fixtures, construction BOM, inspection reports, trials reports etc.)

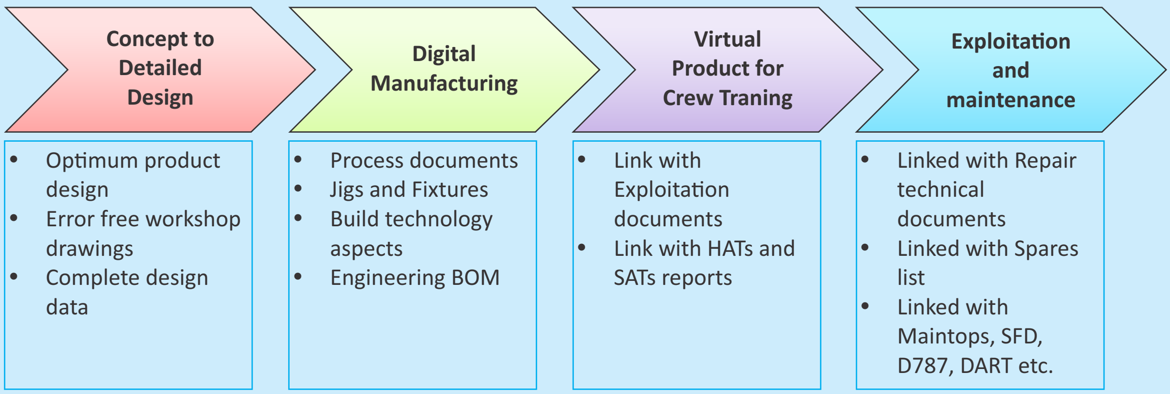
(k) Development of IDP providing single window access for design and construction data in real time between designer, equipment developer, shipyard and overseer.

(l) Virtual product for crew training, linking of exploitation and repair documents in IETM format and Maintops.

(m) Life cycle management including spares management, maintenance logs, refit / repair logs, system / equipment upgradation, replacement etc.

11.2 The concept of “womb to tomb” life cycle management of vessel in ICDE is shown in Fig. 19.

**Fig. 19: Vessel Life Cycle (Womb-to-Tomb) management in ICDE**




11.3 The first leg of ICDE, related to creation of design environment for technical and detailed design has been successfully implemented and is in active use at Directorate of Naval Design (Submarine Design Group) [DND (SDG)]. The ICDE is presently being extended to encompass the concept and sketch design stages. Further, the “Proof of Concept” for subsequent legs has also been successfully tested at DND (SDG). The first step towards creation of an "Integrated Data Package" has been taken in 2017, in the form of setting up of an "Equipment Data Package" linking DND (SDG) with Project HQ, Equipment developer and shipyard through secure WAN for online processing and sharing of all equipment related data used in platform design, comprising of "Statement of Requirements / Statement of Technical Requirements for equipment development, Equipment binding data used in platform design and various OEM documents".

# NATION BUILDING THROUGH EFFICIENT SHIPBUILDING PROSPECTS, CHALLENGES AND POLICY CHOICES

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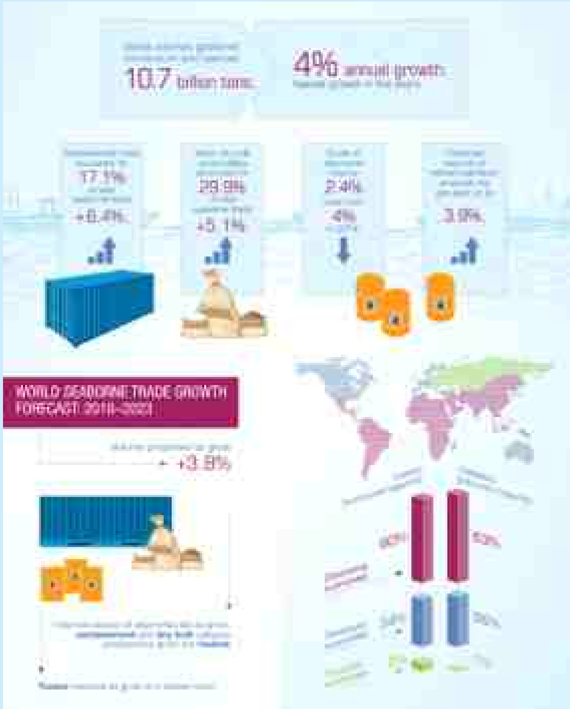
## 1. Introduction

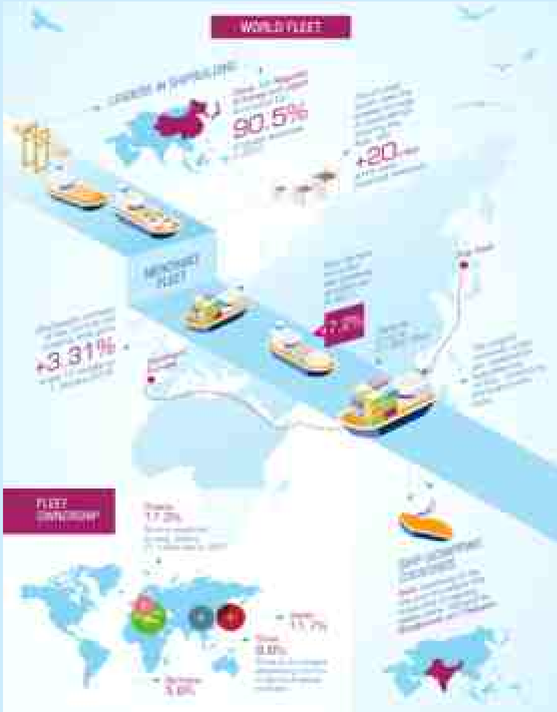
1.1 Shipping is the life blood of the global economy facilitating intercontinental trade and transport of raw materials, import and export of affordable food and manufactured goods. The United Nations Conference on Trade & Development (UNCTAD) (see Fig. 1(a) and Fig. 1(b)) estimates that the operation of merchant ships contributes about US $380 billion in freight rates within the global economy and is responsible for the carriage of around 90% of World Trade.

**Fig. 1(a). World Seaborne Trade in 2017**




*[Source: UNCTAD Maritime Transport Review 2018]*

**Fig. 1(b). World Merchant Fleet**




*[Source: UNCTAD Maritime Transport Review 2018]*

## 2. Nation Building Through Shipbuilding

2.1 The development of a successful shipbuilding sector has been pivotal to the rapid and robust economic development in most countries in the world with long coastal boundaries. Shipbuilding has the potential to increase the contribution of the industry and the services sector to national GDP. The sector has an immense direct and indirect positive impact on most other leading industries such as steel, aluminum, electrical machinery and equipment etc., besides its huge dependence on infrastructure and services sectors in an economy. As a result of its multiplier effect on most manufacturing ancillary industries and on account of its large scale employment generation capability, the shipbuilding industry is also known as a mother industry. Most countries have laid immense emphasis on development of their shipbuilding sectors which has in a way also contributed to national economic development in such countries.

2.2 History shows us that the evolution of nations as manufacturing powerhouses during various periods of time has a strong association with its shipbuilding output. The English during the 19th century and early part of the 20th century, the Americans post World War-II, the Japanese during 1960-90, the Koreans post 1990 and recently the Chinese have emerged as major shipbuilding nations accounting for over 40% (sometimes more than 70%) of annual world ship production in terms of tonnage. It is interesting to note that the period of rise of these countries as economic powerhouses and as major shipbuilding nations overlaps. The shipbuilding industry, in addition to securing vital national security and economic interests, is critical in the development of other sectors such as steel, manufacturing, and other ancillary equipment and product industries. India being one among the fast growing BRIC nations is poised to be a major economic power by 2045. However, India's current shipbuilding output volume indicated in Table 1 is abysmal to match our current economic growth.

**Table 1: New Shipbuilding Orders around the World**

| Rank | Economy | CGT('000) | % |
|---|---|---|---|
| 1 | China | 5,435.70 | 34.55% |
| 2 | Korea | 4,958.70 | 31.52% |
| 3 | Japan | 2,707.70 | 17.21% |
| 4 | Philippines | 359.50 | 2.29% |
| 5 | Brazil | 258.60 | 1.64% |
| 6 | India | 251.80 | 1.60% |
| 7 | Vietnam | 250.80 | 1.59% |
| 8 | France | 208.10 | 1.32% |
| 9 | Croatia | 198.00 | 1.26% |
| 10 | R-O-W | 1,103.80 | 7.02% |
| | **Total** | **15732.20** | **100.00 %** |

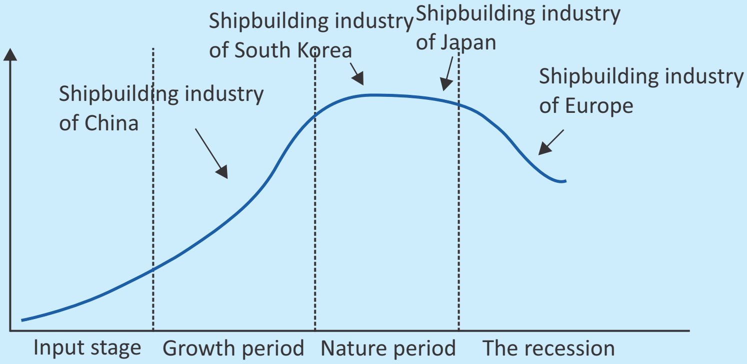
*[Source: Lloyd's register – Fairplay World shipbuilding statistics]*

## 3. Trends in Global Shipbuilding

3.1 World War-II triggered a huge rise in demand for shipbuilding. Post war, the US and the European shipyards dominated the shipbuilding industry. By 1950s, Japan had overtaken the European Shipyards due to its emergence as a global economic powerhouse. The 1970s saw a major crisis in shipping sector and there was a global shipbuilding slump. This lead to massive downscaling and even yard closures in western European countries till the 1990s. South Korea then had just entered the shipbuilding sector, but continued expanding from then on as a result of positive and supportive government policies and better productivity and delivery timelines with cheap labour cost (The Korean Big Four - KSEC, Hyundai, Daewoo and Samsung).

3.2 Having overtaken South Korea in 2009, China has now emerged as the largest shipbuilding nation in the world, currently accounting for as much as 40% of global shipbuilding order book, followed by South Korea (33%) and Japan (14%) in 2013. These three nations together account for

## Fig. 2: Status of World Shipbuilding Industry – Focus *'Asia'*




*[Source: Clarkson's Research Services, 2013]*

around 87% of global shipbuilding. Due to globalization, new players entered the stage, with India, Vietnam, Philippines, and Brazil acquiring substantial order books in the last decade.

3.3 Table 2 presents the trend in global shipbuilding industry, by order book position, during the period 2006 to 2013. In line with the sharp contraction in global trade since 2008, global shipbuilding industry witnessed a sharp and continued down-trend (see Fig. 3), from 368.1 mn Gross Tonnage (GT) in 2008 to 160.4 mn GT in 2012.

### Table 2: Global shipbuilding (>100 GRT) – order book at Year end – 2013 (% share)

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|
| China | 21.4 | 29.6 | 33.7 | 37.0 | 39.5 | 38.7 | 39.6 | 39.9 |
| Korea | 37.0 | 38.4 | 37.4 | 34.7 | 34.3 | 35.0 | 32.5 | 33.2 |
| Japan | 27.3 | 19.4 | 17.3 | 17.3 | 16.3 | 15.8 | 16.1 | 14.2 |
| Philippines | 0.9 | 1.6 | 1.6 | 2.2 | 2.7 | 2.2 | 1.5 | 2.6 |
| Brazil | 0.1 | 0.6 | 0.7 | 0.7 | 0.9 | 1.2 | 2.5 | 2.3 |
| Taiwan | 1.1 | 0.9 | 0.7 | 0.7 | 0.7 | 1.0 | 1.0 | 1.1 |
| Vietnam | 1.0 | 1.0 | 1.2 | 1.0 | 0.9 | 1.0 | 0.8 | 1.1 |
| Romania | 0.8 | 0.9 | 0.9 | 0.6 | 0.4 | 0.5 | 0.5 | 0.9 |
| US | 0.3 | 0.2 | 0.2 | 0.2 | 0.1 | 0.3 | 0.5 | 0.7 |
| India | 0.4 | 0.8 | 1.0 | 1.1 | 0.9 | 0.9 | 0.8 | 0.6 |
| Germany | 2.0 | 1.3 | 1.0 | 0.7 | 0.6 | 0.6 | 0.8 | 0.6 |
| Itlay | 1.0 | 0.8 | 0.5 | 0.7 | 0.5 | 0.5 | 0.5 | 0.6 |
| Total of above | 93.3 | 95.5 | 96.9 | 96.9 | 97.8 | 97.7 | 97.1 | 97.8 |
| **World Total** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** | **100.0** |

*[Source: Shipbuilding statistics 2014 by Shipbuilder's Association, Japan]*

## Fig. 3: Global Shipbuilding Cycle [Source: Clarkson's Research Services, 2013]

## 4. India's Shipbuilding Industry

4.1 The Indian shipbuilding is mainly centred around 27 shipyards comprising 8 public sector and 19 private sector shipyards. The shipyards have 20 dry-docks and 40 slipways between them with an estimated total capacity of 281,200 DWT. India's shipbuilding witnessed a rise from 0.8 mn GT in 2006 to reach 3.5 mn GT in 2008, which was maintained at 3.4 mn GT in 2009. However, the industry witnessed a steady decline thereafter to 1.1 mn GT in 2013. As a result, the share of India in global shipbuilding rose from a marginal 0.4% in 2006 to touch 1.1% in 2009, but has declined steadily thereafter to 0.6% in 2013. Reflecting the sharp rise in India's order book position during 2006 to 2009, India's ranking amongst the major shipbuilders rose from the 10th position (0.4% share) in 2006, to the 6th position in 2008, and further to the 5th position in 2009.

4.2 Thereafter, India's ranking has steadily declined, and in 2013, India ranked at the 11th position. In India, the major policy support mechanism for the shipbuilding industry has been the Shipbuilding Subsidy Scheme 2002, which provided a 30% subsidy and extended to cover private shipyards. However, the subsidy scheme was withdrawn in August 2007. The withdrawal of the subsidy scheme coupled with the Global recession in the shipbuilding industry since 2008 dealt a body blow to the private shipbuilding industry which has been saddled with large unfulfilled order books and huge corporate debts. The comparison of a typical Indian Shipyard vis-à-vis other East Asian Shipyards have been summarised in Table 3.

**Table 3: Summary of comparison of leading East Asian and Indian shipyards**

| Parameter | Leading East Asian Yards | Indian Shipyards |
|---|---|---|
| Product Variety Volume Mix | Few varieties with large volume and many varieties with small volume | Low volume, Moderate-to-High variety |
| Production Volume | Very Large | Small |
| Layout | Product Oriented | Process Oriented |
| Capacity of Facilities | Expanding to meet demand | Insufficient to meet demand |
| Ship Design | Early Start, Done in-house | Late Start, Outsourced |
| Design & Planning Synergy | Extensive | Limited (Very less) |
| Scheduling | Exact Algorithm/ Heuristics | Manual – rule of thumb |
| Automation Level | High | Minimal |
| Pre-Outfitting | 80% | 10% |
| Skilled Workforce | Sufficient | Inadequate |
| Inventory Policy | Just in time | Project basis (Large Inventory) |
| Vendor Location | Very Near (1 hour drive) | Very Far – Across Continents |
| Vendor Integration | Very High | Low |
| Outsourcing | Complex blocks outsourced | Simple blocks outsourced |

## 5. Policy initiatives and Institutional Support Framework in shipbuilding nations

5.1 The summary of favourable policy initiatives and institutional support framework for the shipbuilding industry in various countries have been summarised as under: -

| Ser | Country | Policy Initiatives/ Government Support |
|---|---|---|
| (a) | China | (I) Establishment of China State Shipbuilding Corporation (CSSC), for developing shipyards and ancillary industries.<br>(ii) 5-year Economic Plans with specific mention of the maritime sector with promotion of Joint Ventures & MoUs with Korean and Japanese Yards.<br>(iii) Export credits to borrowers of up to 80% of the value of commercial contracts.<br>(iv) Export tax rebates for the construction of vessels for export.<br>(v) Investment funding reforms allowing Shipbuilding companies to raise capital for plant and site development from public issues or corporate bond sales.<br>(vi) Stabilization of material costs by targeting availability of more than 80& of raw material including steel through domestic manufacturers.<br>(vii) Special Economic Zones for foreign investors with preferential tax, tariff, and investment treatment. |
| (b) | Brazil | (i) Special financing from Merchant Marine Fund (MMF) operated by Brazilian Development Bank (BNDES). |
| (c) | Philipp-ines | (I) Domestic Shipping Development Act 2004 with tax exemption on imports of shipyard equipment and other capital equipment and spares, required for construction, expansion, upgrading, modernization of shipyards and facilities.<br>(ii) Industry accorded "Priority Status", with investment incentives by the Board of Investment. |
| (d) | Malaysia | (I) "Malaysian Shipbuilding and Ship Repair – Industry Strategic Plan (SBSR) 2020.<br>(ii) 70% income tax exemption of shipping company, as well as income tax exemption of persons working on board a Malaysian ship; and income tax exemption for 5 years for shipbuilding and ship repair.<br>(iii) Global Maritime Ventures Berhad (GMVB), as a subsidiary of BPMB, to accelerate the development of the country's maritime industry. |
| (e) | Vietna m | (I) Retention of corporate income tax and capital-use tax for re-investment; preferential corporate income tax; special incentives in industrial zones; protection to domestic shipbuilding industry; import tax exemption; and promoting joint ventures to facilitate technology transfer.<br>(ii) Restructuring Scheme of 2010 has identified 3 major areas for the Vietnam Shipbuilding Industry.<br>(iii) Group (VINASHIN) to become the core of the shipbuilding and repair industry in Vietnam. |

## 6. Intricacies of Warship Building

6.1 The salient differences between commercial and warship building are as under: -

(a) Ship size and complexity.Being a complex multidisciplinary engineering activity involving integration of multitude of equipment and systems, Naval shipbuilding requires significantly higher shipyard effort and dependence on a large number of agencies/OEMs.

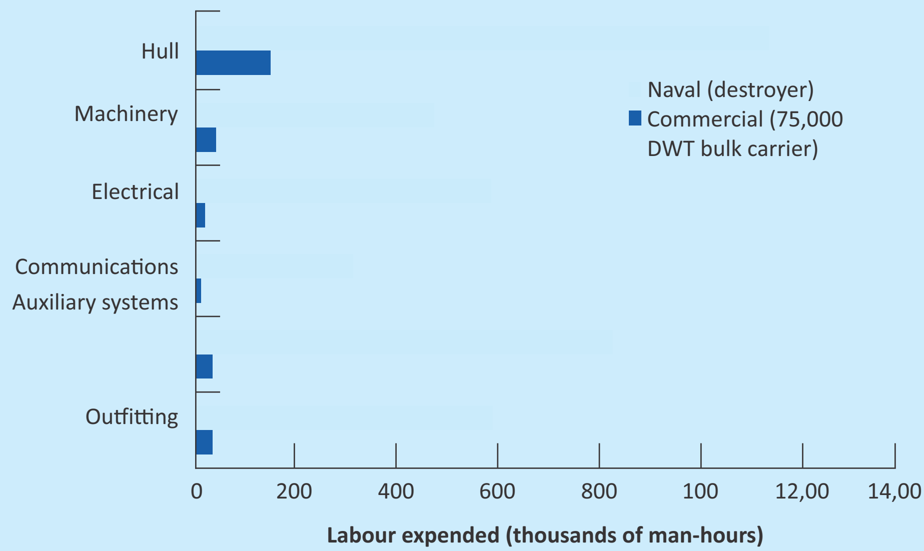
(b) Contracting procedure - More complex.

(c) Design - complex. Ab-initio project specific designs.

(d) Production - Not an assembly line manufacture; limited numbers for production.

(e) Workforce Demand - Warship construction requires much more workforce demand as compared to commercial shipbuilding. A comparison of labour demand in different sections between warship building and commercial shipbuilding is shown in Fig. 4.

**Fig. 4: Warship construction requires much larger workforce.**




*[Source: Differences between Military and Commercial shipbuilding, RAND 2018]*

(f) Low volume and High risk product.

(g) Stringent Quality Control and compliance to Naval requirements of Shock, Vibration, Blast Loads, EMI and EMC etc.

(h) Sea trials – Multi phased weapon system integration and trials.

## 7. Warship Building - Global Scenario

7.1 The naval acquisition plans of major maritime nations over the next 30 years is likely to see an investment of over US$ 835 billion into new warship and submarine construction (see Table 4).

**Table 4: World Naval Market Forecast**

| | In Progress | | Planned | | Projected | | Total | |
|---|---|---|---|---|---|---|---|---|
| **Vessel Type** | **No. of Hulls** | **US$B** | **No. of Hulls** | **US$B** | **No. of Hulls** | **US$B** | **No. of Hulls** | **US$B** |
| Aircraft Carrier | 9 | 49.8 | 2 | 4.0 | 2 | 3.0 | 13 | 56 |
| Amphibious | 129 | 29.5 | 204 | 33.9 | 33 | 3.4 | 366 | 66 |
| Auxiliary | 57 | 8.1 | 112 | 40.1 | 16 | 3.1 | 185 | 51 |
| Corvette | 51 | 7.1 | 43 | 13.1 | 23 | 5.8 | 117 | 26 |
| Cruiser | 2 | 2.6 | 6 | 3.6 | - | - | 8 | 6 |
| Destroyer | 55 | 55.3 | 90 | 113.8 | 3 | 2.9 | 148 | 172 |
| FAC | 147 | 5.5 | 45 | 3.5 | 34 | 2.8 | 226 | 11 |
| Frigate | 193 | 68.8 | 75 | 42.4 | 44 | 17.0 | 312 | 128 |
| MCMV | 28 | 4.5 | 71 | 6.4 | 28 | 2.6 | 127 | 13 |
| OPV | 121 | 12.5 | 139 | 16.7 | 31 | 3.1 | 291 | 32 |
| Patrol Crafts | 1121 | 9.7 | 482 | 7.5 | 157 | 1.6 | 1760 | 18 |
| Submarine | 154 | 142.3 | 142 | 100.7 | 27 | 11.5 | 323 | 254 |
| **Total** | **2067** | **395.7** | **1411** | **385.7** | **398** | **56.8** | **3876** | **838** |

*[Source: AMI International, "2013 Naval Market Forecast", www. amiinter.com]*

7.2 **US Naval Acquisitions**. The US Navy, under the 2014 plan, would buy a total of 268 ships over the 30-year period from 2013 to 2042, which will include 222 combat ships and 46 logistics and support ships.4,5 This includes building one carrier every 5 years, two future ballistic missile submarines, and two advanced destroyers every year, at an annual expenditure of US$ 12 billion per year, in the period 2013 to 2017, which increases to US$ 18 billion per year in the period 2018 to 2022.

7.3 **Asia-Pacific Region**. As per the forecast by AMI International in 2013, the Asia-Pacific naval market will overtake the US to become the world's largest naval market by volume, comprising 1066 vessels or approximately 28% of the market over the next 20 years. This includes over 650 major and minor surface combatants and 116 submarines worth over US$ 167 billion in the next two decades. India and China lead the Asia-Pacific region in projected naval spending. These countries are expected to order 100 new naval ships and submarines, each, by 2032. The two countries combined would account for 30% by volume and 45% by value of these 1048 naval vessels worth US$ 200 billion. China is forecasted to add 16 conventional and nuclear-powered hulls to its fleet over the next 5 years, the greatest number of new hulls by any Asia-Pacific country for this period.

7.4 **Europe**. In this time of tight defence budgets, the increase in cost of defence technology has led to a decrease in the number of ships planned to be deployed by European navies.12 Many North Atlantic Treaty Organization (NATO) countries (excluding the US) continue to restructure their navies and realign new ship programmes to optimize fleet structures in a resource-constrained environment. Future procurements remain relatively flat with 524 ships and submarines forecasted to be built up to 2032, totalling US$ 179 billion.13 Turkey is the only country in NATO Europe, which is expected to be procure almost 100 new hulls worth an estimated US$13 billion, in this period.

**Table 5: Global Fleet Strength**

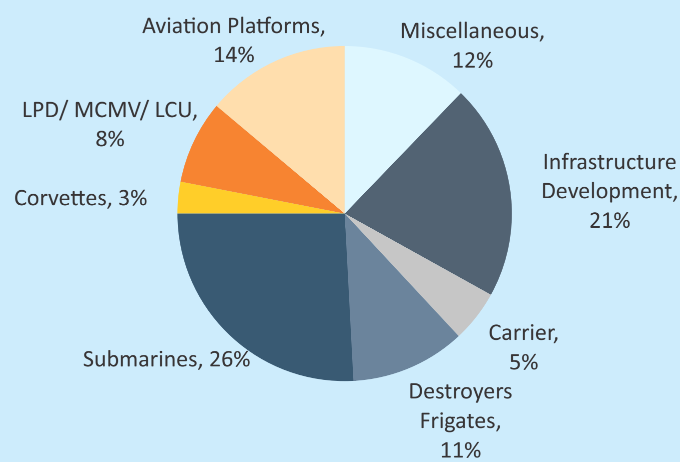
| Country | Aircraft Carriers | Destroyers | Frigates | Corvettes | Submarine | Others* | Total Fleet |
|---|---|---|---|---|---|---|---|
| US | 19 | 63 | 08 | 0 | 70 | 255 | 415 |
| Russia | 01 | 15 | 06 | 81 | 63 | 186 | 352 |
| China | 01 | 35 | 51 | 35 | 68 | 524 | 714 |
| India | 02 | 11 | 14 | 23 | 15 | 230 | 295 |
| Japan | 04 | 42 | 0 | 06 | 17 | 62 | 131 |
| South Korea | 01 | 12 | 13 | 16 | 15 | 109 | 166 |
| UK | 02 | 06 | 13 | 0 | 11 | 44 | 76 |
| France | 04 | 04 | 11 | 0 | 10 | 89 | 118 |
| Germany | 0 | 0 | 10 | 05 | 06 | 60 | 81 |

*[Source: HDFC Retail Research on GRSE, Sep 2018]*
** Others include Fleet Support ships, LPDs, LCUs, OSVs etc.*

## 8. Indigenous Naval Shipbuilding in India

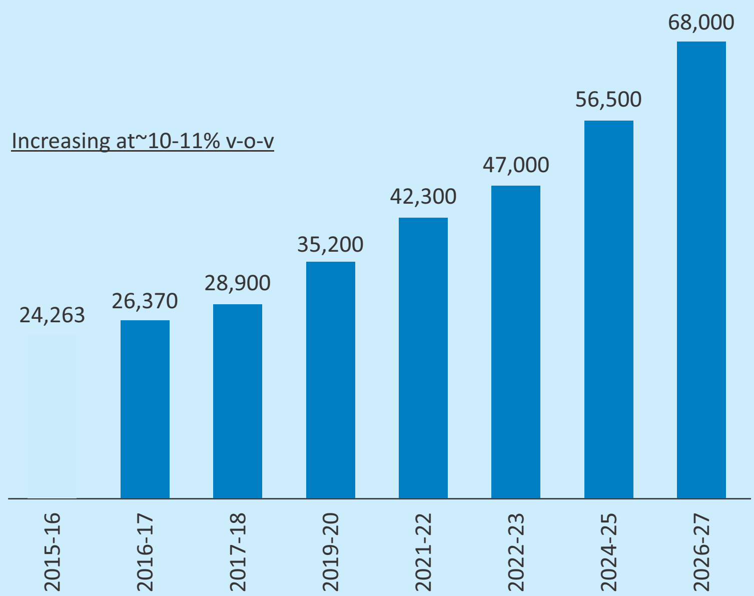
8.1 India is a major maritime nation with vital economic and security interests linked to the seas. Although the Indian Navy's primary role revolves around deterrence to security threats, yet by virtue of India's emerging economic strength and its geography, the Indian Navy has a significant peacetime role as well. The Indian Navy in its Maritime Capability Perspective Plan (MCPP) aspires for a 200 ship-strong navy by 2027 (see Fig. 5). This gives an average yearly order placement value of over INR 3,200 Cr for the next 10 years, with an increasing business potential in the field of warship building as shown in Fig. 6.

**Fig. 5: Maritime Projections 2014 – 27**




*[Source: Article 1 of Compilation of Papers for FICCI Seminar, 2016]*

**Fig 6: Business Potential in Warship Building in India**




*[Source: "Eye on Defence", Mar 2015 by EY]*

8.2 The Defence PSU Shipyards viz. M/s Mazgaon Dock Limited at Mumbai, M/s Garden Reach Shipbuilders and Engineers, Kolkata, M/s Hindustan Shipyard Limited, Visakhapatnam and M/s Goa Shipyard Limited, Goa contribute majorly towards indigenous Naval shipbuilding requirements of the country. M/s Cochin Shipyard Ltd, Kochi is the only non-defence PSU shipyard that is undertaking the construction of the Indigenous Aircraft Carrier (IAC) - Vikrant and the Anti-Submarine Warfare shallow water crafts. Besides these, private shipyards such as M/s Larsen and Toubro shipbuilding, Katupalli, M/s Reliance Defence and Engineering Ltd (RDEL), Pipavav and M/s ABG Shipyard, Dahej (but currently under liquidation) etc. have also bagged orders for construction of auxiliary vessels for IN. In addition, several small private shipyards across the country have delivered Yard crafts and barges for the IN.

8.3 **Demand - Supply Gap in Warship Construction.** Due to various constraints, the Defence PSU shipyards which have won the bulk of the contracts have the capability of delivering an average of four ships per year, as against IN's requirement of induction of a minimum of eight ships per year to attain its envisaged force levels. Moreover, as far as the construction of frontline warships (such as Frigates, Destroyers, and Submarines) is concerned the capability is mostly limited to M/s MDL, Mumbai and M/s GRSE, Kolkata.

## 9. Key Gaps in Indian Warship Building Industry

9.1 The key gaps in the Warship Shipbuilding industry have been summarised below: -

(a) **Long Gestation Build Period.** Due to long gestation period, generally 07 to 08 years, telescopic design and construction are resorted to in most of the projects. The experience gained on the first ship is implemented on the remaining vessels. However, since the batch size is small, each new class has its own learning curve.

(b) **Delay in finalizing the weapon package** leading to late receipt of binding data, resulting in frequent design changes and in some cases re-work.

(c) **Weapons/ Equipment at development stage** at the time of shipyard nomination leading to a situation of risk of unproven systems.

(d) **Endeavour to adopt State-of-the-Art Technology/ Weapons/ Sensors during the build process** - The need to have the latest technology in equipment and materials with the industry having to develop and deliver the same has added to increased delivery schedules.

(e) **Reliance on foreign OEMs for Weapon systems** - With the disintegration of the Soviet Union, the reliance on Weapon systems has shifted to the Central Asian and European countries and now to the US leading to multiple challenges in ensuring timely availability and integration of systems.

(f) **Cost and Time Overruns due to delays in delivery of equipment** - Delay in delivery of equipment by both indigenous and foreign vendors has been a major cause of project delays. Indigenization of certain weapons and sensors, and development by R&D organization takes time, resulting in time over runs.

(g) **Obsolescence** - Considering the long gestation period of warship projects and a ship's life of approximately 25-30 years, despite concurrent design and construction, it becomes necessary at times to upgrade the weapons and sensors during execution of the project which results in time and cost overruns.

(h) **Lack of Industrial Support Base** - In spite of considerable efforts towards indigenization, the ancillary industry is unable to provide desired support to the shipyards in terms of quality and time.

(j) **Lack of adoption of modern shipbuilding technologies** such as Industry 4.0, robotics etc. by the shipyard are leading to further delays.

(k) **Delays in Contracting and Order placement for equipment/ systems** - Elaborate multi-phased contracting procedures in shipyards taking up to 12 - 36 months for placement of orders on OEMs.

(l) **Labour/ Labour Overheads** - The effect of periodic Wage Revisions and Labour Overheads cannot be overlooked. Influence of this factor has been on the rise with time and has sometimes been beyond the estimated escalation of 7% per annum. Even though this increase is anticipated, its actual magnitude can be unpredictable.

**10. Mitigation Strategies for Revival of Indigenous Warship Building Industry**

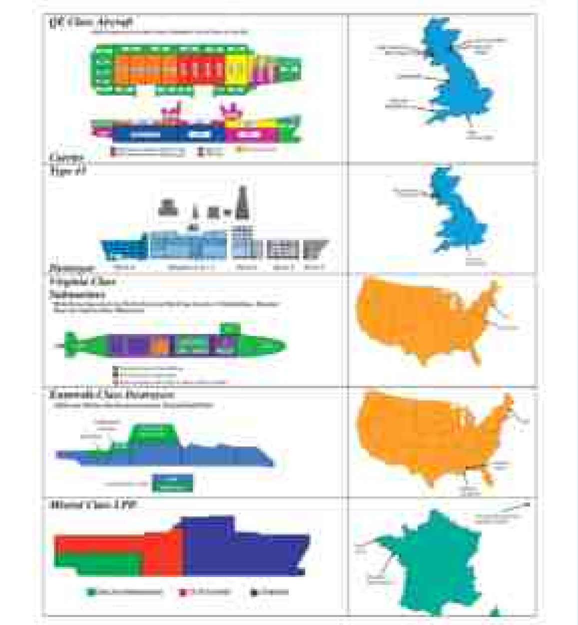
10.1 In order to meet the IN's requirements of vessels as outlined in the Maritime Capacity Perspective Plan, with global cues of a rebound of the shipbuilding industry, broad strategy and recommendations to improve the health of the indigenous Naval shipbuilding industry could include, among others: -

(a) **Combined Multinational Projects.** Focus on combined multinational projects harnessing the best practices of multiple shipyards such as FREMM (French Frégate Européenne Multi-Mission or Italian Fregata Europea Multi-Missione, Scorpene Class, Horizon class Frigates.

(b) **Multiple Shipyard Modular Build Strategy.** Several shipbuilding nations across the globe are resorting to Modular parallel construction of Mega Blocks to facilitate concurrent construction of vessels. A case in point is the Queen Elizabeth Aircraft Carrier and Type 45 Destroyers of the Royal Navy which were constructed across various shipyards in the United Kingdom. Few other such examples are shown in Fig. 7.

(c) **Building more in the same class.** Building more number of a particular class of ships would have significant time and cost advantages ensuring benefits of design and production stabilization and enables procurement of material in bulk for a group of ships.

**Fig. 7: Ships built in multiple shipyards using modular built strategy.**



*[Source: Modular Build of Warships, RAND Report, 2011]*

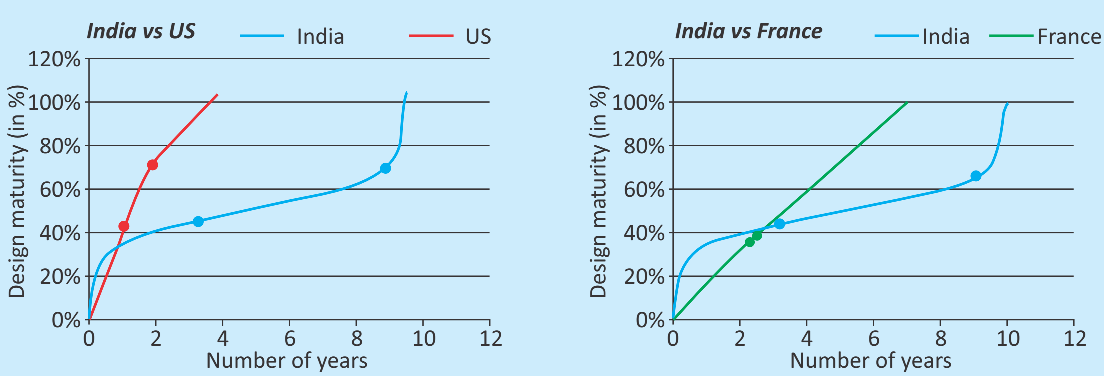
(d) **Integrated Construction and outfitting (80% targeted pre-outfitting).** Integrated construction with advanced pre-outfitting of Blocks prior launch would enable construction of vessels with reduced build periods. This methodology is being adopted for P–17A Ships under construction at M/s MDL and M/s GRSE wherein the build period of 66/ 60 months for each vessel is being targeted vis-à-vis approximately 84 months for conventional construction of Frigates/ Destroyers.

**Fig. 10.Modular construction with pre-outfitted blocks.**

*[Source: Modular Build of Warships, RAND Report, 2011]*

(e) **Achieving Early Maturity in Ship Design.**Early maturity of ship design and availability of binding data, is critical for progressing Integrated Construction resulting in reduced build periods for warships (see Fig. 8).

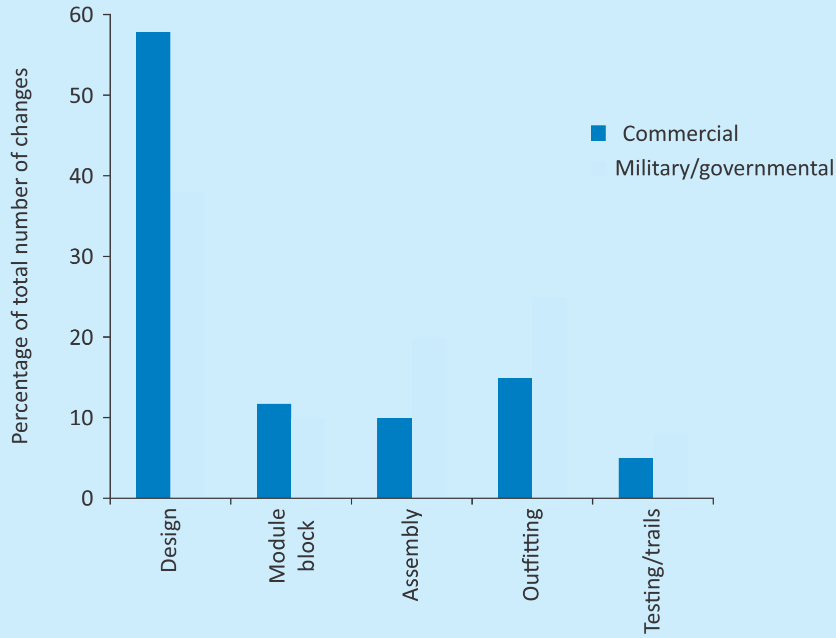
**Fig. 8: Comparison of Design Maturity at different stages between Indian Stealth Frigate, US Littoral Combat ship and FREMM.**




*FP – Finalisation of Platform Systems*
*FC – Finalisation of Combat Systems*

(f) **Minimise and Manage Changes in Design.**60% of the changes on the military contracts occur much later in the production phase, whereas more than half of design changes on commercial contracts occur in the early design phase as shown in Fig. 9. A mechanism to ensure effective Change Management during the build period is essential to ensure timely delivery of ships.

Fig. 9: Comparison of a number of changes at different stages Commercial and Naval shipbuilding.




(g) **Availability of dedicated Trial Platforms** viz. ex - USS Paul Foster under NAVSEA (see Fig. 11), for trials of Naval systems tests and equipment to prior installation on ships under construction.

(h) Encourage **competitive bidding amongst Public and Pvt Shipyards** – Deviating from the current practice of awarding Naval shipbuilding contracts through nomination to Defence PSU Shipyards, encouraging competitive bidding for new projects between Public and Pvt Shipyards (with MoUs with other major Shipbuilding Yards across the world, if necessary) would go a long way in enabling price discovery and on time delivery of projects.

Fig. 11: Ex – USS Paul Foster (Trial Platform under NAVSEA)

## 11. Policy Recommendations for Reviving Indian Shipbuilding Industry

11.1 With the support extended by the government, India had achieved the 5th position in 2009 among the global shipbuilding nations. However, the period thereafter has witnessed a decline in India's global ranking. With the potential India possesses as a shipbuilding nation and economic benefits of a robust shipbuilding industry, conducive policy framework and institutional support systems would go a long way in our endeavours to emerge as a vibrant shipbuilding nation. Towards this end, countries such as Brazil, Philippines and Vietnam, among others, have put in place strong policy framework and support systems that have contributed significantly to these countries' emergence as vibrant and growing shipbuilding nations.

11.2 **Policy Statement**. A policy statement in clear terms should be pronounced conveying the commitment of the Government to undertake various priority measures in the sector. In 2002, the Government introduced a Shipbuilding Subsidy Scheme that provided 30% subsidy applicable to ocean going vessels, for shipyards both in public and private sector. The scheme came to an end after five years in August 2007. Some form of adequate financial / fiscal incentive would need to be considered in order to facilitate the industries to achieve critical mass.

11.3 **Setting up of a Marine Fund and Support to Domestic Shipbuilding**. The Merchant Marine Fund (FMM) put in place by Brazil has often been highlighted as the success behind Brazil's emergence as a major shipbuilding nation. Brazil ranked as the 5th largest shipbuilding nation in 2013 up from the 12th position in 2006. Financial support to the shipping and shipbuilding sector, under this fund, can be assessed from the rising trend in disbursements, which have risen from around US$ 130 mn equivalent in 2001 to reach US$ 1.26 bn in 2011. Besides, support to domestic shipyards under Petrobras' expansion programmes, such as PROREFAM, EBN and PROMEF, with focus on shipbuilding by domestic shipyards have provided much need impetus to the industry in Brazil.

11.4 **Strategic Industry Status**. In the Philippines, which has now emerged as the world's 4th largest shipbuilding nation, the Domestic Shipping Development Act 2004 has put in place supporting fiscal measures to the shipping and shipbuilding industry. Further, the government's thrust to the shipbuilding industry can be assessed from the country's Executive Order of 2006, which has extended "pioneer industry" status to the domestic shipbuilding industry, providing investment incentives under the Board of Investment's Investment Priority Plans (IIPs).

11.5 **Technology Upgradation through Joint Ventures**. An important measure to upgrade technology in the shipbuilding industry could be joint ventures with major shipbuilding companies/ shipyards.

11.6 **Exploring Potential Demand from Overseas Markets**. An important strategy to provide a boost to India's shipbuilding activities as also India's exports could be matching India's export capability with demand existing for ships in emerging markets. A case in point would be exploring specific markets in Africa, which are major importers.

11.7 **Specialized Marine Financing Institution and Marine Finance Scheme**. Setting up of a specialized financing institution / marine finance scheme could also provide the much needed boost to the shipbuilding industry. In Malaysia, in line with the country's Strategic Plan 2020 for the shipbuilding and ship repair industry, Bank Pembangunan Malaysia Berhad (BPMB) actively supports the shipbuilding industry through a marine finance scheme.

11.8 **Purchase Preference for Indian built ships**.Purchase preference for Indian built, Indian flagged vessels from Indian Shipyards in Government / defence purchase. Globally, countries have aggressively promoted the use of locally built vessels by domestic shipping companies. The National

Manufacturing Competitiveness Council (NMCC) has also recommended facilitating greater carriage of Indian trade by Indian built ships, and consequently developing domestic shipbuilding capabilities.

11.9 **Need for State Maritime Policies**. In order for the efforts to boost Indian shipbuilding to be successful, the industry also needs to get adequate support from the maritime states of the country. It is the states that would have to help implement these policies to support and develop the industry. In this context, development of state maritime policies and state maritime boards is extremely important. Gujarat Maritime Board (GMB) has come up with its own shipbuilding policy (Shipbuilding Policy 2010). The policy aims to develop Marine Shipbuilding Parks (MSP) and clusters.

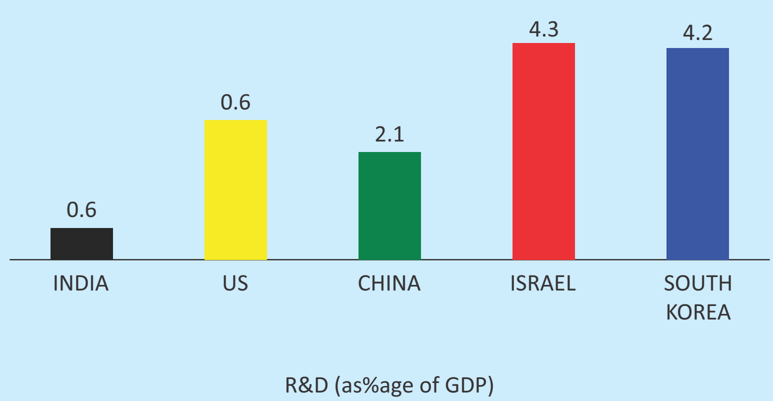
11.10 **Minimise Price Disadvantage of Indian Built Ships**. To examine the issue of incidence of taxes that disadvantages the domestic ship building industry.

11.11 **Foreign Investments**. Measures and Policy initiatives to attract Foreign Direct Investment (FDI) in the shipbuilding sector by reducing corporate taxes, eliminating red tapism and providing tax incentive packages as available in other East Asian countries should be provided to the domestic shipbuilding industry. In India, the present requirement to obtain multiple clearances covering land acquisition, environmental clearance, power and water etc., from various departments for new projects in shipbuilding acts as a deterrent to attracting investment into this sector.

11.12 **Skill Development, Innovation and R&D**. The major shipbuilding countries viz. Japan and South Korea have taken special efforts towards skill development and R&D of the shipbuilding industry. Japan established the Shipbuilding Skill Development Centre in 2004, to develop training material and prepare necessary equipment to support training efforts. During the 1980s, the South Korean government promoted University-Industry R&D activities which resulted in several collaborative initiatives. However, in India there is limited investment in R&D in ship designing and innovation (see Fig. 12). For overall growth of the industry, there is a need to create an R&D base along with developing in-house design capability, infusing new technology, developing skilled workforce, adopting appropriate fiscal measures and industry-friendly regulations, so that the Indian shipbuilding can achieve credibility for delivering quality ships on time.

11.13 **Labour Productivity.** Labour productivity for India's shipbuilding sector is less than Japan and Korea. With enhanced government fiscal and policy support (as available in China and South Korea) and adoption of Skill India initiative of the GoI by the Shipbuilding industry, tangible gains are expected.

**Fig. 12: Comparison of %GDP allocated for R&D**




*Source: Economic Survey 2017-18*

11.14 **Lower Interest Rates.** A shipyard typically requires a working capital of around 25-35% of the cost of the ship during the entire construction period. The interest rates on working capital in India are in the average range of 10-10.5%. In contrast, the interest rates presently offered to shipbuilding yards overseas are significantly lower. They stand at 5-6% in Korea and around 4-8% in China.

11.15 **Developing Ancillary Industries.** Development of ancillary industries is critical for increasing cost competitiveness of shipbuilding and repairs. Both Japan and South Korea have formulated suitable industrial policy for the shipbuilding and the ship repair ancillary industry which could be replicated in our context.

## 12. Conclusion

12.1 The analysis of various facets of the global and Indian shipbuilding industry clearly shows that India needs to look at multiple interventions including in the areas of Regulatory framework, Investment policies, Trade policies, Fiscal policies, Infrastructure, R&D, Skill, Financing, Process, Collaboration and Technology. Given that the share of Indian ships in the carriage of India's overseas cargo has fallen sharply and Indian warship building is limited presently to the PSU shipyards, there is an urgent need to take proactive steps to ensure revival of the domestic shipbuilding sector. This also brings to focus the importance of India's shipbuilding industry which has the capacity and expertise but is presently functioning below capacity. Global shipbuilding industry is presently in the cusp of a rebound after having hit a nadir in 2008 and timely action with effective government support is essential to revitalise the indigenous shipbuilding industry.

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# THYSSENKRUPP MARINE SYSTEMS' FUTURE VISION ON NAVAL SURFACE VESSELS – MEKO ® 5.0

**MR. JENS BALLÉ,**

Senior Manager Project Design, Thyssenkrupp Marine Systems GmbH

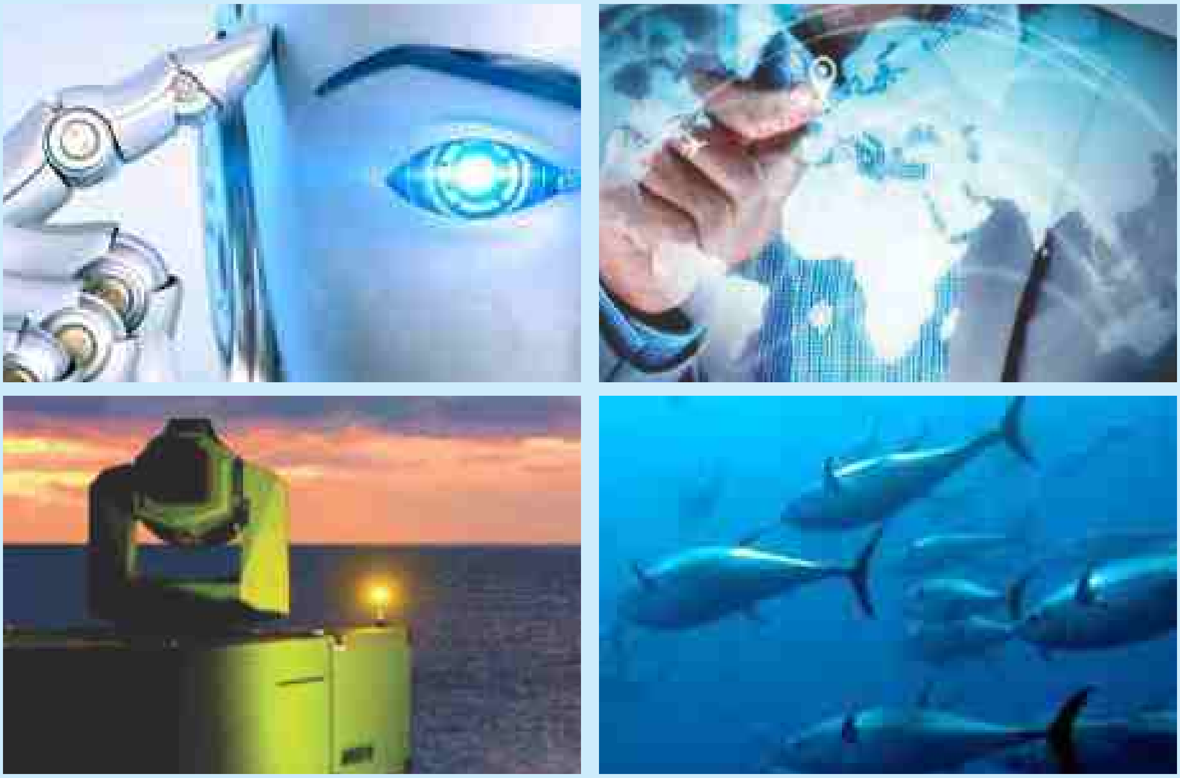
1.1 Industry 4.0 is a synonym for a total integration of design, production and supply chain to a self-organizing production line, managing information flow, material and goods. The speed of transferring technology into products is growing continuously. Some years ago, head up displays, virtual reality, cloud computing and seamless communication between different themes was the future, today it is reality. Thus thinking about the future today means thinking about problems arising tomorrow and creating solutions beyond existing technologies.

1.2 As the world changes, we can recognise four main trends: environmental changes with implications on energy supply, technological changes with ramications on production and availability of products, social changes with implications on social structures such as aging societies in industrialized countries – and we can identify defense trends using new technologies centered around artificial intelligence, cyber warfare and unmanned systems to counter threats arising from those changes. These trends will impact naval surface vessel design and technology.

**2. The Implication of Trends on Operating Naval Ships**

2.1 Environmental changes question fossil fuel as the main energy supply due to budgetary constraints and environmental pollution. Actual solutions such as LNG, batteries and fuel cells are applicable for short sea shipping in the Baltic Sea or the Mediterranean. Transoceanic shipping and naval operations with long dwell times in mission areas require an energy dense fuel storage and an energy dense power generation in order to keep ships within a reasonable size. This cannot be achieved with today's energy concepts. There are only few perspectives that it will change in the future. Synthetic fuel might be a solution to prolong current infrastructures such as Replenishment at Sea.

2.2 If the dramatically increasing demand on energy through new subsystems such as electric energy weapons is taken into consideration, the demand on fuel will accordingly increase, and most probably disproportionately. It is therefore necessary to think about renewable energy sources for the power plant – or at least as support energy. Artificial intelligence is the next big trend. The exponential development of computer hardware performances will continue. In 2025 the calculation performance of a $ 1,000 computer will surpass the human brain's capacity.



Future Trends: increasing energy demands, new production methods such as 3D printing, artificial intelligence, intelligent assistant systems, high energy weapons, unmanned systems etc.

The MEKO ® A-200 Mk II of today already includes elements for response to future trends.

2.3 Algorithms will get smarter. Transforming Big Data into Smart Data will be key to manage and support complex systems. Condition Based Maintenance is a perfect example of this. Such algo rithms are the nucleus for intelligent assistant systems that support the crew in decision making processes, or enable remote controlled commercial ships and floating production sites.

2.4 Cyber Warfare is a growing threat and we will see an arms race between hacking algorithms and protection algo - rithms. Thus unmanned warships or even remote controlled platform systems with extremely high levels of safety and reliability of control are subject to investigation.

2.5 Digitalization in design and construction together with new production methods such as 3D printing will revolutionize the maintenance and repair of ships, or even the production of the whole ship. With 3D printing, complex, weight optimized structures or structures with additional functionalities (e.g. shock absorption) can be produced at affordable costs. Today 3D printing is limited to small and medium sized structures such as spare parts. Tomorrow we can expect large scale structure printing with big printers or through coordinated small printers or printer robots. The necessary data will be provided by the ship data model the digital twin. Tomorrow ships will print their own spare parts on board as needed and thus dramatically increase availabilities.

2.6 Unmanned systems are a further trend. Today unmanned systems such as UUVs for mine disposal and sea bed scanning, unmanned boats carrying surface and subsurface sensors, or remote controlled weapon stations operate in naval senarios.

2.7 In the future, the development of artificial intelligence and further hardware miniaturizations will enable self-coordinating swarms of unmanned systems to perform multi-static surveillance that will undermine any ship stealth measures. We also can expect swarms to carry explosives or small weapons enabling mission kill by destroying ship sensor suites. New countermeasures to counter such threats will most probably influence ship design.

2.8 Electric energy weapons such as the rail gun, laser and high power microwaves promise unlimited ammunition, fast reaction times and to some extent scalable impact on targets. The technical readiness of these systems is already quite high (TRL 6 to 9).

2.9 On-board integration solutions such as delivering the necessary high electrical power within extremely short reaction times as well as the related safety requirements, still have to be developed. Nevertheless electric energy weapons will play their part in close-in-defense, but traditional long range weapons such as surface-to-air and air-to-air missiles will remain.

2.10 As society in industrialized countries ages, the fight for skilled personnel is forcing navies to reduce crew sizes. In order to operate and maintain complex warships, support is needed and today's solution is automation. In the future robots will clean and fight fires, smart materials and systems will repair themselves or re-route the system to bypass damaged components. Human centric support with personalized artificial intelligence assistance and wear able technology such as smart-glasses with augmented reality will help crew plan work schedules and give advice on what to do. The required skills for personnel will change from "specialized technical experts" to "versatile technicians" with broad knowledge on functional chains and the flexibility to act in different roles.

2.11 We have to recognize that technology developed for commercial applications has to be adapted for naval applications and the effects may be different.

### 3. Implication of Trends on Ship Design and Technology – Meko® 5.0

3.1 The increasing speed of technology development seems to contradict a 30 year – and potentially extended further lifetimes of our platforms. To keep ships up to date, they should be upgraded every 10 years and with regards to computer systems, in cases, every two years, programs that entail costs, risks and low availabilities. Already 40 years ago thyssenkrupp Marine Systems recognized the contradiction of modernization versus cost and availability and developed the MEKO ® concept providing modularity without compromise in survivability and combat strength. We have continuously developed it further according to the requirements imposed on ship design, construction and combat system design with the integration of new technologies that improve performances of our ships.

3.2 Our latest design of a mid-size frigate of 4,300 t, the MEKO® A-200 MK II, already includes features and capabilities in re sponse to the previously mentioned trends – as far as the technologies are available. These include for example, the design flexibility to integrate different conventional propulsion systems, a flex-deck and mission bay to support mission flexibility through the integration of containerized systems such as ACTAS, or the integration of USVs such as ARCIMS which can carry ASW sensors, or MCM systems such as SEAFOX ® and SEACAT ®.

3.3 We can already provide condition monitoring and automatic sequences to support reduced manning and battle damage control. Features and means for IT-security in combat systems, as well as in platform systems, are an integral part of our system design. With a slight enlargement of the design to about 4,800 t, the MEKO® A-200 can be configured into an all-electric ship to support the future integration of electric energy weapons. It can accommodate more or bigger unmanned systems and provide growth potential for additional, yet unknown sensors and weapons to counter future threats. Moreover, integrating further levels of technology supports additional crew reductions.

3.4 Thus, the MEKO ® A-200 is designed for the future – 2040, and beyond. The limiting factor for growth potential is ship size and the fact that the platform itself cannot be changed and the fact that platform systems such as the propulsion and electrical systems cannot be changed in a manner as done today with MEKO® combat system modules.

3.5 Thyssenkrupp Marine Systems' vision of a MEKO® 5.0 is a mid-size frigate design adaptable to accommodate future platform technologies with low integration costs and minimum impact on the availability of the ship, without compromise on seakeeping, survivability and lethality. Impossible? Perhaps today – but what about tomorrow?

3.6 The key element of platform flexibility is direct access to all platform arrangements via an Open Top – well known and successfully deployed on container vessels. We will still have structural elements supporting sustainability and survivability such as box girders, blast resistant bulkheads and damage control compartments, and we will retain the two island principle. These structural elements allow the flexibility to change room arrangements and subsystems. The slightly increased size will enable additional weapon systems (e.g. 104 cells VLS) and a bigger hangar capable of accommodating up to four large helicopters or the equivalent amount of UAVs, or a mixture of both. Alternative propulsion systems based on renewable energy systems such as retractable soft wing sails will be able to deliver speeds of up to 12 knots with wind energy. Integrated solar panels will support service and hotel power networks.

Left and right: MEKO® 5.0, the first step:
A conventional design featuring enhanced capabilities.

3.7 In order to manage condition based maintenance, a huge number of sensors generating millions of signals will be installed and the accrued data will be interpreted to determine the status of subsystems as well as collectively determine that of the ship. Key to success will be an optimized number of sensors, the correct interpretation of data to initiate appropriate maintenance measures to secure cost effectiveness furthered by a careful system design based on technical know-how about subsystems, functional chains and the overall system design, as well as an overall maintenance organization concept.

3.8 3D printing will enable the integration of features such as shock resistance into the ship's steel structure and produce complex vessel structures utilizing less material and in the process save space and weight. The design will integrate robots to unburden the crew from routine duties. There will stowage and workshops for 3D spare part printing. The smaller sized crew will enjoy increased comforts such as a fitness room with 4-D virtual reality enabling users the experience of running in a forest, playing an 18-hole golf course, or riding the alpine passes of the Tour de France.

3.9 Thyssenkrupp Marine Systems is working on how to make use of commercial technological developments for effective and efficient integration into our ships, based on the MEKO ® principles of modularity, flexibility, sustainability, availability and combat strength, including system safety and IT-security. We are examining the effect of these technologies in our ship's design, as well as the trade-offs to adapt commercial system designs to operate safely in a warship environment. We are also evaluating the effects on shipyard environments to ensure the effective production of our designs. Our contribution to Industry 4.0 and Navy 4.0 is not the technology itself. This is being developed and produced by our suppliers.

3.10 Our contribution is working together with our suppliers on integration requirements and integrating single systems to create efficient and effective warships serving future needs of navies.

3.11 MEKO® 5.0 is still a vision with many questions to be answered, and many details to be investigated. But to master the challenges of the future means to think of the future today and be prepared to implement it tomorrow.

3.12 This is our understanding of, and commitment to thyssenkrupp's brand promise "engineering.tomorrow.together".

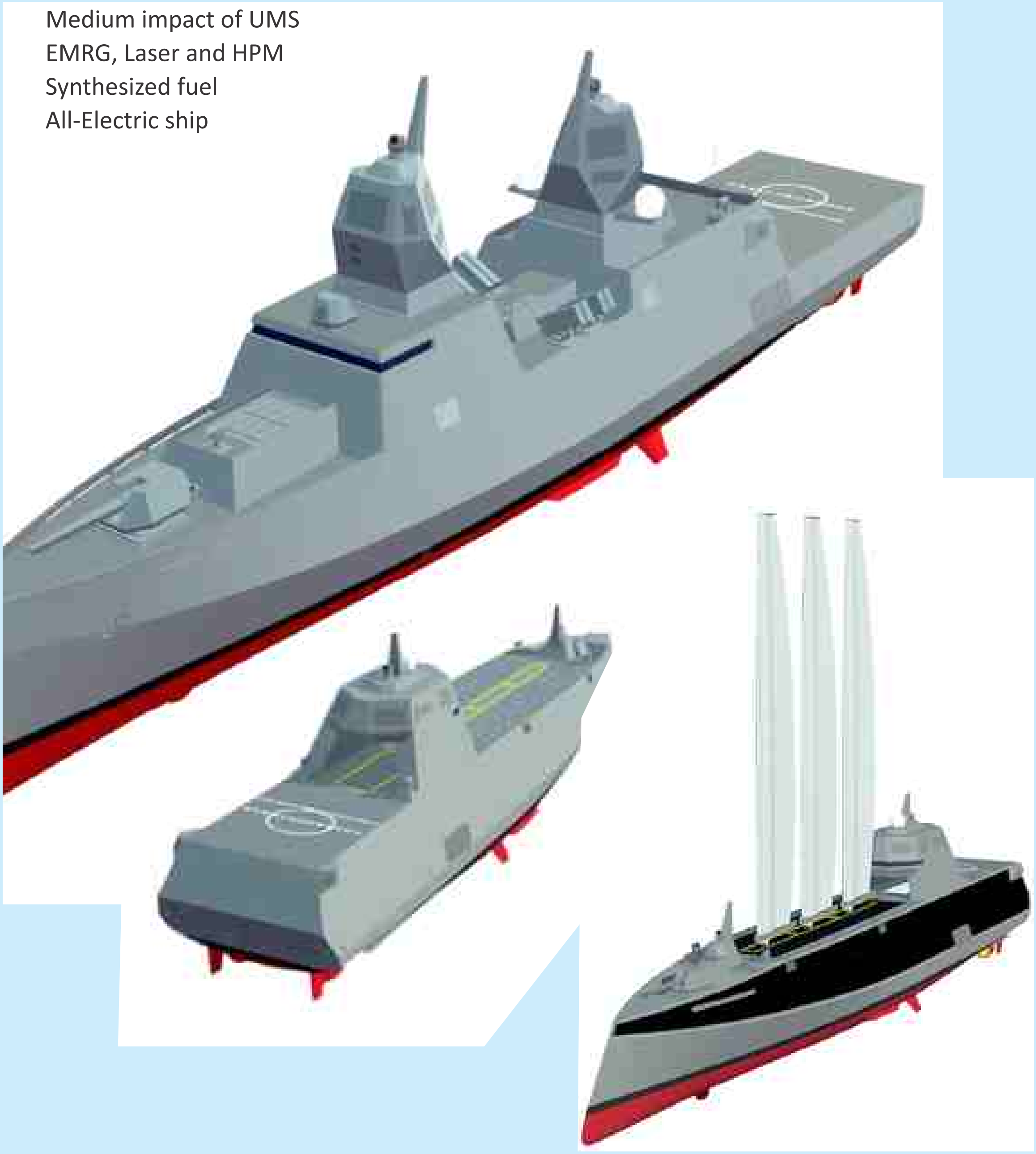
## MEKO® 5.0

### MAIN DIMENSIONS

| | |
|---|---|
| Lpp: | 128,5 m |
| Beam: | 19 m |
| Displacement: | ~ 4,800 t |
| Speed: | ~ 28 knots |

### FEATURES

- MEKO® modularity for the combat system
- Lean manning
- Medium impact of UMS
- EMRG, Laser and HPM
- Synthesized fuel
- All-Electric ship



MEKO® 5.0 – thinking the future. Alternative energy systems such retractable soft wing sails for speeds reaching 12 knots, or solar panels supplementing the supply of electricity.

# ONBOARD DC GRID – A SYSTEM PLATFORM AT THE HEART OF SHIPPING 4.0

**MR. JOHN OLAV LINDTJØRN**

Global Product Manager, Onboard DC Grid

1.1 In March 2013, ABB delivered our first Onboard DC Grid system on the MPSV Dina Star, making Myklebusthaug Management the first in the world with an IMO vessel powered by a modern primary DC power system.

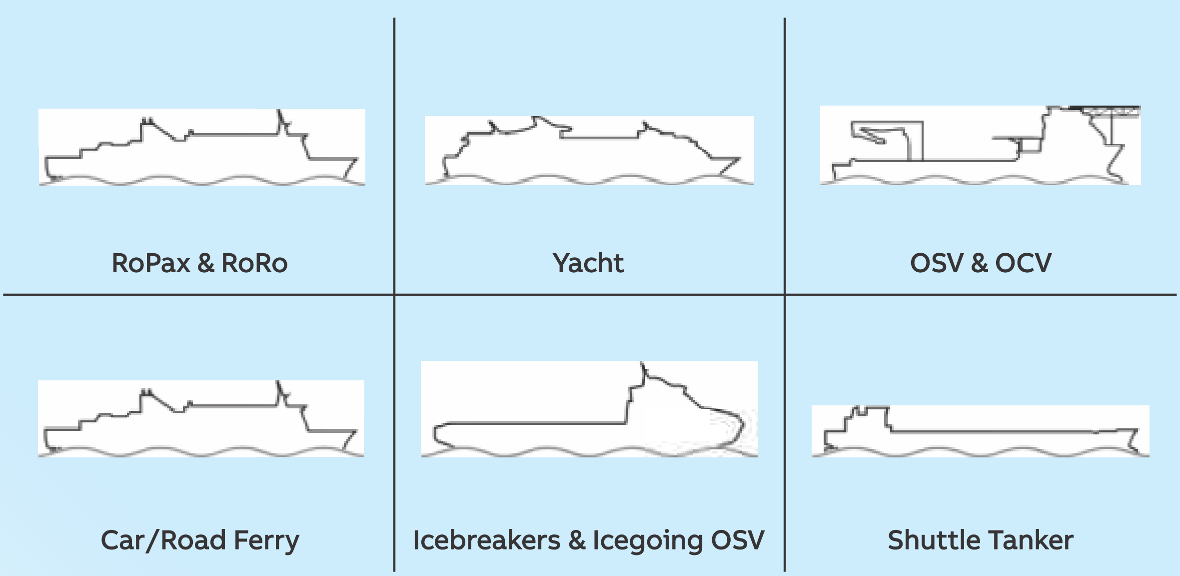
1.2 The main focus at the time was variable speed generators, space savings and dynamic performance. Much has happened since; the role of DC in the marine industry is maturing and it is clear that Shipping 4.0 – electric, digital, and connected – spells a bright future for DC-based electric propulsion.

1.3 The world is changing and the shipping industry with it. For some, this new reality has already made its presence known, for others it is looming on the horizon. Regardless, the future holds a new mix of low- to zero-carbon energy sources and a new level of digitalisation.

**2. What is Special About DC?**

2.1 A DC-based power system enables simple, flexible and functional integration of energy sources such as variable speed gensets and shaft generators, batteries and fuel cells. Also, a DC and power electronics based power system provides a unique platform for digital solutions onboard a vessel. Equipped with sensors and communication infrastructure, data is transmitted between systems in an instance. This gives access to information that enable the bridge to monitor and optimise their performance. And, better connectivity between ship and shore mean that performance management is taken to the next level.

**Reference Overwiew – October 2017**



2.2 Onboard DC Grid is gaining traction in a wide range of vessel types, and the reason for this varies. Ferries choose it because it is the most cost efficient and functional platform for integrating energy storage, making hybrid and fully electric operation a reality. This is true even to the extent that the two retrofit ferry projects Aurora and Tycho Brahe chose to update their AC power plant into a predominantly DC power plant to get maximum benefits out of their new plant.

2.3 Offshore support vessels chose it primarily for the heightened fault tolerance, variable speed generators and ease of energy storage integration, whilst a couple of icebreakers needed a way of fitting an otherwise too large electric power plant within the confines of their hulls.

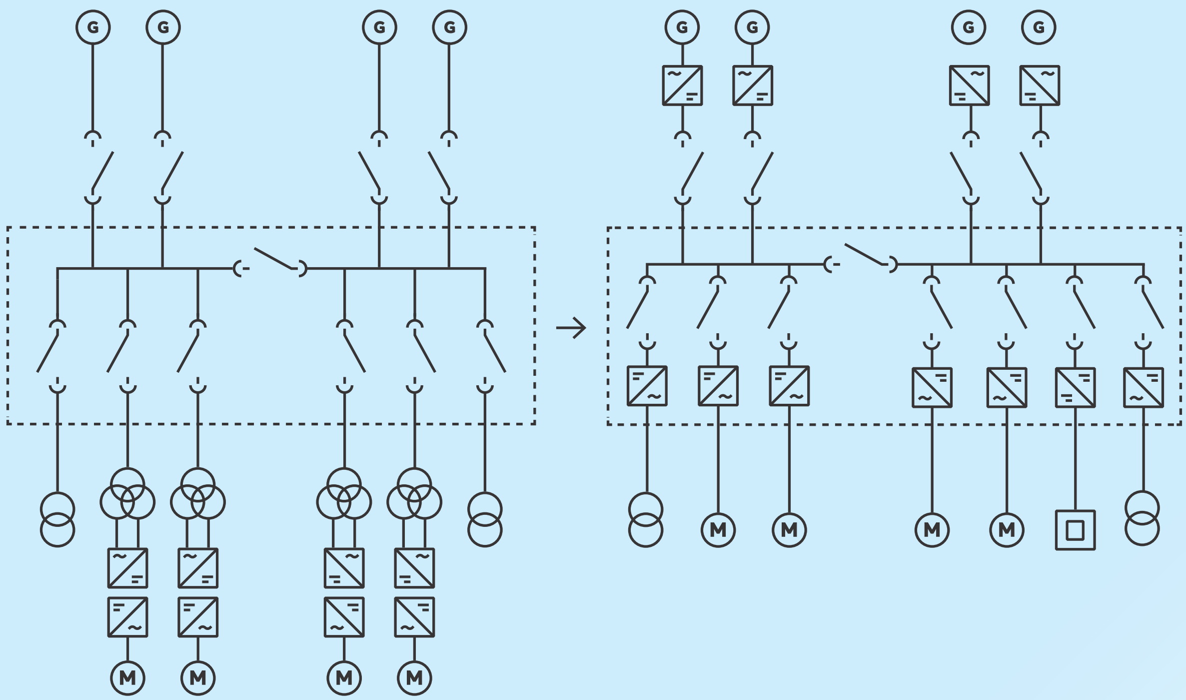
2.4 Shuttle-tankers will choose it for simple and functional integration of variable speed shaft generators and, right around the corner, expedition cruises for its suitability to integrate batteries and fuel cells for extended zero-emissions operation in sensitive areas. The larger of these vessels will also enjoy the possibility of distributing main power at 1000Vdc instead of 690 or 660Vac, representing savings of up 40% or more on cabling.

**3. Onboard DC Grid – a system platform**

3.1 Onboard DC Grid is a system platform tailored to the needs of the next generation of vessels. It serves applications from low to mid-power range by offering a competitive, flexible and state of-the-art system platform. It is especially well suited to the integration of variable speed generators, energy storage and new energy sources such as fuel cells in a safe, fault tolerant way. It is highly configurable, enabling a close fit for the simplest to the most demanding application.

3.2 It is a modular power system platform comprising modules for sources and loads built using industry leading power and automation products This approach reduces customer risk by enabling a high quality and efficient engineering process and post-delivery support whilst not forsaking necessary flexibility needed for a tailored application fit.

**The basic transformation from an AC based power distribution to a DC based power distribution**



4. **Some of the main benefits include:**

(a) Footprint reduction of up to 30%

(b) Variable speed generators for improved SFOC engine characteristic coupled with reduced emissions and maintenance and improved SCR performance

(c) Most efficient integration of energy storage/ fuel cells/shaft generators from perspective of cost, functionality and weight and footprint

(d) Best in class fault-tolerance is intrinsic to the design

(e) Highly controllable power plant suited for advanced operation and optimisation by overriding controls (Advisory)

(f) Unique DC distribution capability

(g) Unique remote diagnostic and service functionality

5. **Protection Philosophy**

5.1 Onboard DC Grid employs a patented protection scheme that uses a combination of fuses, isolators and breakers and converter control to effectively protect the system.

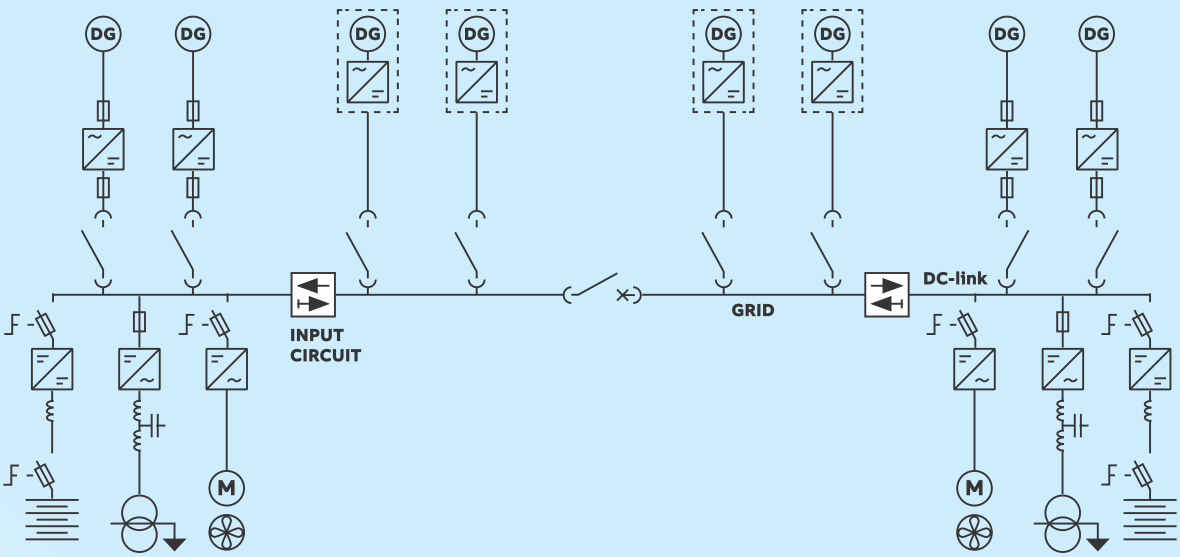
5.2 The protection system provides safe and reliable operation of the vessel and high safety for personnel and equipment. This approach relies on input circuits to segregate the system into two types of protection zones:

(a) Grid (blue): this is the power distribution zone.

(b) DC-link (red): this is equivalent to the traditional dc-link of a multi-drive.

5.3 The input circuit forms the boundary between the link and grid zones and allows free flow of current in both directions during normal operation. In case of faults on the grid side of an input circuit, the input circuit will block near instantaneously, blocking fault current contribution in this direction. Fault currents in the opposite direction are not blocked.

**Onboard DC Grid Protection Zones**



5.4 The DC-link zone is characterised by the fact that most converters connected to it have integrated capacitor banks that support the DC link voltage. The capacitive nature of the DC link means that fault currents in this zone have very short time constants and consequently reach high levels very quickly after a fault. This also means that any faults in the zone must be handled extremely quickly to avoid adverse effects on its converters. This environment is ideally suited to solid-state breakers and high speed fuses which clear faults in the range of a few microseconds to a few milliseconds. The input circuit ensures that faults outside the link-zone do not immediately cause the converters to trip on under voltage.

5.5 The Grid zone is characterised by fault currents with longer time constants. This means that it is possible to use a slower-acting protection approach such as a fold-back scheme or air circuit breakers in this zone. All entry points into the Grid are guarded by devices that can control fault current (e.g. the input circuits).

5.6 As a function of its low fault current level and fold-back or air circuit breaker protection, the grid zone is very well suited to distributing power throughout the vessel. This is an alternative to 690 or 660Vac distribution resulting in >40% reduction in needed conductor cross section and the possibility to use lower cost single-core cables as opposed to multi-core double-screened cables.

**6. Vessel Control System**

6.1 Onboard DC Grid uses ABB's 800xA automation platform to implement system control functions, including **PEMS** and **VMS**. The system integration and control is done in such a way that it plays to the strengths of the various energy sources in the system, and keeps tight control on consumers.

6.2 ABB has adopted a new approach to power and energy management in the form of the Power and Energy **Management System** – **PEMS. PEMS** manages both the balance of power (traditional PMS responsibility) and energy in the power system. The latter becomes important when adding sources like batteries or super capacitors with very finite amounts of energy available. The balance of power also takes on new dimensions in a DC Grid system when sources like variable speed generators, shaft generators and batteries operate in parallel.

6.3 So, what does it mean to "play to the strengths" of a system's energy sources? For a simple hybrid system this means that ES (Energy Storage) will primarily perform an energy buffering function whilst engines provide the steady-state power. Some of the functionality to achieve this is implemented at lower levels, closer to the converters and ES – typically functions requiring fast response such as standard load sharing and overload protections. This is done autonomously by the different energy sources. Other functions have been implemented at a higher level such as the traditional PMS domain – typically functions that require a level of coordination between sources. Optimal functionality and performance is achieved through tight horizontal integration between power sources and consumers, as well as tight vertical integration between fast embedded control of converters and generators and the system level application.

6.4 Onboard DC Grid has a harmonised control and communication infrastructure that allows for a transparent and lightning-fast flow of information between system components. This ensures a holistic approach to the task of coaxing the best performance, be it for safety or efficiency, out of a power system. The high level of integration also means that high quality information is available to an operator or remote support service engineer should he need it. For vessels with automatic charging from shore, the **PEMS** coordinates the process of connecting, charging and disconnecting from charging station.

6.5 The PEMS is structured so that each energy source forms an autonomous subsystem. This increases the fault tolerance of the system controls by reducing interdependence between energy sources. Sub-system functionality is realised as far as practicable on a sub-system level, only involving the wider system when it becomes necessary. This also means that operation of the vessel remains intuitive and simple even when done so from local control since the majority of sub-system functionality remains intact.

**7. System Benefits – Why Onboard DC Grid**

7.1 This shift from AC to DC in the form of DC Grid is primarily driven by three main features:

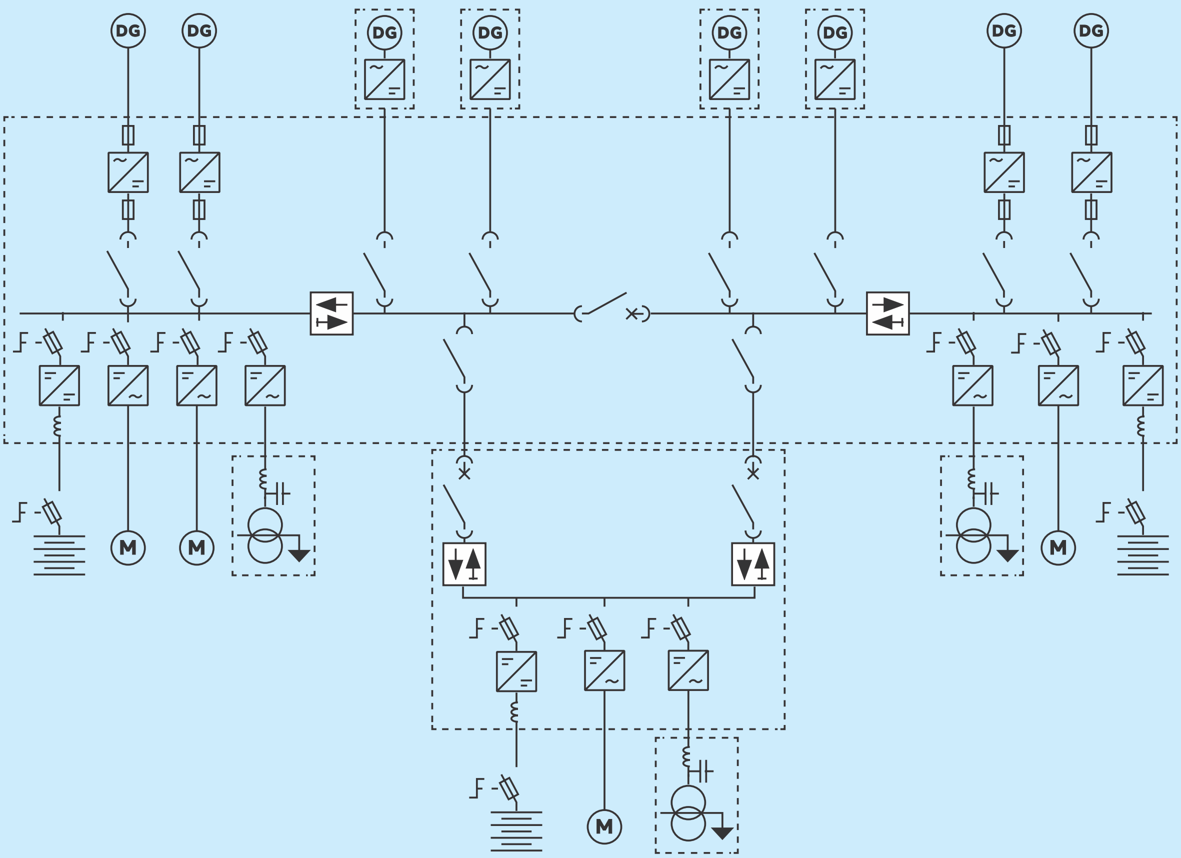
(a) Variable Speed Engines

(b) The integration of Energy Storage

(c) Ease of integrating other types of energy sources such as shaft generators and, in the near future, fuel cells

7.2 However the benefits with DC Grid is not limited to these points. The following sections will describe some of main benefits in more detail.

**The Double-fed Thruster**




**8. Variable Speed Engines**

8.1 Unlike AC based distribution systems where connected generators need to match system voltage and frequency, the DC Grid system only requires the generators to match system voltage. This means that the generator and engine speed can be dynamically optimised to the system load situation. When the engine load decreases, the engine speed is also reduced.

8.2 The most immediate benefit of this change is reduced fuel consumption, visualised in the graph above. There are also additional benefits to variable speed operation, summarised below:

(a) Reduce Specific fuel consumption by up ~20% and ~40% for medium and high speed engines respectively for partial load operation

(b) Cleaner combustion process with less build-up of soot when operating at partial loads

(c) Reduced GHG emissions due to lower fuel consumption and reduced particle emissions due to cleaner combustion

(d) Increased temperature of exhaust gases at lower loads means that SCRs can be fully operational at all load levels, reducing both Nox emissions and urea consumption

(e) Potential reduction of audible noise level by more than 5dB

(f) Reduced maintenance costs due to up to 30% reduced wear and tear on the engine

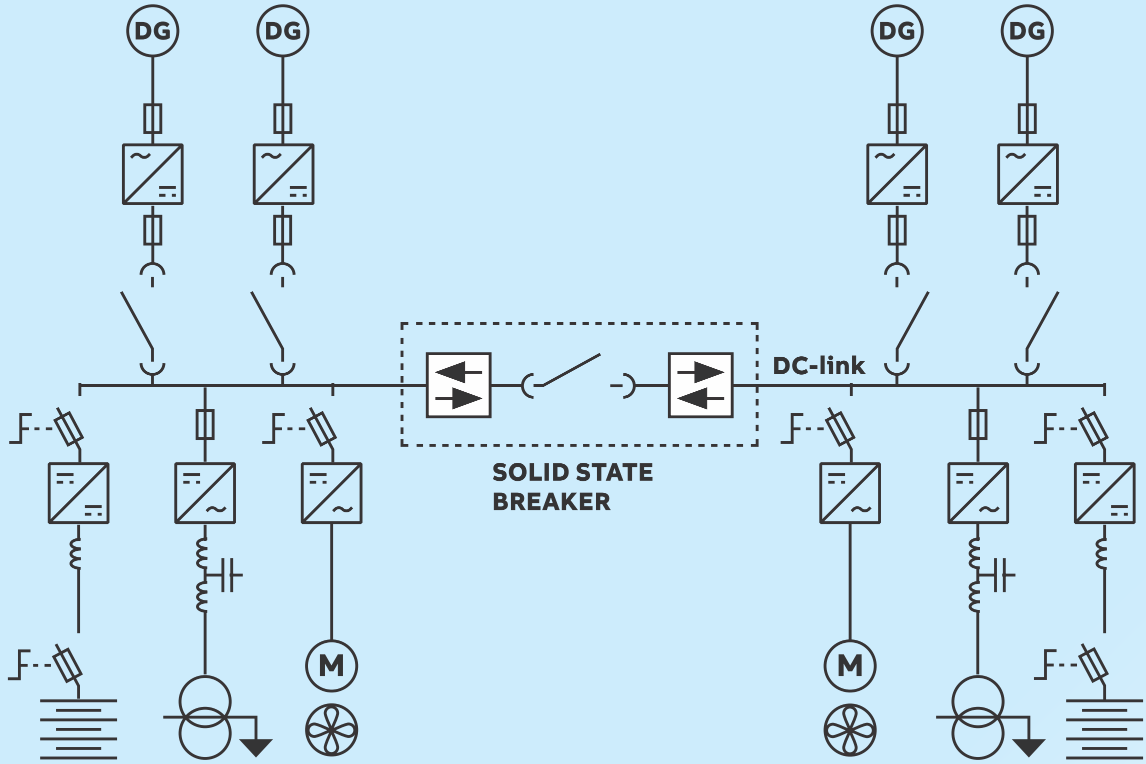
**9. Energy Storage**

9.1 Energy Storage (ES) and associated technologies have received a dramatic increase in attention in recent years, not least in the maritime industry. Whilst this can be attributed to a number of different factors, what is certain is that ES has the potential to improve safety, efficiency and performance of future vessels.

9.2 **Integrating Energy Storage into a Power System** The availability of ES is only one part of improved safety, efficiency and performance. First, the energy must be made available to consumers.

9.3 Since most Energy Storage media are DC based, the integration into a DC distribution system becomes simpler and becomes more functional for less added cost than doing the same into an AC based distribution system.

**A simpler variant of the system – here two input circuits are functionally bundled with an isolator or breaker to make a bi-directional solid-state breaker.**



9.4 DC solutions require less equipment in general and the converter (if used) also becomes significantly more compact than its AC counterpart. For basic functions where no selectivity or starting scenarios are considered, the AC converter solution is almost twice the length of the DC equivalent. If selectivity, overvoltage and starting scenarios are also considered, then this ratio becomes closer to four.

9.5 The option of connecting the ES directly to the DC link can offer a slight reduction in length and improved efficiency compared to the converter option. However, this is at the expense of controllability of the current in and out of the ES and system voltage level.

9.6 From a control perspective, this option means that ES power flow is determined by the sum of the actions of all other sources and consumers in the system. This means that this method of connection is only suited to a limited number of applications, typically systems of low complexity where batteries represent a dominant power source.

9.7 From a system voltage perspective this option means that the system voltage is defined by the ES and its state of charge. This can vary significantly and may therefore require the rest of the system to be over-dimensioned.

9.8 For these reasons, direct online solution is often chosen when efficiency is more important than controllability. An example of this is are ferries that operate in zero-emissions mode where large portions of the consumed energy pass through the battery on the way to the propeller. The converted based solution is preferred in applications where controllability and fault tolerance are of higher importance than the efficiency of the ES system. A good example of this is a DP vessel where the battery is used to support the power system by means of functions like peak shaving, enhanced dynamic support and spinning reserve. In these cases ES efficiency does not have asignificant impact on power system overall efficiency because the battery is primarily used as an energy buffer and relatively little energy is passed through it during normal operation.

**10. Energy Storage & Variable Speed Engines**

10.1 The combination of ES and variable speed engines offers some additional synergies.

10.2 In a system with variable speed engines where energy storage is not included, the engine needs to be operated in such a way that it always has enough reserves to be able to absorb load steps. The need to always have some power margins in reserve means that some optimisation potential is left untouched. When a system is equipped with ES and the Enhanced Dynamic Support function is activated, the ES can take on the role of absorbing quick load changes and the engine optimisation has one constraint less to consider, and can now optimise its operation even further.

10.3 Going from fixed speed to variable speed operation, the speed vs. load path is moved from the vertical 1800rpm axis (red line, see left) to the propeller curve (blue line). When energy storage is added, this path can be moved even further to the left, sometimes all the way to the MCR curve (green line). The effect this has on the specific fuel oil consumption (SFOC) is shown in the graph below left. The figure shows the SFOC for the traditional AC System (blue), DC grid with variable speed (green) and DC grid with variable speed and energy storage (orange).

**11. Safety**

11.1 DC is inherently simpler than AC. When building up a system platform this means that it is easier to predict fault scenarios and devise effective protection against them. For Onboard DC Grid this has resulted in:

(a) Closed bus operation in DP2 without additional equipment because common mode faults like governor and AVR failures are handled more effectively.

**PEMS main display**

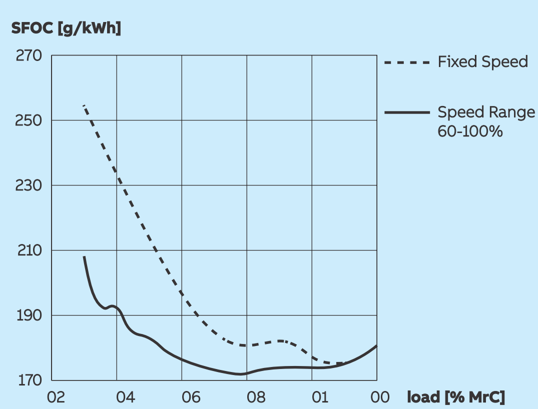

(b) Generators that can be online in close to 10 seconds (for high-speed engines) because they don't need to wait for synchronisation.

(c) Engines that are virtually impossible to overload even when operated at lower speeds. This is because each generator has built-in overload protection that limits output power. The end result is that the engine does not stall and remains online.

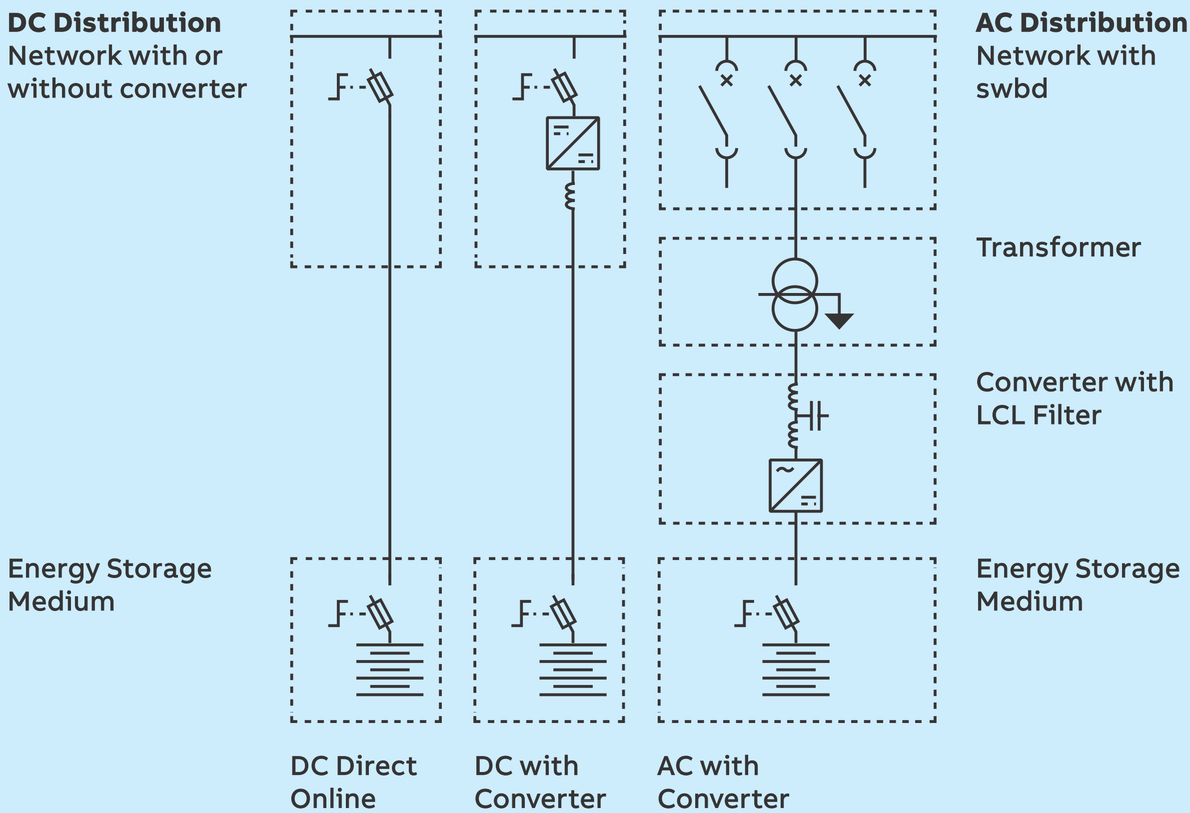
(d) Clearing of major short-circuit currents in a "soft" way so that the system recovers quickly and predictably. This is a function of both system capacitance and converter control. The system is therefore not plagued by ugly transients as is often the case in AC systems when large fault currents are interrupted by protective devices.

11.2 A safe and fault tolerant system is a benefit in itself, but there is another often forgotten benefit of this. Operators quickly understand that in the rare event that failures do occur, the system will recover quickly and reliably. Such confidence in the system has proven to result in significantly more economical operation of the vessel because the system is not split and additional generators are not brought online until necessary.

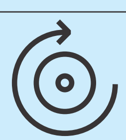
**Reduced fuel consumption with variable speed**

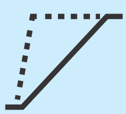


**DC solutions require less equipment in general.**




**Energy Storage Functions: ES can be used in a wide range of ways onboard a vessel and most of these can be broken down into the few basic functions (or combinations thereof)**

| Symbol | Name | Description | Pupose |
|---|---|---|---|
|  | **Spinning Reserve** | Unit is connected and running but not charging or discharging energy into the system. On loss of generating capacity it steps in to take the load for a predefined period of time. | • Backup for running gensets<br>• Fewer engines needed online<br>• Improved fuel efficiency through higher partial load<br>• Reduced engine running hours |
| | | If other functions are activated simultaneously, this function ensures that sufficient energy is left in battery. | |

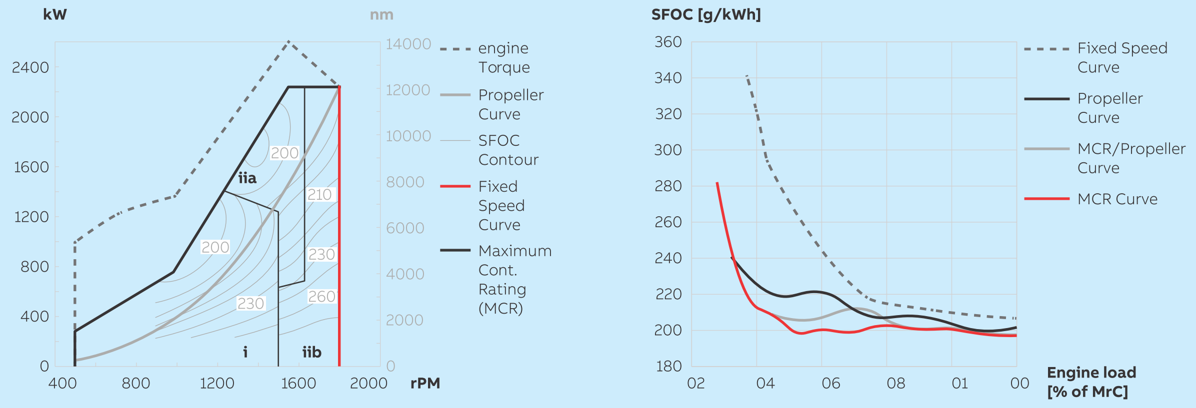
| Symbol | Name | Description | Pupose |
|---|---|---|---|
|  | **Enhanced Ride Through** | Same as spinning reserve, but on a local level in a sub system like a thruster or drilling drive. | • ES storage solutions can give UPS like functionality for all or portions of power system<br>• New ways of achieving higher ERN numbers<br>• Higher power system availability |
|  | **Peak Shaving** | Unit absorbs load variations in the network so that engines only see the average system power. | • Level the power seen by engines<br>• Offset the need to start new engine<br>• Improved fuel efficiency<br>• Reduced engine running hours |
|  | **Enhanced Dynamic Performance** | Unit absorbs sudden load changes and then ramps the change over on running engines. If peak shaving is used, then this function is automatically included. | • Instant power in support of running gensets<br>• Enable use of «slower» engines;<br>– LNG/Dual Fuel engines<br>– Fuel Cells |
|  | **Strategic Loading** | Unit charges and discharges to optimise the operational point of running engines, ensuring that energy is produced at the lowest cost, taking the efficiency of the ES system into account. | • Charging and discharging ES media in such a way that it optimises the operating point of the gensets.<br>• Power is produced at peak efficiency |
| × $CO_2$<br>× $No_x$<br>× dB | **Zero Emissions Operation** | Unit powers the system so that engines can be turned off. | • Zero emissions in harbour<br>• Quiet engine room |

**12. Other Benefits**

12.1 In addition to the benefits described above, there are numerous other benefits with DC distribution. Some of these are summarised below:

(a) **Power transmission:** Distributing on 1000Vdc instead of 690Vac reduces cable need by as much as ~40% and permits use of lower-cost cables.

## The effect for an example high speed machine




(b) **Voltage distortion**. (THD) common in AC systems with frequency converters is no longer an issue.

(c) **Shore connection**. If shore connection is done on the DC side, vessels can more easily use shore connections in different ports because network frequency is no longer an issue. Also, starting currents from motors and transformers are not drawn from the shore connection, thus allowing more operational flexibility in ports with low-power feeders. If ES is available onboard, then this can be operated in parallel to take peak loads, improving operational flexibility in port even further.

(d) **Shaft Generators**. Variable speed shaft generators can be integrated in the same simple way as variable speed generators. Similarly, a PTI/ TO solution can be solved in a very streamlined fashion, analogous with ES.

(e) **Fuel Cells**. Fuel cells are already making an entry into the marine industry, and the fuel-cell business case may make them a viable power source within a few years. Fuel cell integration into an Onboard DC Grid system is solved in a very streamlined fashion, analogous with ES and shaft-generators.

(f) **Centralised Drive Lineup**. Collecting all the drives in a central lineup means that the need for ambient conditions (temp and humidity) and cleanliness is reduced in e.g. thruster rooms. This is particularly useful during construction and commissioning.

(g) **Centralised vs Distributed**. Whilst most systems will be highly centralised, the DC Grid platform also supports fully distributed systems using cables or bus-ducts.

(h) **Space and Weight Reduction**. The number of components in the system has been reduced, resulting in a reduced footprint of up to 30% as compared with an AC system.

(i) **Electrical Efficiency**. In the process of going from AC to DC distribution, the electrical system efficiency has improved by 0.5-1 percentage points.

(j) **Variable Speed Motors**. Fans and pumps represent a large portion of the auxiliary loads onboard modern vessels. Most of these can be operated at significantly improved efficiency by fitting variable speed drives. This enables regulation of flow by means of adjusting fan or pump speed instead of e.g. throttling. The DC Grid platform is uniquely suited to tapping into his potential in a cost-efficient manner.

## 13. Where does that leave us?

13.1 Shipping 4.0 spells a bright future for electric propulsion, and the Onboard DC Grid system platform will be at the heart of this transformation. It is uniquely prepared to optimise current energy sources, integrate new energy sources and tap into the very significant potentials afforded by digitalisation. It appears that the future of shipping may very well be electric!

# NEW CONSIDERATION IN SHIP DESIGN: ADVANCEMENTS IN SHIP DESIGN


**MR. FRANÇOIS-RÉGIS BOULVERT**

International Scientific Cooperation Director, Naval Group


1.1 Innovation has always been at the heart of Naval Group's work and has now formed the DNA of the company.

1.2 Naval Group's spirit of innovation is built on very strong foundations after centuries of history of designing, building and maintaining frontline warships dating back from the time when first of yard was built in France during 1631 by Cardinal Richelieu.

1.3 Naval Group regularly creates breakthrough in ship design. Everyone remembers the Lafayette Class frigate with its very specific shape, has been seen in James Bond movies "Golden Eye" in 1995. It was a beginning of what is now a common shape for surface warships. It is only the submerged part of the iceberg, and as you know it is only 10% of the global size.; most of the innovation are not visible from outside. This Lafayette Class frigate also ushered in the beginning of a new way to build surface ship in modular way with pre-equipped blocks. An important point to remember is that Naval Group being customer centric uses the best of technology to ease the operations of the crew and improve the global efficiency of the ship with a real naval crew-machine teaming.

1.4 A second point of Naval Group's innovation is that we use technological breakthroughs by continuous listening to the technology and using disruptive technologies which therefore add value to our customer.

1.5 Last, but not least, Naval Group approach to innovation is very structured. The research is built on 6 federated axes (namely: Invulnerable Ship > Smart Availability > Smart Industry > Smart Energy > Smart Naval Force > Smart Ship) which are here to anticipate tomorrow's operational needs.

1.6 In addition, it has to be noted that Naval Group is involved in all the phases of the life of a ship - from idea to conception, then design and build, then use and maintenance and thereafter during its

dismantlement. This through-life management gives a unique view which is tremendously important for a complex integrator like us. A very well integration is a complex technical and scientific matter, but it is vital for the operational performance of a surface combatant. Integration is the core skill and know-how of Naval Group, for submarines as for surface vessels. In this part, worth to mention that future threats and disruptive technologies will impact integration and engineering processes of future naval acquisition projects.

1.7 This paper will give you insights of what are the present-day technological innovations which will change the design of future ships. The outside shape of the ship is still important and the presentation will explain why. It will delve into more important topics like the digital architecture of the ship, the combat systems' future capabilities to fight against futuristic threats like high speed missiles but also asymmetric threats which are everywhere today.

1.8 The paper will be illustrated with real innovations which are today used in the French Navy's future intermediate frigate (FTI) which is directly derived from the **Naval Group's Belharra® line of product.**

1.9 Belharra® is a fully multi-mission frigate, integrating the latest surveillance and weapon systems of the major French equipment manufacturers to respond to the most modern threats (sea fire radar, sonar and latest generation electronic warfare, ASTER and MU90, up to NCM if authorized).

1.10 The design offers an important growth potential for futures upgrades, thanks to an innovative computing architecture, it is continuously adaptable to the rapid evolutions of embarked systems as operational tactics, according to the challenging evolutions of new information technologies.

1.11 This design offers the most powerful Combat Management System SETIS® for a clear and comprehensive tactical picture, multi-sensor, multi-operator and user-friendly decision aids, in all contexts of interoperability. This ship has the ability to protect a High Value Unit thanks to its ASTER weapon system.

1.12 It is natively designed to be used and maintained by a reduced number of crew.

1.13 It is natively designed (physically and logically) to facilitate the exploitation of multi-domain unmanned systems in order to extend the warfare capabilities of the vessel.

1.14 It has an Ops-oriented answer to cyber-security challenge, thanks to cyber protection architecture and equipment, as well as advanced cyber defense capability adapted to naval constraints, with optional associated services for advanced cyber risk management.

1.15 This design offers the best of digital technologies and some very specific innovations. Digital technologies and solutions as designed by Naval Group are a way to accelerate problem solving, ease human interface management and expand existing solutions, while answering strong security requirements.

1.16 Naval Group solution is based on simple, robust, evolutive and much ruggedized architecture with reduced footprint.

1.17 An important example of what is today Naval Group's innovation for a warship is the Digital combat bridge. This new bridge allows crews to detect all objects in the close vicinity around the ship and to safely drive the ship in all situations, whether they are common (navigational, maneuvering) or threatening (asymmetric threats), by night and day.

1.18 A second example is the I4drones solutions and its integration capabilities:

1.19 It offers a mission system fully integrated to the ship's combat system; a solution available for naval partners and which is drone-agnostic. Naval Group has 10+ year experience in naval integration and i4®drones capabilities have been demonstrated in 2017 with "Drone shield" demonstration consisting in the simultaneous roll-out of 3 drones (UAV/USV/UUV)

1.20 I4®drones enables Navies to simultaneously and securely roll out and operate all kinds of drones in real time, enabling data exchange, get and exploit their payload (radar, AIS, optronic camera) in full consistence with the ship's combat systems.

1.21 To complete and assure this core capability, Naval Group is also co-developing with some key OEMs to establish as future manufacturer of some important systems and technologies like for unmanned vehicles.

1.22 For UAV = VSR700, we have on-going development with Airbus Helicopter; this UAV is designed to be deployed from ships for rapid intelligence, surveillance and reconnaissance missions. On USV, we have the Remorina, designed by our Subsidiary SIREHNA to be deployed for patrol, short-range control and interception missions. Finally on UUV, we have several options designed to be deployed from ships and submarines, for discreet surveillance and investigation missions

1.23 In addition of all these improvement and advancements liked to combats systems, the future presentation will show some improvements also on availability with some e-maintenance concept; some hydrodynamics inputs like inverted bow and also a smart energy management aboard ship.

1.24 The Belharra® is designed to be built, under technology transfer and technical assistance, in any construction site equipped for ships of this category. It is also a totally modular design to meet customer's specific needs.

**2. Conclusion:**

2.1 Naval Group, in its role of architect, builder and naval systems integrator, develops innovations for operational needs for the navies to access a combat technological superiority.

2.2 Naval Group offers efficient products and services and lays the ground for ship's incremental and continuous evolutions, meanwhile following essential evolutions of industrials means and skills.

2.3 There are 2 further conditions for the approach such success:

(a) A collaborative work, at the early stage as possible, between customers, architects, engineers and industrial partners,

(b) A more transversal vision of contractual patterns (new ships/ maintenance) and associated budgets to ease seamless integration of all the phases of development.

# INTEGRATED OPERATIONS: ABB'S DIGITAL BUSINESS TRANSFORMATION FOR THE MARITIME INDUSTRY


**MR. RICHARD WINDISCHHOFER AND MR. MIKKO LEPISTÖ**

Business Unit Marine and Ports



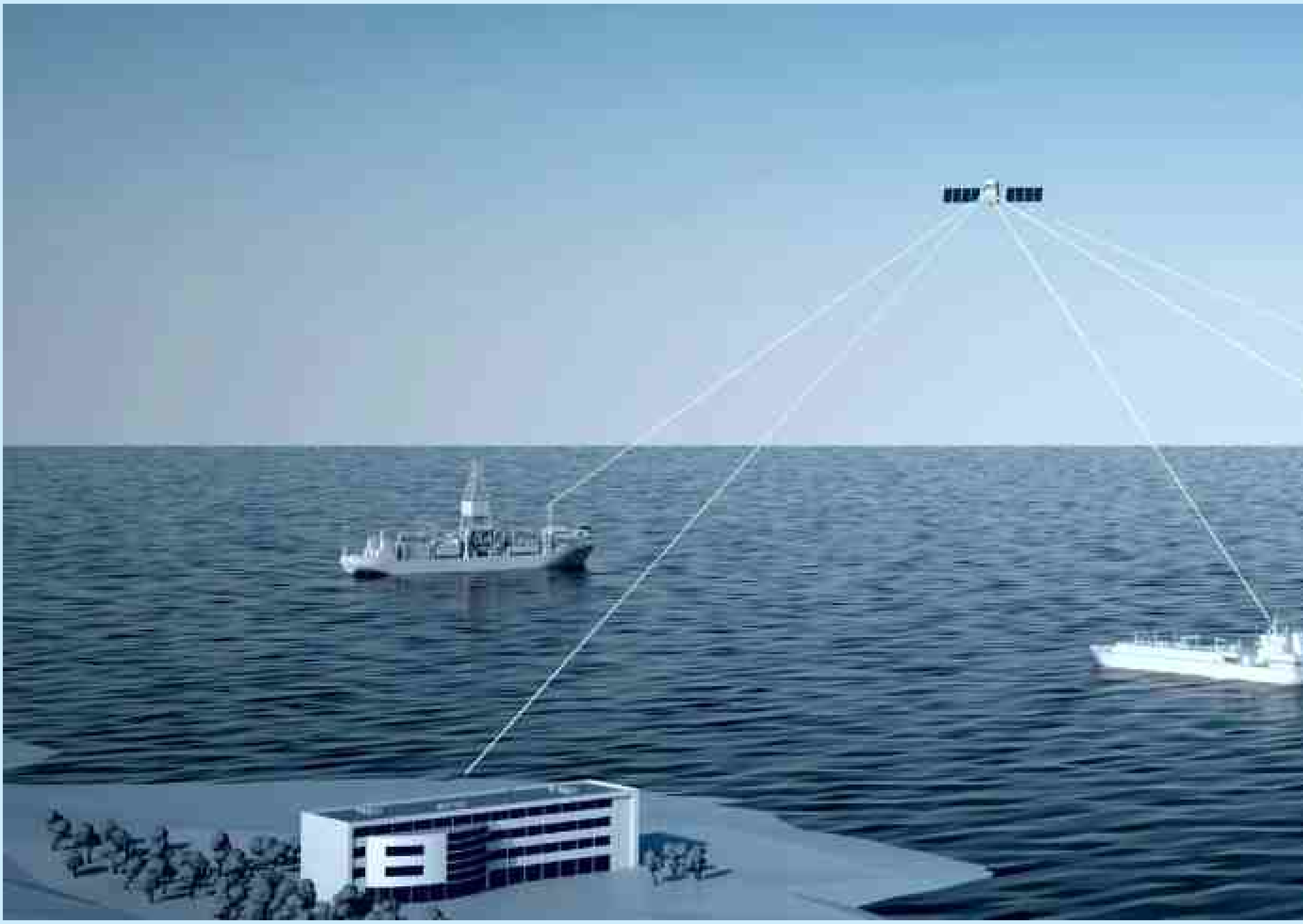
**1. Abstract**

1.1 The previously conservative maritime industry is now tapping into the possibilities of connectivity and digitalization due to improved satellite coverage and cloud computing. Owners and operators are increasingly looking for suppliers that offer remote troubleshooting, performance monitoring, and condition-based maintenance. This allows operating the fleet at lower fuel and maintenance cost, while improving crew, passenger, and cargo safety and productivity. In order to facilitate the change, ABB is adding sensors and software to system deliveries on board the vessels; improving data transfer storage, and analysis of the data. Our service centers now start utilizing the information to support customers in emergency situations, in maintenance planning, and in helping to optimize ship operations. The future fleet will be better connected to the owner's shore side technical department, and to ABB's technical departments – by having access to the same information and monitoring systems. We call this way of operating Integrated Operations. Combining the new technologies with our traditional on-call and maintenance services will enable us to be part of our customers' daily operations and make better decisions together. Because vessels will become more complex, the ship owners will want to simplify how they manage their fleet. By working with ABB, our customers get a package that is integrated from office to propeller - provided by a partner with strong domain knowledge. This way of operating will enable us and our customers to take the first step towards autonomous shipping.


**2. A conservative industry is changing**

2.1 Shipping has come under scrutiny by regulatory and environmental bodies for its environmental and safety record. Speculation in shipbuilding and slow economic growth have put the industry under significant economic pressure. The maritime industry needs to become more modern, efficient, and safe. In fact, we are witnessing how this industry is turning from being one of the most conservative industries to being open for new ways of operating.

2.2 Improved satellite connectivity at sea allows the introduction of modern software and cloud computing. Life at sea as we know it, is going to change profoundly. And so will the life at the office. Digitalization will affect everything, 'from office to propeller'. Planning, operational tasks, and decision-making will be carried out by involving more people and information, and by creating virtual teams whose members are located on board, on shore at the owners' offices, and at the suppliers'. Improved connectivity, teamwork, and availability of information means a big change for an industry that used to operate in a very fragmented and isolated manner. Most ships are still run as rather self-sufficient units, and the shore side departments' focus is commercial and technical planning. Whenever there is a technical issue, it is the crew's job to try solving it first themselves, and if they can't, they contact their shore side technical department or the equipment manufacturer. The fact that vessels are moving and need to keep their schedule makes it difficult for anyone to organize the



right support, in the right place, at the right time. Also the crew keeps changing, which means that the person who knew the system on board best, might not always be there.

2.3 Coordination problems, lack of efficiency, and technical risks are costing the maritime industry and its suppliers billions every year and they are a risk for the safety of passengers, crew, cargo, marine wildlife, fisheries. In addition, the maritime industry is being increasingly pressured to reduce its carbon footprint and contribution to global warming.

2.4 One of the biggest operational improvements lies in the integration of the operations taking place on board the vessel and on the shore side, from anywhere, and with anyone who is critical to the value chain, such as original equipment manufacturers (OEM) like ABB.

**3. Any company that aims to supply to that maritime industry will have to master the following four megatrends:**

3.1 **Digitalization and connectivity**. satellite connectivity and software will improve further and allow fast and reliable connectivity between the vessel and the shore side. Increasing amount of operational and diagnostics data will be available to support decision making on shore and offshore. The suppliers of critical systems such as the propulsion, power, automation, cargo handling, drilling, air conditioning, and other systems will have to provide data from their systems.

3.2 **Automation and electrification of systems**. everything that can be automated will be automated. Also on board, the engine room and the bridge will merge and become a single command and operational center, and they will be closely integrated with the shore side operational centers of the

vessel owner. This will further increase opportunities for digitalization and connectivity as data will not be distributed to isolated systems. By effective use of simulation models and advanced control algorithms systems can be made more efficient and more reliable.

3.3 **Emissions reduction and electrification.** reducing the carbon footprint of the maritime industry will become a priority for governments and regulators in order to force that industry to make its contribution to the reduction of greenhouse gases. This will put pressure on ship owners, ship builders, and their customers such as major logistics and oil companies and we will see a more active adoption of innovative technologies such as the use of batteries for energy storage and propulsion. Maintenance intensive mechanic systems such as the combustion engine and thrusters will be increasingly replaced by electrical and battery storage systems and electric propulsion. The vast majority of today's technical operations will be planned maintenance work that is performed every five to ten years, and technical problems during operation will be solved through remote diagnostic services. Reaching aviation standard safety, productivity, will be the target. Smaller vessels such as double ended car ferries will become completely powered by electricity, as other short sea vessels.

3.4 **Automation of work**. just as the digitalization, electrification and automation of on board vessel systems will make the work for operators on board easier, the introduction of new software and cloud applications will improve the efficiency of administrative personnel. The integration of the vessels' resource planning system with the shore side, and with the suppliers' means that people need to spend less time on coordination activities and can focus better on the content of their work. New professions will emerge that blend operational experience with IT skills. Enabling technology may also lead to entirely new business models for the operator and the OEMs.

3.5 The era we are dealing with here is the 4th Industrial Revolution. Work will be revolutionized and the production and use of energy will be revolutionized. Even if these changes still seem far away for many of us, some shipbuilding tenders include exactly these kinds of features we are laying out here in this white paper.

**4. Operators and their Suppliers will Integrate and Automate their Processes**

4.1 Due to the megatrends smart and digital features are differentiators right now but eventually they will be part of the new standard offerings of maritime suppliers. The race towards the cloud has started and by 2020 we will probably see a couple of established Maritime Industry cloud platforms already dedicated to hosting marine specific data and applications. The question is whether these platforms will have originated from OEMs, software companies, large multinationals, international industry initiatives, or a combination of these.

4.2 All OEMs will eventually meet competition from the software and analytics industry, which is entering the maritime industry now. This means we will see digital services become part of daily business, and daily operations. Operations Execution Systems (OES), analytics software and information technology security platforms are going to play an important role in future maritime operations.

4.3 This puts pressure to OEMs to develop a state of the art Operations Execution System. This operations execution system is created by combining equipment, control, automation, cloud, business intelligence toolkits, and services. For ABB the key differentiator will be how well our scope of supply integrates to our customers' business and processes.

4.4 We believe that only a vertical integration of the entire product and activity chain, from the machine, sensors, historian on board, the cloud platform, applications, and dispatch of service engineers, design, and R&D is going to provide ship owners and their fleet with a next-level standard in safety, productivity, and low carbon footprint. Or as one of our major customers put it, "our ambition is to operate by aviation industry safety and productivity standards by 2020".

4.5 Large amounts of data should be collected by using professional IT architectures and technologies, but a meaningful analysis and interpretation of the collected data is only possible through the application of domain knowledge.

4.6 While ABB has always had this domain knowledge, such as hydrodynamics, advanced power management, propulsion, and control systems, it is only now through the technologies of the Internet of Things that we are able to share this knowledge with our customers in an efficient manner. In simple terms, much of the technology we are developing now aims at integrating ABB with its customer, for the purpose of sharing knowledge and making better decisions on both sides of the table.This means that also ABB, as a supplier of automation, power, and propulsion systems and services is going through an industrial revolution. Today a hundred highly skilled service engineers are able to support 500 vessels with phone and on-call technical support, but in the future, the same amount of engineers and technical experts will be able to support a significantly higher number of vessels at sea, if a remote connection exists. The amount of on-call visits would be reduced dramatically as well which means safety and reliability goes up. Already today, we reduced the on board visits by service engineers to those ships with remote condition monitoring on propulsion drives by 70%, and with improving predictive monitoring we are able to inform the crew before damages may occur.

4.7 The automation and centralization of work will be one of the most significant drivers for our business, in order to attract more business from customers who are transforming their own operations in similar ways. The slower growth of the world economy means maritime operators will focus less on expansion and more on improving their efficiency of operations. Because of sensors, software, satellite connectivity, and cloud technology, our customers are able to centralize operational teams by using software and introducing automated or semi-automated processes. On shore, the fleet management will become more efficient as well because visibility of vessel operations will be improved, and software will handle tasks from order fulfilment processes to detecting inefficiencies in scheduling and fuel consumption.

4.8 This is a fundamental change to our business, our competence, and structure. In 2025, our products and services will have a significantly lower failure rate due to preventive monitoring, many of our customers will be seamlessly integrated with us by using joint software and communication, and order processing tools. This will allow us and our customers to reduce response times and make operations simpler.

4.9 The most progressive ship owners and operators have already implemented advanced operational models and tools, and they look for partners who are on similar technology level, in order to integrate with them, and run the business at next level safety, and productivity. The automation of work will affect every company, and every department inside the company.

**5. Where We are Today in Terms of Connectivity**

5.1 Back in 2015, we had more than 500 vessels with some form of monitoring system on board. For example, we can monitor the Azipod® propulsors' oil and bearing temperature, moisture and particles in oil, vibrations of bearings, RPM, and other Azipod® propulsor parameters. In the electrical system, we can monitor for example motor winding temperatures, the water pressure of the cooling system of propulsion drives, monitor critical alarms, actual values like RPM, power, torque, and events such as unbalances, the status of the satellite link, and the status of RDS system on board. We monitor fuel consumption, propeller power, hull condition, chillers, hotel load, machinery, boilers, fresh water production, voyage speed, RPMs, weather, and forecast the motion.

5.2 When we have this critical equipment and operational information available, we can help our customers avoid maneuvers that are harmful to critical equipment; we can alert them before a drive is going to fail, when to clean the hull or service a bearing; or how to reduce the average speed of the vessel. This all results in fuel savings, less downtime, reduced use of on-call service engineers, increased operational performance and lower dry docking cost.

5.3 Based on our experience, owners can reduce the need for receiving engineers on board by up to 30% to 70% based on the type of equipment.

5.4 We will integrate these software-based solutions with our automation, power, and propulsion system delivery, and ensure that these information systems can be jointly used by the crew on board, and personnel on the shore side. Already today, the captain of a container vessel can receive guidance from onshore, which route around the heavy weather will be the most fuel efficient. A chief engineer on board a drill ship can grant remote access to a technical expert sitting onshore, in order to get a thruster up and running again.

**6. Five steps to autonomous operations**

6.1 We take the first steps towards autonomous shipping by combining new digital services with our existing technical services.

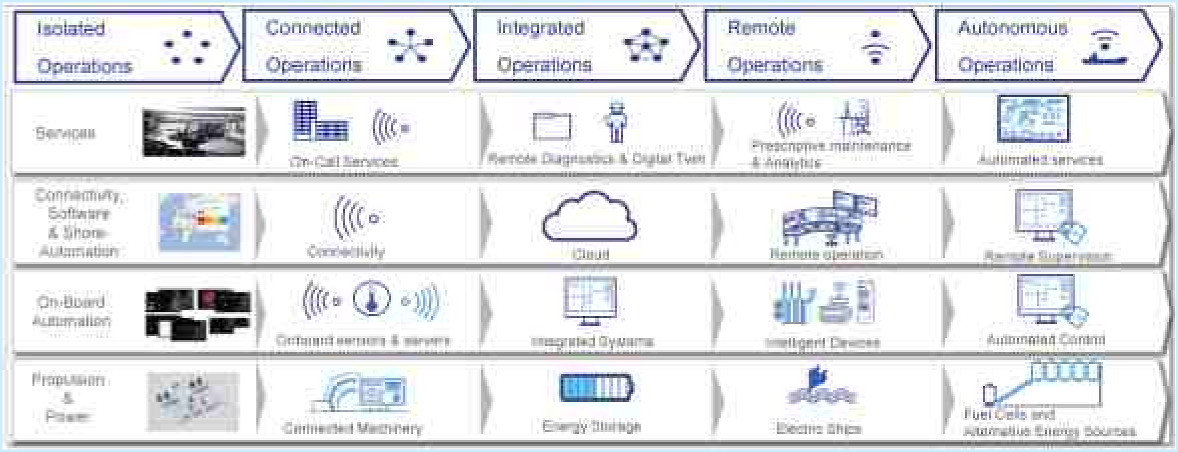
6.2 We call this phase Integrated Operations' because it speaks to a new way of operating. We are not here to replace the crew but to support them. We also believe that new technologies will help to improve efficiency to the a similar level where best-in-class industries (such as Aviation industry) operate.

6.3 Some would call "Integrated Operations" Digital Solutions (and they of course are) but we believe that 'Digital', just as 'IoT', or other buzzwords will in a few years disappear, just as no one talks about eBusiness (the buzzword of 2000) anymore because it is considered simply as a part of doing business. Therefore we chose a name that describes the business and solutions and that can be maintained for years to come, when the marketing hype has gone. Integrated Operations is enabled by digitalization, or what ABB calls the Internet of Things, Services, and People (IoTSP). The IoTSP is defined as "intelligent industrial devices, connected via networks that expand opportunities for remote services and that allow people to make better decisions thanks to their ability to collect, analyze, and act on data, by working closer together and sharing applications, tools, and processes." Integrated Operations is defined as "a way of operating that allows ships, onshore operations, and ABB to operate on the same information and communication technology (ICT) backbone in order to deliver troubleshooting, technical support, condition monitoring, performance monitoring, and analytics, and condition-based maintenance in a seamless, and fast manner that improves operational costs and safety on board the vessel but also onshore."

6.4 The picture on the next page explains how sensors and software onboard the ship send equipment and performance data via satellite link which allows ship owners, in collaboration with ABB's experts, to perform remote troubleshooting and make informed judgements about the ship's performance and maintenance plan.

6.5 Integrated Operations increases our customers' uptime, ability to plan, and the cost to operate. In addition, this way of working provides internal benefits to ABB, such as reducing quality related cases in production, execution and service delivery. It also helps to compete for new talent, and increases workforce productivity, due to reduced coordination that is required to communicate and organize internally, and towards our customers. Availability of accurate and analyzed information allows data-based decision making that allows more focused actions and better results.

6.6 Through the Integrated Operations concept, critical equipment and control systems on board a vessel can be monitored, and are used at ABB on shore service center and the customer's on shore fleet operational center, for optimizing the vessel and fleet operations.




6.7 While earlier, the systems we sold to our customers consisted of automation, power and propulsion equipment, our new system delivery includes more sensors and monitoring hardware and software on board – to monitor the critical systems, and give the crew in the engine control room, and the bridge, more visibility of their operations. That is what we call the integration 'from bridge to propeller'. Some of the data provided by these systems is analyzed already on board the vessel, by automated algorithms, which allows immediate and fast reaction from the crew to act on anomalies, performance issues and emergency situations. But in addition, we can send some of that data to the shore and make it accessible to the customer wherever they need it, whether that is in an operational center or just on a laptop or a smart phone. This data transfer takes place either through a cloud server or within their own IT network. This gives the customer's technical department (which is located on the shore side), better visibility of each vessel and the total fleet, and enables it to react in a more efficient way in emergency situations and to plan better for maintenance and operations. In addition, we are using this information ourselves, in our own service centers, from where we can remotely access key equipment in order to troubleshoot, or to analyze losses and support our customer in maintenance planning and making improvements to systems during operation.

6.8 Basically, we can run a virtual copy of the system on a server and make it 'age' according to the vessel that is operating at sea. This concept, also often described as 'Digital Twin' will soon be a commercial reality and it will be a key to provide condition-based maintenance.

6.9 This scope of an integrated offering and technology package is called 'from office to propeller'.

6.10 What we are going to sell can be described as a horizontally and vertically integrated system – not only by integrating products and software on board the vessel horizontally (such as having transformers, motors, and drives talk with each other directly without higher level supervisory system) – but also by integrating the troubleshooting and maintenance services we deliver to the vessel, the lifecycle and fleet services we deliver to the customer's technical departments on shore, and the monitoring of the systems on board. Essentially, we are selling a new way of operating, because our new offering allows the different stakeholders on board and on shore to close existing communication gaps and switch from a fragmented way of operating to a more integrated one. No information should get lost anymore, and our response times should become the best in the industry. The result is a new system and services integration that allows to introduce remote operation for selected functions on selected vessel types, or for selected operational and navigational situations. Our offering will be vessel type specific, and we will use many of the services and technologies across these different vessel types. By tapping in to the data and operations characteristics, more efficient technology solutions can be created and designed to better match the specific needs.

6.11 Some of our customers are establishing Fleet Operational Centers already, which means that they are centralizing certain management tasks, and giving more support to their fleet from ashore. For example, the largest container operators have operational centers where they monitor and support their cargo vessels. This makes it also easier for us at ABB to centralize our support to that particular customer, by establishing Integrated Operations Centers, which can support a number of customer accounts. We will establish our technical hubs and integrate all Service Centers with each other. With this set up, we will create a stronger and more positive bond between us and our customers because it makes it easier to serve our users and create insights.

6.12 With this offering, we aim to continue differentiating ourselves from our competition, mainly due to two reasons. First, the sensors and optimization software we offer, is integrated with our systems and products. This means our customers get solutions that are much better integrated with their critical systems, allowing them to optimize fuel consumption, prevent failures, lengthen the operational window, or reduce maintenance. It makes our products and systems smarter, and we do not have to compete on software alone.

6.13 By implementing a way of maintenance planning and execution, of 20% or more on dry docking costs on ABB equipment can be saved if monitoring, pre-survey, and project execution are managed in close cooperation between ABB and the ship owner.

6.14 Second, we are the only one of the system suppliers that can offer an integrated automation, power, and propulsion system with our own products produced in ABB factories, as well as global service coverage.

6.15 By monitoring the most critical systems on board and making key information visible on the bridge, in the engine control room, and at the customer's onshore operations center, we allow our customer to manage the fleet in a better and safer way.

6.16 Since we are part of this communication by having access to the vessel from our own onshore service operations centers, we are a safer and more reliable choice for our customers to call when they have a critical situation. Having an access to the product level information is beneficial when accurate decisions need to be made and recommendations given how to rectify faults or improve performance.

**7. How this will Benefit Our Customers**

7.1 There will be significant changes how work is carried out and organized, by the automation of work. Therefore we need to understand who the users will be, and how they will use our products and services. All kinds of users, whether the service engineer, the plant manager, the vessel's captain, the business controller, the designer, or the supplier's operations manager, have access to information that helps them making different types of decisions.

7.2 This also means that customers are looking for new ways of operating, and for solutions that deliver practical benefits to different personnel, on shore and on board. Therefore, a useful portfolio of smart services, which is linked to the customers' installed base, daily operations, to technical planning departments, to troubleshooting, spare part inventories, and the customers' improvement initiatives, is clearly needed. Integrated Operations enables access to the best possible knowledge as the centralized service operations is not that dependent on individual service engineer's ability to solve problems on site. Therefore few experts can support larger fleet, which does not mean that our service delivery will feel more anonymous to our customers. We will still make extensive use of local resources but they will be better integrated in communication and coordination.

7.3 Applications which display KPIs to top management should only be a by-product of information systems that are used in daily operations. This translates into customer benefits at two different

locations: the vessel, and the shore. In addition, the benefits depend on the customer's type of business, as well as the vessel type. For example, a cruise vessel has a different operational profile, demand for power, and is subject to different class requirements than a drill ship. But both customers may want to centralize their onshore operations, transfer more management tasks from the vessel to the shore, and have better access to vessel systems. On a large ship like a cruise ship, removing routine tasks from the vessel, may allow the crew on board to use more time on critical operations and ensuring the safety.

7.4 The solutions we already have today, provide the vessel with energy savings by monitoring and managing power and propulsion, forecasting ship motion and taking into account the operational actions such as changing the route, speed, or when to retract the stabilizing fins.

7.5 With our motion power production, power consumption, motion forecasting and voyage advisory software we have saved customers up to 5% in fuel cost.

7.6 Another effect is the increased up-time for offshore related work such as pipe laying an drilling. The more efficient collaboration also results in cost benefits for the customers´ on shore technical operations due to less coordination work, reduced supply chain costs for planned maintenance, and less work for technical planning and management. Customers have already centralized many other functions, such as logistics and supply chain management. The Technical Operations function is for some companies the last function that still operates in a fragmented way.

**7.7 Customer Benefits**

(a) Full transparency of critical systems down to detailed level

(b) Visibility of critical processes and alarms

(c) Detection of failures and analyze together with the OEM

(d) Ability to reduce voyage speed of ships and the whole fleet

(e) Higher availability of systems and vessels by accepting known, low risks

(f) Incident management combining onshore, OEM, and vessel crew

(g) Plan, manage and increase maintenance during operations

(h) Save man years in technical planning department, by better OEM cooperation

(j) Comply with Classification, in extended and reduced maintenance

(k) Help plan fuel efficienty during voyage and operation

(l) Develop new solutions that solve challenges based on data

(m) History of performance, condition, and intervention performed on the systems

(n) Attract and retain a new generation of professionals

(p) Benefit from your staff's and OEM's expertise through cooperating better

(q) Manage documentation globally, easy to update and locate files

(r) Manage software installed base, and upgrades, globally and reliably

(s) Leaner global footprint due to better access to resources from OEM and internally

**8. How this will Affect the Service Business of ABB**

8.1 By implementing technologies of the Internet of Things, Services, and People (IoTSP), we will be replacing manual work with software and change the economics and performance of our business. By adding software and analytical expertise to our competence, the same amount of people will be able to support a fleet many times greater than today.

8.2 White collar productivity will be increased through a greater use of software and connectivity. Sales and sales support will be partly automated, including order handling and processing. Much of

analytics will be automated, as well as alarm monitoring. We will be able to operate our business in real-time, which allows to react faster to demand, avoid resource misallocations, and reduce the real cost of poor quality, significantly.

8.3 Service agreements in the future will be executed through the integration of our maintenance, supply chain, and order handling processes with those of our customers' which will allow automating many of the tasks and processes, leading to reduction in sales, order handling, and reporting tasks. This will reduce cost for both sides.

8.4 The goal is to transform our business into a modern enterprise that can withstand the changes the next Industrial Revolution is going to bring us. Especially the automation of work and processes that our customers are going to implement (and which we therefore must implement as well) will require investments in software, tools, and new competences. But digitalization and enabling technology will also provide us with significant growth opportunities, which means software-related services will grow, and enable the growth of traditional services.

8.5 Thus, Integrated Operations is not only a growth initiative but also an operational excellence program, because we improve many of the basics in our service delivery processes, technology platform, engineering, installation, commissioning, and in Service. When we implemented our ticket management system that runs our internal and customer technical support, we realized this information is valuable internally for quality control and for our customers to analyze exactly which equipment on which vessels requires attention.

8.6 This means our possibilities to provide our knowledge to customers has greatly improved. Software-related investments in our operational excellence will pay back by internal cost savings and revenue from customers. This will improve customer satisfaction, employee motivation, and sales, due to a smoother and more professional and more collaborative work environment where experts can focus better on their tasks.

8.7 Also required will be a closer integration with our suppliers, who are mainly ABB factories and their service departments. This supplier integration will provide significant cost savings and improvement of response times towards our customers. Another benefit of the improved lever of integration with the customer is the possibility to expand the scope of services by integrating different sources of data, while at the same time reducing system complexity by streamlining hardware and software architecture with larger systems. This brings down the cost for services such as hull condition monitoring and monitoring of critical rotating equipment.

8.8 The goal is to transform our business into a modern enterprise that can withstand the changes the next Industrial Revolution is going to bring us.

**8.9 Benefits for ABB**

(a) Productivity in technical support, field service, and commissioning

(b) Reducing costs due to quality issues in manufacturing, installation, and operations

(c) Reduce warranty cost- Reduced commissioning cost

(d) Reduced sales cost per customer and opportunity

(e) Manage documentation globally, easy to update and locate files

(f) Improved response time and reduced coordination of responses

(g) Research and development closer to customer needs

(h) Attract and retain a new generation of professionals

(j) Benefit from our staff's and customer's expertise

(k) Leaner global footprint due to better access to our own resources

**9. The Modular Offering**

9.1 Our service offering is modular and customers can start with whatever service addresses the issues they have at that given moment. Because we are doing the services 'with' our customers, we need to be able to integrate with the tools and providers they are using as well.



9.3 **Remote Diagnostics**

(a) RDS remote diagnostic service onboard infrastructure for remote troubleshooting

(b) Preventive and continuous monitoring, combining online with manual monitoring if necessary

(c) Available for the entire ABB marine drive train, Azipod® propulsion, the Automation System, and Power Systems

(d) Integrated with ABB automation and advisory systems to provide Integrated Solutions and Services

(e) Monitoring of ABB system delivery (non-ABB equipment can be included in exceptional cases)


9.4 **Operations Monitoring**

(a) Monitors energy production and consumption

(b) Improved forecasting of behavior of vessel in weather and motion

(c) Decision-making support while operating in different weather conditions

(d) Map energy flows, understand where you can optimize

(e) Measures fuel and energy consumption

(f) Measure energy and power savings of products such as drives and motors, sending data to cloud

(g) Displays consumption and losses

(h) Recommends actions

9.5 **Fleet Intelligence**

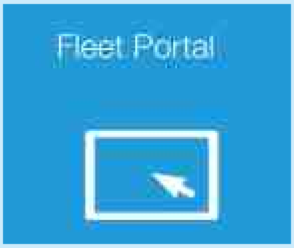

(a) Documentation of cases, easy case tracking

(b) Utilization of case data for identifying issues with specific equipment on specific vessels

(c) Utilization of data for maintenance planning on individual vessels and across the fleet

(d) Utilization of data for identifying improvements in crew's and suppliers' maintenance practices

9.6 **Fleet Portal**




(a) Easy access to all customer relevant information ABB Marine has

(b) Single sign on to a dashboard that provides a quick summary of key activities per vessel and fleet

(c) Allows interaction with ABB for all services that are included in the customer's agreement

(d) Portal features are switched on or turned off, based on agreement content with customer

9.7 **Advanced Analytics**


(a) Analysis of data coming from different sources, combining that data with off-line expertise

(b) Reporting of key facts, according to customer's needs and requirements by stakeholders

(c) Going through large volumes of data and identifying the essential, small amounts of data that are important

(d) Using data analysis to make statistical calculations and predictions on failures and fatigue

(e) Using data analysis for optimizing new buildings and making structural changes to existing vessel

9.8 **Condition-based Maintenance**


(a) Prediction of equipment failure and risks

(b) Advice when to perform maintenance actions

(c) Advice whether maintenance and repair can be delayed to a later point, based on the real risk

(d) Certified by the Class

(e) Focus on ABB systems

9.9 How we accelerate our digital transformation The implementation of the Integrated Operations strategy requires the integration of many existing development initiatives, aligning internal units in different countries with each other, and with the digitalization strategy.

9.10 The initiative spans across technology, systems delivery, project and engineering departments, new sales, operational support and service. In addition, global processes and tools need to be implemented for services such as Global Remote Diagnostic Support, and Global Technical Support.

9.11 Many initiatives which were earlier managed separately, such as Remote Monitoring and Management, Global Technical Support, Diagnostic Services, the Marine Online Portal, Software Development, Systems Engineering, and many of the Operational Excellence initiatives, are now combined with each other.

9.12 We continue the integration of Automation to the power and propulsion package, the integration of all sub systems with each other, as well as integrating monitoring, analytics, and troubleshooting services on ABB's side, with our customer's fleet of vessels and their onshore operational centers.

9.13 Integrated Operations was kicked off as a Digitalization Strategy in the end of 2014, after half a year of planning activities and pulling all necessary tasks and departments together. Now, in 2016 the transformational program will be taken over by the business organizations, and the new departments that were established in the past years.

9.14 Combining the monitoring capabilities of its centres in Norway, Finland, and the Netherlands, we can connect to more than 600 vessels and there are further centres scheduled to open in Asia and the US in 2016.

9.15 Digitalization, and digital services and processes will simply be a part of our daily core business.

9.16 For the past years, we have been conscious of the fact that our Digital business transformation is essentially different from typical product inventions, or simply launching a cloud service. We are bringing digitalization to the core or our business, products, and processes. This means our innovation process is fundamentally different compared to traditional transitions or new product launches.

**10. Final Words and Vision Forward**

10.1 The Internet of Things, Services, and People is an emerging industry megatrend that will change the way the maritime industry and many other industries operate.

10.2 The Internet of Things, Services, and People is an emerging industry megatrend that will change the way the maritime industry and many other industries operate. But the key is to know which new solutions and services to combine with the existing core of our business, in order to provide the customer with enhanced productivity of their assets, and investments – whether that is a productivity improvement in the production process, in safety, quality, or in cash.

10.3 **By end of 2016**, we will have turned four Marine Service Centers and Competence Centers into Integrated Operations Centers. In these locations, we will have an Integrated Operations room, able to support customers and our own workforce worldwide, 24-7, based on new software tools and cloud services. Already today, the majority of systems supplied by ABB have a basic scope of Integrated Operations features, which allows ship owners and operators to utilize some of our digital services right from the beginning of operations. Retrofit solutions are available as well. The newest generation in system architecture design will allow customizing project deliveries more efficiently while giving ship owners additional product features at less complexity.

10.4 **By 2020**, we aim to be connected to 3000 vessels. We estimate that 20 percent of our customers have a modern operations center and our target is to be part of these centers. The share of software developers and softwarerelated jobs among our workforce will increase significantly. By 2020, Integrated Operations features will be part of every new vessel, and we expect that most newbuilding specifications will require these types of features to be part of the suppliers' scope.

10.5 **By 2030** we aim to have supplied vessels with technology that allows to remotely and autonomously operate selected functions on board the vessel. We will support ship owners and operators in monitoring all critical sub systems, in realtime. In the future, a substantial amount of our business volume and competence will be software-based, also driven by customers that operate on modern, IT-based processes. Our core services will also increase in revenue and software content, which means that modernizations and planned maintenance will be based on the insight we gain through the new technologies.

10.6 Working closely with our customers and using the same tools means there will be more interdependencies between our work processes and value chains. The work we perform in engineering, service, and supply chain will become more performance-driven and customer focused because Integrated Operations improves our ability to provide our knowledge and services to the users.

10.7 The more all parties in the value chain are connected, the higher Operational Excellence will move to the agenda. Improvement initiatives will be joint efforts between the owner, operator, and supplier, for example in supply chain and spare part management, handling emergency procedures, and asset lifecycle management.

10.8 Integrated Operations is also a good example of ABB's Internet of Things, Services, and People (IoTSP). We have taken action to accelerate the digitalization, by improving our competencies in new areas and integrating them with the existing organization. Our new Integrated Operations Centers are proof of that. We consider this the beginning of the next Industrial Revolution and a wave of shipbuilding activity that will see more connected, integrated, electrical, and autonomous vessels and maritime operations.

10.9 We believe the next step-change in productivity and safety in shipping comes from integrating ships better with shore side operations. Integrated Operations is the concept that will drive this change in the coming years.

# DEVELOPING MATURE VENDOR BASE FOR SELF RELIANCE IN INDIGENISATION


**COMMANDER S ADIL MOHIDEEN**

Training Commander, INS Vishwakarma


**1. Abstract**


1.1 The role of the private industries in the Defence Sector in India cannot be disregarded. It is not a hidden fact that unless we promote the private industries to participate and grow, the dream of self-reliance in indigenisation will not be achieved and will remain unrealistic for ever. With the Indian Navy set to grow two fold in the near future, promoting the indigenous manufacturing capabilities is the need of the hour. At the same time developing a sustainable, competent and mature vendor base would ensure timely availability of quality equipment and material for our growing defence shipbuilding industry. While Indian manufacturing has improved significantly in quality control over the time, a mature supplier base is still in an early stage of evolution. Additionally, accreditation is time-consuming and expensive in this low-tolerance industry in which the buyer expects the highest quality of products and services at the lowest possible price. Understanding the concerns of both SMEs and established private industries has been the prime motive of the MoD and the promulgation of DPP, DPM, INIP 2015-30, and the Science and Technology Roadmap is a welcome step in this regard. This paper highlights the aspects involved in the development of such a stable vendor base which will meet the envisaged warship building program of India.


**2. Introduction**

2.1 The Indian Navy is slowly transforming from a Buyers' to a Builder's Navy. The Navy has, in its Maritime Capability Perspective Plan (MCPP), projected a 200 ship-strong navy by 2027, including 90 front-line combat platforms [1]. Considering the present geopolitical and economic situation, the Navy is poised to grow further along with development of robust and indigenous manufacturing capabilities towards self-reliance.

2.2 With almost 2 per cent of its GDP spent on Defence and import of about 70 per cent [2] of the equipment, the country's requirements are only likely to increase in the future making indigenous development of modern hardware and technology an imperative priority.

2.3 Policies such as Foreign Direct Investment (FDI), Procurement Policy (DPP) and reduction in import dependence by 35-40 per cent, will allow for faster procurement, in a streamlined manner, especially through indigenously designed, developed and manufactured (IDDM) provisions [2]. OEMs as well as SMEs in the manufacturing sector are now converging on moving from a buyer-seller to a co-developer and co-manufacturer relationship. They have not only come together and formed strategic partnerships to support the development of a sustainable supplier base for the sector, but have also precast themselves quickly to foster a culture of innovation and R&D. So far, they have demonstrated a huge amount of potential and capability to deliver on this promise.

## 3. Self Reliance & Indigenisation

3.1 In the current scenario of shipbuilding in the country, equipment and systems onboard an IN warship/ submarine can be broadly classified into the following three categories:-

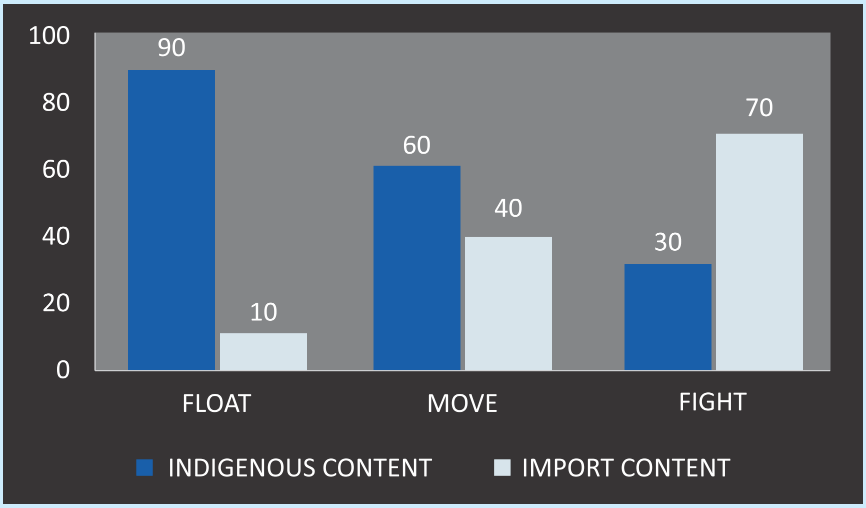
(a) **Float.** This category encompasses all material, equipment and systems associated with the hull structures and fittings.

(b) **Move.** Equipment under this category encompasses propulsion system and power generation diesel/ gas/ steam turbine engines, alternators, associated control systems, auxiliary mechanical systems like pumping and flooding, HVAC, Fire-fighting and other ship systems including general electrical equipment.

(c) **Fight.** Equipment under this category encompasses all types of ship-borne weapons and sensor systems that directly affect the combat capability of the ship.

3.2 The equipment and machinery fitted on board ships in the three categories of Float, Move and Fight has been indigenised to the extent of approximately 90 per cent, 60 per cent and 30 per cent respectively (see Fig. 1) [3]. The analysis of these categories indicates that while sufficient self-reliance has been achieved in the first category and a reasonable one in the second category, there is a large shortfall in the third category.

**Fig.1: Indigenous content in Float, Move and Fight category**




3.3 The Self-Reliance Index (SRI) which may be defined as the ratio of indigenous content of defence procurements to the total expenditure on defence procurements in a financial year is at an abysmal 0.3. In 1992, Shri Abdul Kalam, the then Scientific Advisor to the Raksha Mantri, constituted a Self-Reliance Review Committee to formulate a 10-year long-term plan to transit from a dismal SRI of 0.3 to 0.7 by 2005 [5]. This would have implied that the import content of defence procurements, which includes import of weapon systems/ platforms by the armed forces as well as services sought from foreign vendors/ Original Equipment Manufacturers (OEMs) by Defence Public Sector Units (DPSUs) and Ordnance Factories (OFs), be brought down to 30 per cent or less. Sadly this was the first and perhaps the last time such an exercise was undertaken and there is good reason to believe that the SRI has ever since remained stagnant at 0.3, if not dipped further.

3.4 The Services on their part have established dedicated Directorates for Indigenisation in their respective services. The Army and the Navy, for instance, have even formulated a well-articulated 15-year Perspective Plan for Indigenisation with a mission to carry out purposeful indigenisation of spare parts, sub-systems, special maintenance tools, test equipment and entire equipment (non-war like) with a view to effecting significant savings in life cycle costs of imported weapon systems. This roadmap gives a clear perspective of technologies and defence products that are likely to be inducted. The Indian Naval Indigenisation Plan 2015-30 has also been promulgated in July 2015, which attempts to formulate the requirements of the IN towards indigenous development of equipment and systems, over the next 15 years [3]. The document identifies capability gaps for indigenisation and lists out the equipment which can be taken up for indigenisation in the coming years.

**4. Procurement System**

4.1 The standard and quality of equipment required for the naval warships are extremely stringent in terms of the specifications. At most times the specifications cannot be met by the commercially available equipment. A detailed assessment of the equipment offered by the OEM vis-à-vis the requirements of the Indian Navy is therefore undertaken by the Professional Directorates at Naval Headquarters before the vendors are shortlisted for supply of the equipment. These specifications include the ability to withstand shock, stealth requirements like Structure Borne Noise and Air Borne Noise, reliability, maintainability, adherence to defence/ military standards during manufacture, etc. Further, limiting the vendor base for a particular item will ensure standardization of the equipment and avoid equipment proliferation leading to lesser inventory holding cost and improving availability of the spares in the Material Organizations. New vendors who wish to offer their equipment are also encouraged and given an opportunity and the vendor list is constantly updated based on availability of equipment that are able to meet the naval/ military standards.

4.2 Certain items, particularly equipment, are sometimes the propriety product of a manufacturing firm. Such items are only available with that firm or their dealers, stockists or distributors as the detailed specifications are not available for others to manufacture. Situations may also arise when, for standardization of machinery or for ensuring compatibility of spare parts with the existing sets of equipment, as per the advice of the competent technical expert, goods and services had to be obtained from a particular source. In such situations, a Propriety Article Certificate (PAC) is issued to the original equipment manufacturer (OEM) and items procured on PAC basis from that particular firm or its authorized dealers, stockists or distributors in accordance with DPM - 2009 [10]. This has a twofold benefit of ensuring genuine spares/ equipment which are directly procured from the OEM and the middlemen are obviated from the process.

4.3 As far as possible, items of general nature are procured through competitive bidding. However, manufacturer specific items of equipment, machinery and spares required for specific use in the Navy are required to be procured on PAC basis for reasons of fitness, availability, quality and standardization [10].

4.4 In addition, identification of new and reliable vendors from overseas is also undertaken as part of induction of new systems through the process of RFI, as stipulated in the DPP. The refining of the vendor base is a continuous process done through RFIs, capability demonstration during seminars, exhibitions and literature study from the open source/ various domains including through Defence attaché posted in different countries abroad. Perspective vendors are thereafter requested to submit their products for evaluation trials by the Indian Navy.

## 5. What has Hindered Private Sector's Participation

5.1 By 2014, when Make in India was announced, MoD's Defence Procurement Procedures (DPP) had already undergone eight rounds of major revisions. However, it is the revisions carried out after 2006 that created some private sector specific opportunities, by way of articulating two crucial procurement categories: Make and Buy and Make (Indian). Under these categories, the private sector was expected to execute major contracts like the public sector units. However, the private sector has suffered from a various other difficulties in its one-and-a-half decade journey since 2001.

5.2 The government has no doubt taken a host of initiatives to incentivise the private sector's participation in defence production. These include a hike in FDI cap, streamlining of IL process, opening up of government-controlled testing facilities, articulation of export promotional measures, extension of ERV benefits to the private sector, and providing a level playing field between the public and private sectors in so far as duty and tax are concerned. But there are many other concerns still pending for the government's attention. Some of these are as follows:-

(a) ***Lack of Conducive Financial Framework***. Many countries provide a host of fiscal and other incentives to nurture and develop the defence production sector, which is undoubtedly a strategic sector. The prevailing duty/ tax structure potentially bars private sector investment in defence production.

(b) ***Lack of Representation at Defence Ministry***. Senior MoD officials are on the governing boards of the public sector units and need to show that they are performing well. From the private sector's point of view what is particularly of concern is the government's continuance of the nomination approach, breaching its own commitment.

(c) ***Incentives Demanded by the Private Sector***. The incentives demanded by the private sector defence industry broadly relate to cheaper cost of finance, infrastructure status, and deemed export status for certain types of sales. To provide a level playing field to the domestic manufacturers, the government under the Foreign Trade Policy (FTP) accords deemed export status to select specified cases which are notified from time to time. The status is for 'encouraging import substitution and mainly covers such supply of goods which are otherwise allowed at zero customs duty'. In case of Buy (Global) procurement, Indian companies can also compete with foreign companies. If an Indian company wins a contract in such a procurement category, it amounts to import substitution.

(d) ***Poor R&D***. R&D is probably the biggest weakness in the Indian private sector's foray into defence production. The private sector's minuscule effort in defence R&D is a mere reflection of the poor R&D focus of Indian industry as a whole.

(e) ***Skill Deficiency***. Unlike the public sector units, which are the established players and have a relatively better skilled workforce, the private sector does not yet have the kind of workforce required for a high-end manufacturing sector like defence. To meet this need, the Confederation of Indian Industry (CII) has partnered with the National Skill Development Council (NSDC) of the Ministry of Skill Development and Entrepreneurship to set up a Strategic Manufacturing Skills Council (SMSC).

(f) ***Delay in Acquisition Process***. Although the government has opened a host of big-ticket projects for the private sector's participation, these projects are at the very early stage of the acquisition process. As per the DPP, it takes somewhere between two and three years for a project to be awarded after the in-principle approval is given by the Defence Acquisition Council (DAC), the highest decision-making body of MoD headed by the defence minister. However, it is not the stipulated time scale but the delays and frequent cancellation/ retraction of tenders that hurts the industry the most.

(g) ***Inspection Delays***. One of the major hindrances for the private sector to continue its participation in the Defence contracts is the delay attributable to the inspection process, consisting of lengthy documentation work including drawing and Quality Assurance Plan (QAP) approvals from several authorities. This invariably leads to delay in scheduled delivery of the item along with implementation of LD in most cases. The material and manufacturing costs due to rejection and deterioration are in addition. The time lapse since placement of order to commencement of the manufacturing process sometimes could be about six to eight months for fresh vendors. It costs the vendors a few orders and some years to stabilise and understand the nuances of the inspection procedures. With the SOPs being modified recently wrt drawing approvals and SQAP formulation, only time will tell if the same will act as fresh impetus for participation amongst interested vendors.

(h) ***Order Books***. Despite the efforts and applicable R&D invested by the Private Sector in development of technology, bagging orders and delivering big-ticket items, there is no guarantee of subsequent and repeat orders coming through their way. With rapid advancement in technology, the need for such an item and associated technology itself might vanish. This would further worsen the investment in R&D as well as their participation, as the marginal profits would not allow the industry to sustain in the long run. Poor R&D and cost cutting for being competitive enough will directly impact the quality of the product and reliability of the industry in delivering top-notch equipment and technology to the defence sector.

## 6. RESEARCH AND DEVELOPMENT

6.1 R&D is a mission-oriented activity comprising of basic and applied research for the development, testing and production of new weapon platforms. The term also covers improvement and modernization of existing weapons and sensors. In the prevalent 'quality or quantity' dilemma, it is R&D that improves the quality of the equipment systems used by armed forces'. Nowadays, advanced technologies, coupled with highly trained personnel, are perceived as the sine qua non of the military [3]. While successfully deployed technologies have transformed modern Armed Forces, and changed the ways in which wars are fought and conflicts resolved, their development is a lengthy, risky and expensive process.

6.2 In the country, the field of defence R&D has been the bastion of the Defence Research and Development Organisation (DRDO) ever since its foundation in 1958. It started as a small organisation with 10 laboratories, and today has grown to over 50 labs and a workforce of over 35,000 personnel.

6.3 Without adequate and sustained R&D in private sector, it is very difficult to achieve Self Reliance and make the 'Make in India' dream a huge success. The Defence Procurement Procedure (DPP) has focused on indigenization and encouraging private sector participation. It has introduced a category called Indigenous Design Development and Manufacturing (IDDM) category in addition to the existing four categories in the Make programme. All these acquisition categories mandate transfer of technology and increasing indigenization. Presently, the Government and its undertakings dominate R&D activity in India. But to build a truly robust defence production eco-system, the private sector will have to engage in R&D and the Government must reduce barriers and provide incentives to it. The promulgation of the Science and Technology Roadmap (2015-35) in May 2015, which serves to identify key technologies required to be developed in the next 20 years, is a welcome step. The document seeks to harness national capabilities and focus coordinated efforts amongst the IN, DRDO, public sector and private industry to develop technologies for the future Navy.

**7. Sustained High Quality Manufacturing**

7.1 The Public Accounts Committee in 2016 based on the CAG report has highlighted the challenges in the complex and multi-disciplinary engineering activities involved in shipbuilding and the Role of Quality while ensuring maximum indigenisation. Further, Quality Council of India (QCI) has presented a model ZED, (Zero Defect, Zero Effect) where the concept of quality has a holistic change from a tool for compliance to a source of competitiveness [2]. Addressing the Nation on India's 68th Independence Day, the Hon'ble Prime Minister had urged the industry, especially the Micro, Small and Medium Enterprises (MSMEs) of India, to manufacture goods with "zero defects" and to ensure that the goods have "zero effect" on the environment. Ensuring competitiveness of India's MSME is critical as it will contribute to the overall growth of the manufacturing sector and the country's economy.

7.2 Recent policy instruments and market interventions in both public and private spaces starting with the implementation of Public Procurement Policy for MSMEs, FDI in single and multi-brand retail, interventions in manufacturing sectors like Railways, defence and e-businesses, emerging strong manufacturing sectors like defence and aerospace and finally the opportunity to access global market with globally competitive products are strong drivers to take ZED manufacturing forward and to support fast changing market scenarios in the country [2]. This will be a win-win situation for all stakeholders involved in the foreseeable future. Additional benefits to MSMEs are as follows:

(a) Credible and reliable vendor database.

(b) Reducing negative effect on our environment.

(c) Awards and Rewards.

(d) Aligning with best practices.

(e) Global Competitiveness.

(f) Visibility and brand recognition.

**8. Consortium and Strategic Partnership Model**

8.1 Most of the shipbuilding for the Indian Navy is catered to by MDL, HSL, GSL and GRSE. About 60 to 65 per cent of equipment, assemblies and subassemblies required for shipbuilding and repair are supplied to these shipyards by MSMEs, either directly or indirectly. Active involvement of the private sector in the manufacturing of major defence equipment will have a transformational impact and it will serve to enhance competition, increase efficiencies, facilitate faster and more significant absorption of technology, create a tiered industrial ecosystem, ensure development of a wider skill base, trigger innovation, and promote participation in global value chains as well as exports. From a strategic perspective, this will help reduce current dependence on imports and gradually ensure greater self-reliance and dependability of supplies essential to meet national security objectives.

8.2 To manufacture major defence platforms, the SP will require tie-ups with foreign Original Equipment Manufacturers (OEM), to cover manufacturing, transfer of technology (ToT), assistance in training skilled human resources and other support.

8.3 Capital funding remains the MSME sector's biggest hurdle. Typical cyclic problem which an MSME faces is high cost of loans, giving rise to financial constraints. This in turn inhibits infrastructure and technology development. Add to these are low volumes with high Research and Development (R&D) and licensing cost [3]. Also, the Indian Navy's requirements for materiel be it for new production or refits is quite dynamic and thus sourcing materiel is neither constant nor sustained for a particular vendor. Additionally, products are complex and it is difficult to apply the 'one size fits all' approach since each acquisition poses different challenges. Even from a bankers' perspective, MSMEs are regarded as high risk borrowers due to insufficient assets and low capitalization. Vulnerability to market factors is another factor impacting cash flow.

8.4 The Government / MoD through its recently updated DPP, has instituted lot of measures and changes to achieve the national aim of Make in India. MoD in a bid to fix procurement issues has now recognised that these issues are systemic and the whole process of acquisition right from Request for Proposal (RFP) stage to procurement and finally to maintenance and repair (life cycle support) needs to be considered from inception stage itself [6].

**9. Recommendations**

9.1 ***Development of MSMEs.*** Shipbuilding activities for the Indian Navy are centred around the DPSU shipyards with each shipyard specialising in certain types of warships. These shipyards geographically cover western, southern and eastern coasts of the country. Due to their basic role, these shipyards can be termed as integrators. Major equipment like Main Engines, weapons and sensors, Refrigeration and AC plants, Integrated Platform Management System (IPMS) for the ship is sourced from the Original Equipment Manufacturers (OEMs) / big public or private sector units and are the Level 1 vendors. These OEMs in turn, source a major chunk of their supplies from smaller industries say medium / small scale industries, which can be designated as Level 2 vendors and the pyramidal structure goes on this way.

9.2 Due to the ability to invest sufficient funds in R&D and skilled manpower, Level 1 vendors are still dominant and the bottom rungs of the supply chain are relegated as suppliers of commonplace materiel and over a period of time face stagnation. Therefore, advancement / progress of these Level 2, Level 3 onwards as strategic and development partners with the integrators and Level 1 vendors is the need of the hour. As a growing Navy, this system will be of immense benefit by way of having a set of competent suppliers, who will be ever-ready to supply and give life cycle support because of assured orders and that too at a much lesser cost. The quality of materials used for manufacturing and the cost of inspection will also reduce; timely payments being the overriding factor for continued sustenance. In the bargain the MSMEs will also prosper and in due course of time move up the ladder to give their space to newer MSMEs.

9.3 ***Development of Technical Specs.*** Another step towards widening the industry participation in Defence could be the development of materiel required for the life cycle support of new projects. Many of the items to be renewed during major refits, a few years down the line, could be developed through MSMEs, provided the technical specs are defined jointly by the Navy and the industry. QRs, which form the basis for procurement, are often prepared by aggregating the best of the features taken from the equipment available in the world market. The process does not allow trade-offs between what is realistic/ feasible through the available industrial/ technological means and the minimum requirement of the armed forces. The absence of trade-offs puts the domestic industry at a disadvantage, since the high-pitched technical requirement either bars its participation or, in case of participation, contributes to delay and uncertainties by way of chasing the unrealistic goals. To prevent this, it is imperative that the industry is consulted while formulating the technical specs. The MoD and the industry bodies like CII, FICCI could consider assisting a few selected MSMEs who are contracted for supplying these items, to contact other Navies operating similar ships and entering the export market.

9.4 ***Development of Vendor Base.*** Based on the stringent technical specs developed in association with the capacity existing within the industry, a limited vendor base could be developed post Vendor assessment and registration. Based on a detailed capacity assessment and supplier grading including financial soundness, after sales service feedback, Quality Control facilities and products delivered worldwide, only the shortlisted vendors would qualify for participating in the tenders pertaining to the defence sector. This would not only ensure delivery of quality products and service to the defence industry but also allow the firms/ vendors to fairly compete on a level playing field and seek more orders.

9.5 ***Drive for Self Reliance.*** India offers tremendous opportunities in engineering services, supply chain sourcing and associated maintenance, repair and overhaul-related activities, however to achieve self-reliance we need to create a robust ecosystem that can address the capacity and capability requirements for the industry. While the government is taking numerous measures to bolster defence manufacturing, the pace of modernisation must be balanced with both short and long term initiatives. A strong supply chain is critical for a defence manufacturer looking to optimize costs. India is uniquely positioned to create a vibrant defence manufacturing ecosystem that can help us achieve self-reliance. With defence being one of the government's high priority focus area, the country will soon emerge as a preferred destination for the co-development and co-creation of an indigenous and self-sufficient defence manufacturing ecosystem.

9.6 Fostering a constructive partnership with Indian private defence industry is considered not just a sound economic option but a strategic imperative to minimise dependence on imports and infuse self-sufficiency in defence manufacturing. Larger and sustained production volumes of a system will lead to optimisation of cost, improved production efficiency and ability to absorb higher end technologies, besides creating an extensive eco-system of defence related industries in the country so that defence manufacturing emerges as a key driver in India's economic growth and development. Some other factors which merit attention in this regard are:-

(a) To meet the skilled human resources requirement in the private sector, the government should focus on dedicated defence-specific universities on the lines of similar setups by the atomic and space departments.

(b) The government should stick to its articulated position of awarding no defence contracts on nomination basis. In addition, it should stick to the timelines of the procurement process.

(c) There is a need to look at the payment terms, including the LC option. It would add to the government's efforts towards ease of doing business and at the same time create a level playing field.

(d) There is also a need to relook at the indigenisation content requirement in the Buy and Make (Indian) contracts.

(e) There is a need to review the defence FDI policy. Even after the increase in FDI to 49 per cent, foreign defence companies have not shown much interest in investing in Indian JVs. Lack of assurance seems to be a major reason for the lacklustre response.

## 10. Conclusion

10.1 The Indian private sector has come a long way from being a mere supplier of parts, components and raw materials to the public sector defence production units to be recognised as a force to reckon with. Its plans to make huge investments and its success in winning contracts against both the established domestic players and foreign companies and its larger share in defence export demonstrate its competiveness. However, the sector has witnessed a host of difficulties arising due to the prevailing structure of taxation and duties. It is desirable that this sector is given incentives as has been given to other sectors of the economy. Deemed export status should also be considered for certain types of contracts, particularly those falling under Buy (Global) categories. In principle the contracts executed by an Indian entity under this category are a substitute for direct import.

10.2 R&D is a big weakness in the private sector's foray in defence manufacturing. While the private sector has to take certain initiatives on its own, there is a need for a big push from the government. While retaining the existing 200 per cent weighted tax incentive for the industry's in-house R&D, the government may like to consider the entire R&D value chain for the purpose of providing the tax incentive. At the same time, the government should also stick to its promise of processing 6-8 Make projects in a year. This would not only spur R&D activity in the private sector but also promote a higher level of manufacturing activity.

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# STUDY OF ACOUSTIC CHARACTERISTICS OF A MARINE PROPELLER DUE TO TIP RAKE

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## 1. Summary

1.1 The impact of increased Underwater Radiated Noise (URN) over the past two decades on marine mammals has resulted in the pressing requirement to reduce it. Shipping contributes immensely to the URN. Propeller noise is a major source of URN. The reduction in propeller noise can hence significantly help in the reduction of URN. Currently, the study of propeller design improvement is being undertaken with a sole objective of improving the hydrodynamic performance of propellers ways to prevent cavitation. However, the reduction of non-cavitating noise produced by these propellers would still remain a challenge. Since the change in the propeller geometry can modify the acoustic characteristics, in this present study, effect of modifying the tip of DTMB 4119 propeller on the acoustic and hydrodynamic characteristics is presented. The change in the flow pattern at the tip due to introduction of tip rake is also discussed. The Sound pressure level (SPL) has been calculated by using the two-step Ffowcs William and Hawkings (FW-H) equations from the pressure distribution at various points around the propeller. The SPL at various points in the downstream and propeller disk plane are numerically predicted and discussed.

## 2. Nomenclature

| | |
|---|---|
| AC | Mean cavitation area on the blades ($m^2$) |
| AD | Propeller disk area ($m^2$) |
| $V_{Tip}$ | Blade tip velocity ($m\ s^{-1}$) |
| D | Propeller diameter (m) |
| F | frequency (Hz) |
| P | Pressure ($N\ m^{-2}$) |
| c | Speed of sound in water ($m\ s^{-1}$) |
| $L_S$ | Sound Pressure Level (dB ref 1µPa)) |
| n | Propeller rpm (rpm) |
| Z | Number of propeller blades |
| FWH | Ffowcs-Williams Hawkings |
| V | Ship speed ($m\ s^{-1}$) |
| $V_A$ | Speed of advance ($m\ s^{-1}$) |
| URN | Underwater Radiated Noise |
| $\upsilon$ | Kinematic viscosity ($N\ s\ m^{-2}$) |
| $\rho$ | Density of water ($kg\ m^{-3}$) |
| SPL | Sound Pressure Level (dB) |

## 3. Introduction

3.1 Propeller noise is a major contributor to URN. Increase of shipping noise has resulted in an adverse impact on marine life. Reduction of propeller noise also finds its application in producing silent warships with increased acoustic stealth. Hence, efforts to reduce the propeller noise should be made at the design stage itself.

3.2 In a propeller, the drag is overcome by the thrust produced by it. This thrust producing mechanism of the propeller inherently produces noise. It has been observed that the propeller faces unsteady forces during its rotation. This rotation causes pressure waves which are created in the water through four mechanisms. These are (Carlton, 2007):

(a) Thickness noise - The displacement of the water by the propeller blade profile displaces the water in its path of rotation.

(b) Loading noise - During the rotation there is a pressure difference between suction and pressure surfaces of the propeller.

(c) The rotation of blades in variable wake field behind the vessel produces fluctuation of cavity volumes.

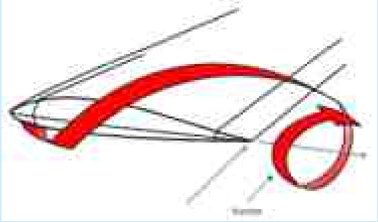
(d) The collapse of a cavitation bubble or vortex.

3.3 Cavitation is the cause of mechanisms at (c) and (d). Mechanisms (a) and (b) can occur both in a cavitating or a non-cavitating state. The noise generating mechanisms for a propeller operating in non-cavitation regime consists of broadband noise (due to laminar boundary layer instability noise or vortex shredding, inflow turbulence and surface turbulence) (Richard and Munjal, 1980) (Parchen, 2000) and tonal (due to steady and fluctuating component of thrust and torque and thickness effects). The modification of the vortex shedding can therefore affect the propeller noise.

3.4 Tip vortices are an unavoidable side effect of producing lift with an aerofoil of finite length. An aerofoil is designed first to have a relatively high pressure at the face and lower pressure at the back. Second, the fluid passing over the top of the aerofoil is directed downwards as it leaves the trailing edge (thus "pulling" the wing upwards in accordance with Newton's Third Law). These two characteristics of an aerofoil combine to make fluid around the blade-tip to "spin". High-pressure fluid below the blade "leak" upwards over the blade-tip, then be directed back downwards along with the rest of the fluid, creating the tip vortex.

3.5 Reducing the pressure differential between the fluid above and below the blade will by definition reduce lift, because it is this pressure differential that is producing lift. By the same token, reducing the "downwash" off the back of the blade will reduce lift because the force creating the downwash too produces lift on the blade. Therefore, conventional wings will produce wingtip vortices by definition. A way to reduce vortices is therefore to make it harder for the fluid to "leak" upward over the blade-tip. This is the principle behind the "winglets" seen on many aircrafts (see Fig. 1). The idea of tip rake was applied on the airplane wing (Cone and Clarence 1962). They prevent air underneath the wing being able to move over the top of it, thus reducing the severity of the rotation of the vortex (which reduces drag). Modified tip propellers, Kappel propeller and the Contracted and Loaded Tip (CLT) propeller (Gennaro and Gonzalez-Adalid 2012; Gaggero et. al. 2016) are available for marine applications. However, in all the past research, focus has only been on improving the hydrodynamic efficiency of the propeller.

**Fig.1: Tip vortices on an aircraft wing - conventional**



3.6 The experimental measurement of noise of a cavitating propeller was made by (Arakeri et. al. 1990). The first numerical prediction of propeller noise in cavitating regime was made by Seol et. al. in

2003, wherein he used DTMB 4119 model propeller and potential based panel method coupled with acoustic analogy. Kheradmand et. al. in 2014 carried out the numerical simulation of tonal and broadband hydrodynamic noises in non-cavitating regime. The RANS model was used for hydroacoustic studies on DTMB 4119 (Hu et. al. 2009). Numerical prediction of flow around a propeller was investigated by Li and Yang 2009. The numerical study on effects of introducing tip rake on the acoustic properties of DTMB 4382 propeller with an inherent skew has been carried out by Ghassemi et. al., 2018). Further, a study on the introduction of tip rake angle of $6^0$ was also attempted (Danio et. al., 2018). The present study attempts to take the investigation on the effect of tip rake angle on conventional propellers further. Applying the same technique used to reduce vortices in an aircraft wing, a rake angle is introduced in the tip of a propeller blade. In the present study, the effect this modification has on the propeller efficiency and on the SPL is attempted.

**4. Governing Equation and Methodology**

4.1 The methodology adopted to predict noise from a marine propeller has been used over the years (Tewari et. al., 2019). The prediction of noise originating from the presence of a turbulent flow is done using FWH acoustic analogy (Williams *et. al.*, 1969). The FWH theory in an indirect method for numerical prediction of noise. Surface pressure sources as well as turbulent flow pressure sources form part of the FWH equation. Being an indirect method, the pressure on the surfaces needs to be found. The CFD analysis of the flow is carried out using discretization techniques like FEM, FDM or FVM. The PDEs of the governing equations (1) and (2) are used to solve the flow field variables for the set of boundary and initial conditions of the computational domain.

4.2 The flow was simulated using CFD software STARCCM+. The blade harmonic noise components can be effectively captured using unsteady RANS method (Lidtke, Turnock and Humphrey, 2015). Hence, RANS solver is used in the hydrodynamic analysis.

*Continuity Equation*

$$\frac{D\rho}{Dt} + \nabla(\rho u) = \frac{\partial(\rho u_i)}{\partial x_i} + \frac{\partial(\rho u)}{\partial t} \qquad -(1)$$

*Navier Stokes Equation*

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial \zeta}{\partial x_i} + \rho f_x \qquad -(2)$$

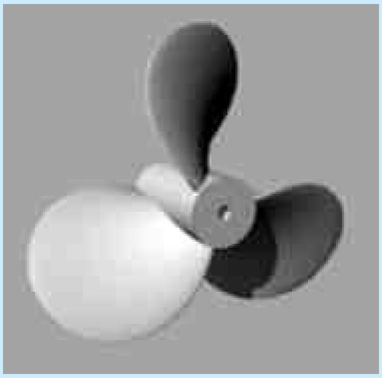
4.3 **Propeller Geometry**. DTMB 4119 propeller (see Table1 and Fig. 2(a)) has been used for the study. CAD models with tip rake (+/- $\mathbf{6^0}$ and +/- $\mathbf{10^0}$) (Fig. 2(b)) were created. The models of the propeller were created using Rhino™.

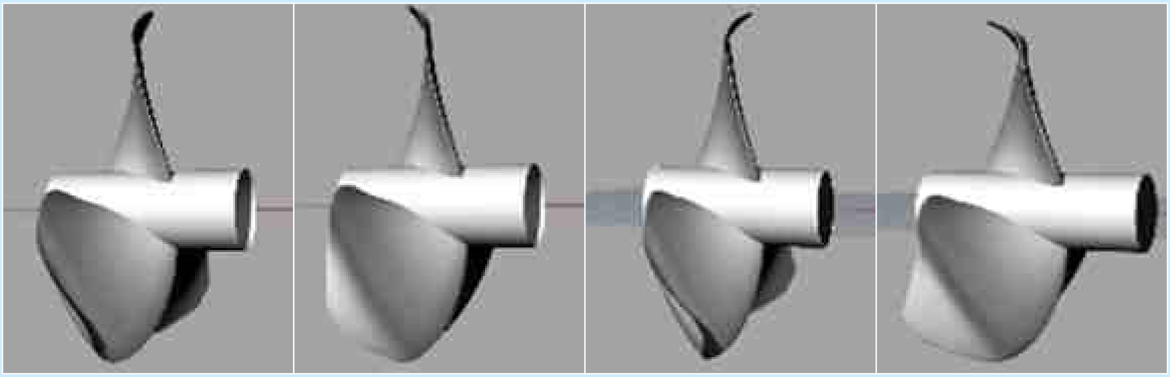
4.4 **Domain and Meshing**. The computational domain, Fig 3(a) consists of a rotating part (around the propeller to capture rotation effects) and a stationary part (to capture the flow around rotor). A cylindrical domain has been used domain- (Sezen, Dogrul and Bal, 2016), (Noughabi, Bayati and Tadjfar, 2017). ITTC guidelines are used for domain sizing to nullify effect of the boundaries i.e. no reflection from the boundaries. (ITTC, 2014) Fig. 3(a).

**Table 1: Principal characteristics of a 3 bladed DTMB 4119 propeller**

| Parameter | Value |
|---|---|
| Number of blades, Z | **3** |
| Skew (degree) | **0** |
| Diameter (m),D | **0.305** |
| Section thickness form | **NACA 66** |
| Boss ratio | **0.2** |
| Design advance ratio | **0.833** |

Fig. 2: (a) DTMB 4119 Propeller (b) Tip rake -/+ 6° (c) Tip rake -/+ 10°





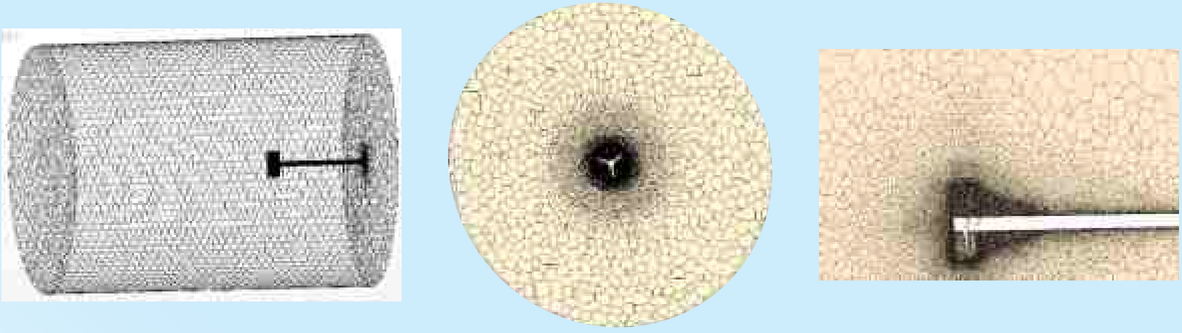
4.5 A hybrid and unstructured mesh was used for grid generation. Finer meshing has been used at blade tips and edges. A conformal grid has been obtained at the Rotor-Stator interface. The cell size increases progressively from 5% to 500% of the base size. The computational cost is economized without affecting the capture of flow parameters. The base size of the cell is 20 mm. About two million cells have been created in the domain, as shown in Fig. 3(b) and Fig. 3(c). Realisable k-$\varepsilon$ model for turbulence modelling are used. The rotor is given a rotation of n=10 rps. Open water characteristics of DTMB 4119 have been estimated and compared with results from published literature (Bagheri, Seif, *et al.*, 2015), (Sezen, Dogrul and Bal, 2016).

**5. Hydro-acoustic Analysis: Ffowcs-williams Hawkings Equation (FWHE)**

5.1 FWH acoustic analogy is used to predict noise from a turbulent flow (Williams et. al., 1969). The FWH equation includes surface sources (monopole or thickness sources and dipole or loading sources) and quadrapole sources introduced by Caridi (2007). FWH equation is shown below:

Where , p' is the source pressure level at the far-field, (p'=p-p0)), c0 is the sound speed at far-field. $T_{ij}$ is

Fig. 3: (a) Computational domain (b) Cross section Mesh Diagram
(c) Axial mesh diagram



the Lighthill stress tensor (Lighthill M., 1952) (Eqn. 4). The rest of the terms at RHS are quadrapole, dipole and monopole sources respectively.

The terms are turbulent velocity fluctuation (Reynolds stresses), term due to change in pressure and density and term is due to the shear stress tensor respectively. Since the source region is acoustically

$$\frac{\partial^2 p'}{c_0^2 \partial t^2} - \nabla^2 p' = \frac{\partial^2}{\partial x_i x_j}[T_{ij}H(f)] - \frac{\partial}{\partial x_i}\left([P_{ij}n_j + \rho u_i(u_n - v_n)]\delta(f)\right) + \frac{\partial}{\partial t}([\rho_0 v_n + \rho(u_n - v_n)])\delta(f) \qquad \text{- (3)}$$

compact and the observer is in far field, impermeable FWH is used. Farassat formulation 1A has been used as it is recommended for marine propellers (Farassat, 2007). The pressure field is defined in the Farassat formulation as:

$$T_{ij} = \rho u_i u_j + \delta_{ij}(p - \rho c_0^2) + \tau_{ij} \qquad \text{- (4)}$$

where P' - acoustic pressure, P_T^' and P_L^' - acoustic pressure field resulting from thickness (monopole) and loading(dipole). The thickness and loading noise components are defined by Equation 6 and 7.

The receivers are adjusted in four points above and behind the propeller at x and z axis (x/D, z/D =3, 4,

$$P'(\vec{x}, t) = P_T'(\vec{x}, t) + P_L'(\vec{x}, t) \qquad \text{– (5)}$$

5, 6). The unsteady flow around the propeller models are simulated at J=0.833 with a moving reference frame at n= 10 rps. A time step of t= 10-4 sec is used. Hydroacoustic analysis has been carried out using FWH solver. SPL predicted are compared with the published numerical results of Seol et. al. (2002).

$$4\,\pi\, p_T'(x,t) = \int_{f=0}\left[\frac{\rho_0 . \dot{v}_n}{r(1-M_r)^2} + \frac{\rho_0 v_n \hat{r}_i \dot{M}_i}{r(1-M_r)^3}\right]_{ret} dS + \int_{f=0}\left[\frac{\rho_0 . c . v_n\,(M_r - M^2)}{r^2(1-M_r)^3}\right]_{ret} dS \qquad \text{- (6)}$$

$$4\,\pi\, p_L'(x,t) = \int_{f=0}\left[\frac{\dot{p}.\cos\theta}{c.r(1-M_r)^2} + \frac{\hat{r}_i \dot{M}_i . p.\cos\theta}{c.r(1-M_r)^3}\right]_{ret} dS + \int_{f=0}\left[\frac{p.(\cos\theta - M_i n_i)}{r^2(1-M_r)^2} + \frac{(M_r - M^2).p.\cos\theta}{r^2.(1-M_r)^3}\right]_{ret} dS \qquad \text{– (7)}$$

## 6. Results and Analysis

6.1 A parametric study on the performance and hydroacoustic characteristics for DTMB 4119 propeller with and without tip rake (+/- 6$^o$, +/-10$^o$) is carried out. The hydrodynamic performance for the DTMB 4119 propeller at J= 0.833 is found to be in good agreement with the published literature. The hydrodynamic characteristics of the DTMB propeller with a tip rake (+/- 6$^o$, +/-10$^o$) is also found. A comparison of the performance characteristics of the propeller post modification is tabulated (see Table 2). There is a reduction in the overall efficiencies which can be observed except in case of propeller with tip rake -10$^o$ (forward rake). The primary reason for the reduction in efficiencies is the increase in the torque coefficient $K_Q$. The significant increase in Thrust Coefficient, $K_T$ in case of -10$^o$ tip rake has resulted in keeping the overall efficiency same as the original propeller. Pressure distribution around the modified propeller is shown in Fig. 4(a) and Fig. 4(b). The pressure just above the blade tip and around the pressure side is the maximum. The region between 0.7 to 0.9 R in the suction side of the blade has minimum pressure. The velocity distribution around the propeller is shown in Fig. 5(a) and Fig. 5(b). The blade tip produces high speed backward flow. At the same time a forward flow with lower axial velocity is also generated. These two reverse flows stimulate a vertical flow around the blade tip creating tip vortices. The variation in the pressures and velocities around the blade due to tip modification has resulted in the change in propeller performance. The flow around the blades creates the pressure fluctuations which act as noise sources. The SPL was estimated by acoustic analogy. The effect of tip rake angle will produce flow modifications and hence change in the SPL. The estimation has been carried out with density as 1000 kg/m³ and sound speed in water 1500 m/s. The reference pressure for SPL is 1.0 µPa. However, a reduction in SPL in the propeller with tip rake has been observed (see Fig. 6). A reduction of about 10 dB has been achieved for propeller with -6° tip rake. The variation in SPL measured radially and axially. The SPL is found to follow the inverse square law with distance. This means that if the distance doubles, the overall SPL reduces around 6-7 dB (Tian et. al. 2014). It can be seen that both along shaft axis and propeller disk, the SPL reduces with increased distance from the source.

## 7. Conclusion

7.1 The hydrodynamic simulation was carried out on DTMB 4119 with and without tip rake angle using RANS solver and Realisable k-ε model for turbulence modelling and unsteady flow regime. The SPL was estimated using FWH equation at various points in axial and radial directions. Based on the obtained results, the following conclusions can be made:

**Table 2: Comparison of Propeller performance after introducing tip rake**

| | `Thrust Coeff, $K_T$ | Torque Coeff, 10 $K_Q$ | Open water efficiency ,µO |
|---|---|---|---|
| Zero rake | 0.118 | 0.236 | 0.664 |
| Tip rake - 6° (forward rake) | 0.127 | 0.261 | 0.645 |
| Tip rake +6° (backward rake) | 0.116 | 0.243 | 0.634 |
| Tip rake- 10° (forward rake) | 0.138 | 0.275 | 0.664 |
| Tip rake +10° (backward rake) | 0.117 | 0.249 | 0.625 |

**Fig. 4: Pressure distribution around propeller blade at -6° tip rake (a) Cross section (b) Axial**

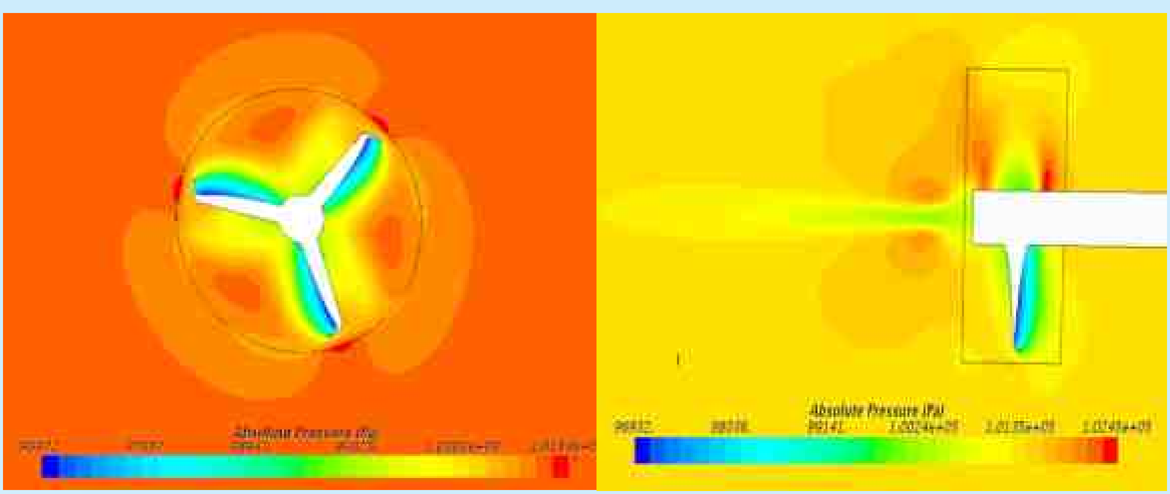


Fig. 5: Velocity distribution around propeller blade at -6° tip rake (a) Cross section (b) Axial

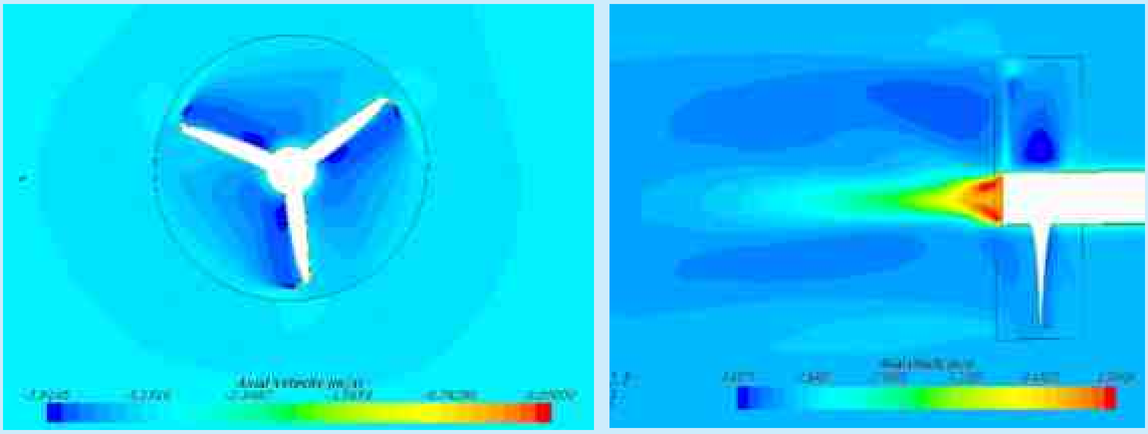
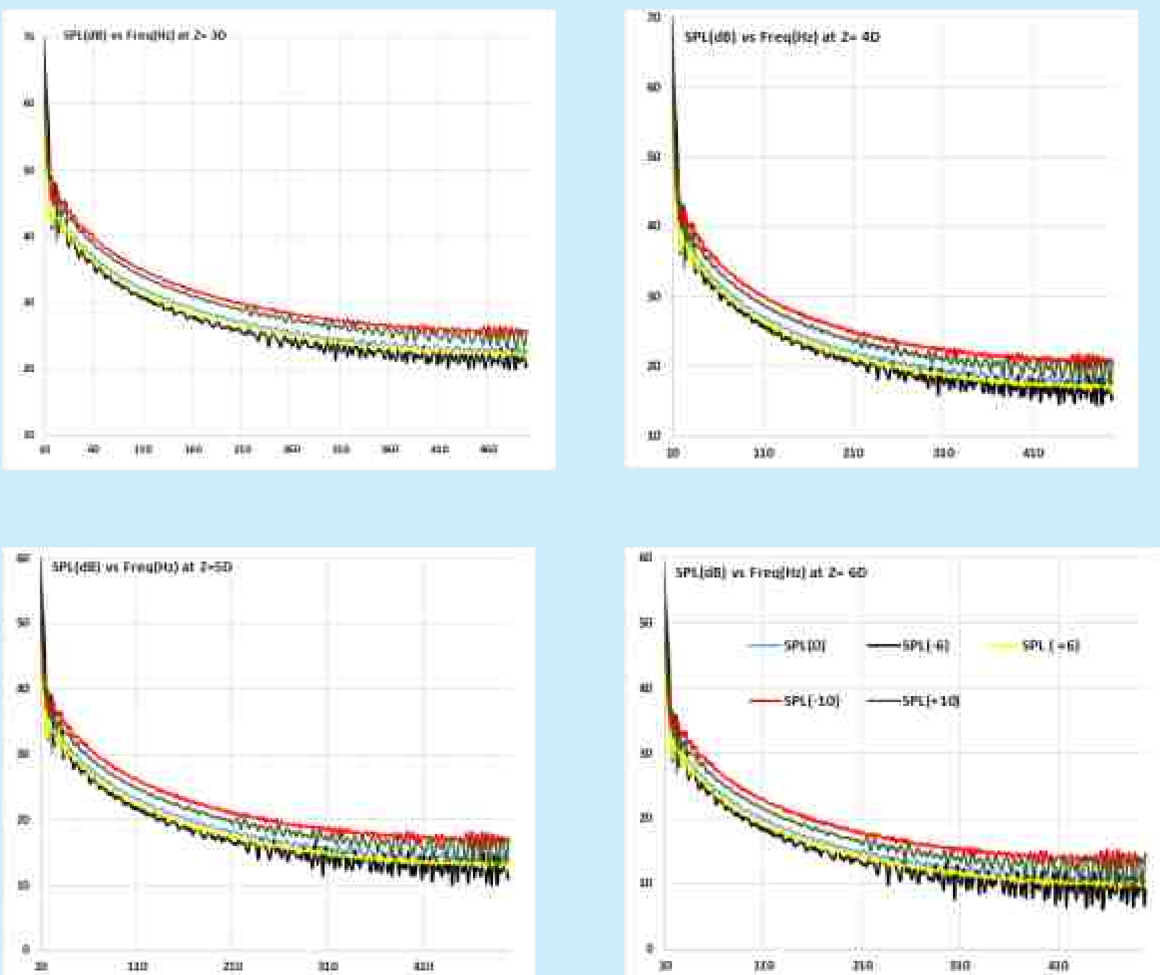


Fig. 6: Comparison of SPL for propeller with and without tip rake (a) z= 3D (b) z= 4D (c) z= 5D (d) z= 6D



(a) Hydrodynamic performance of marine propellers change with the introduction of tip rake.

(b) $K_T$ and $K_Q$ are modified with introduction of tip rake resulting in an overall reduction in propeller efficiency of 2% with -6° tip rake.

(c) The tip rake of -10° (forward rake) results in the same efficiency as that of the original propeller.

(d) The tip vortices are modified/ shifted due to introduction of tip rake angle.

(e) Reduction in SPL of propeller with tip rake has also been observed at low frequency range (10 - 500 Hz). The reduction in SPL is about 10 dB has been achieved with -6° tip rake.

(f) It can be seen that both along shaft axis and propeller disk, the SPL reduces with increased distance from the source.

The authors intend to work on studying the effect of tip modifications in different propellers both numerically and experimentally as a future work.

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# MODULAR CONSTRUCTION AND IHOP FOR INCREASED PRODUCTIVITY IN SHIPBUILDING


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**1. Abstract**

1.1 The shipbuilding industry is a cyclical industry that has seen many a seasons of growth, recession and resulting change in leadership. While the growth and recession are inherent to the industry's working, the change of leadership has largely been possible due to the evolving management techniques that countries have put in practice to reduce cost, increase productivity and become effective to eventually take over the baton of being the world's shipbuilding leader. Some management techniques that have changed shipbuilding from a 'customised product' to a 'commercial' one include the 'modular' construction, the 'integrated hull construction, outfitting and painting' or IHOP as it is better known and the 'lean construction' technique..

1.2 This article aims to discuss how these Total Quality Management (TQM) techniques have changed the canvas of competition and production in shipbuilding.



**2. *Keywords:*** Modularization; Lean construction, IHOP – Integrated hull construction, outfitting and painting; Product work breakdown structure; group technology; productivity.


**3. Introduction**

3.1 Shipbuilding is a cyclical industry with a fluctuating demand. It has experienced over nine major cycles since 1896 with each one of them showing more than a 40 per cent reduction in demand. Three of these cycles have occurred since World War II alone. Since this industry is cyclical it is susceptible to business demands. Accordingly, the revenue of this industry is high when the economic prosperity, née business, is high and visa-versa. In order to meet this cyclical nature, the industry resorts to layoffs and cuts during lean periods and pays bonus or hires en-masse in good times. This thus forces the industry to create long term survival strategies that include reduced built-periods, timely delivery and competitive pricing.

3.2 In order to ensure a reduced built-period, the industry has employed Total Quality Management (TQM) techniques in the form of modular construction, integrated hull construction, outfitting and painting (IHOP) and Lean construction techniques. These techniques have been developed progressively over the years, in that order, and are related such that the subsequent technique cannot be utilised till the previous one is in place. The basic ethos behind these techniques is mass production, standardisation and assembly line production, the advantages of which have been seen in the automobile industry. Till before the WWII, ships was considered a 'custom built' product and mass production was considered virtually impossible. This myth was shattered during WWII when the 'Liberty ships' were constructed in just 155 days using the philosophy of mass production and the concept of 'modular construction'.

3.3 This 'modularisation' focused on improvements in manufacturing and assembly methods, procurement and material control, business processes, ship design and engineering processes. Though interpretation of '*modularisation*' is different for different works, the idea is to divide large systems into smaller, self-sufficient parts. This allows a large complex structure to be converted to manageable structures, parallel working, building and testing modules on land with more fit-out being completed before they become a part of the larger system. The size of the module that can be built using this methodology is defined by the least capacity of the crane in the shop floor, on the building berth, and the available transportation facility.

3.4 With block weight and size reaching their maximum limit, the next area of production improvement was outfitting. Till the 1970s, outfitting was undertaken by the shipyard's selftrained workers with offloading limited to some services. The 1980s saw an increased use of modular construction that allowed increased work in workshops away from the shipyard. This allowed some professional works to be subcontracted. With time, as the margins of the shipyards reduced, most of the professional work for the construction of blocks was subcontracted, that permitted a greater level of outfitting to be undertaken in the workshop. These along with the control of the outfitting and painting activities allowed inventory control, reduction of overheads and higher monetary returns led to the development of the Integrated Hull-construction, Outfitting and Painting (IHOP) techniques propounded by the Japanese shipbuilders in the late 1960s.

3.5 The next to follow was the 'Lean construction' technique by *Ishiwajima-Harima Heavy Industries (IHI)* and *Kawasaki* in Japan. This technique focuses on reducing manufacturing waste, that is effectively anything that adds to the time and cost of making a product but does not add value to the product from the customer's point of view. With the integration of lean manufacturing, it has been found that the production facilities become more efficient and reduce man-hours up to 60% from the original state (Kolić et. al. 2011).

3.6 Since the lean construction technique is still to be implemented in most shipyards across the world, we will focus our attention on the accrued gains from the modular construction and IHOP. The article will thus discuss how both these TQM techniques have changed the canvas of competition and production in shipbuilding.

**4. Classification System**

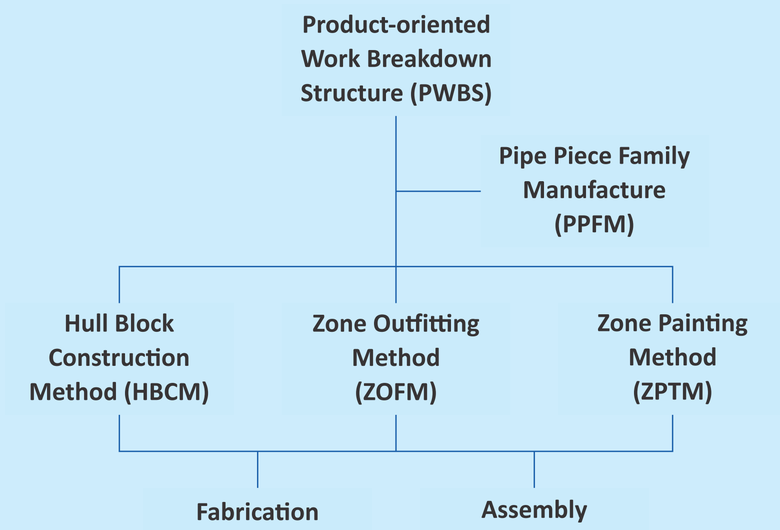
4.1 Like any management approach that must specify what, where and when for an activity to be undertaken, and the resources to be used, the TQM techniques of modularisation, IHOP and lean construction to specify these parameters through the group technology. This takes the form of division of the total process into component parts that is controlled by a classification system called – Work Breakdown Structure (WBS). The WBS commonly used in shipbuilding is either systems- or product- oriented.

(a) The *systems-oriented work breakdown structure (SWBS)* is useful for initial estimates and the early design stages. It is not appropriate for planning, scheduling, and executing a zone-oriented manufacturing process and is unable to address work packages which are too large for effective control of material, man-hours, and schedules.

(b) The *product-oriented work breakdown structure (PWBS)* is a classification system that was tailored on the SWBS. This too is appropriate for initial estimates and the early design stage. The system was evolved to subdivide the ship construction work and to focus on needed parts and subassemblies (interim products), which eventually combine to make larger subassemblies, and are an essential way of producing ships.

4.2 Accordingly, the PWBS divides the shipbuilding process into three basic types of work: hull construction, outfitting, and, painting, because each imposes manufacturing problems that are inherently different from the others (see Fig. 1). These three are further subdivided into *fabrication* and *assembly* with the assembly linked to zones that form the basis for zone dominance in the management cycle. Within painting, fabrication applies to the manufacture or preparation of paint, and. assembly means its application.

**Fig. 1: Product-oriented work breakdown structure components**




4.3 The PWBS classifies interim products in accordance with their needs for resources, i.e., material, manpower, facilities, and expenses, regardless of their location in the ship. Different outfit units are treated the same way. In order to optimize productivity for different ships, the division is done by – system and zone – for planned manageable parcels, and by – problem area and stage – for dividing the work process from material procurement (see Fig. 2). Hence:

(a) *System* - A structural function or an operational function of a product, e.g., longitudinal bulkhead, transverse bulkhead, fire main system, mooring system, fuel oil service system, lighting system, etc.

(b) *Zone* - An objective of production which is any geographical division of a product, e.g., cargo hold, superstructure, engine room, etc., and their subdivisions or combinations, e.g., a structural block or outfit unit, a subassembly of either, and ultimately a part or component.

(c) *Problem area* - A division of the production process into similar types of work problems which can be:

(i) by feature, e.g., curved vs. flat blocks, steel vs. aluminium structure, smalldiameter vs. large-diameter pipe, pipe material, etc.

(ii) by quantity, e.g., job-by-job vs. flow lane, volume of onblock outfitting for machinery space vs. volume of on-block outfitting for other than machinery space, etc.

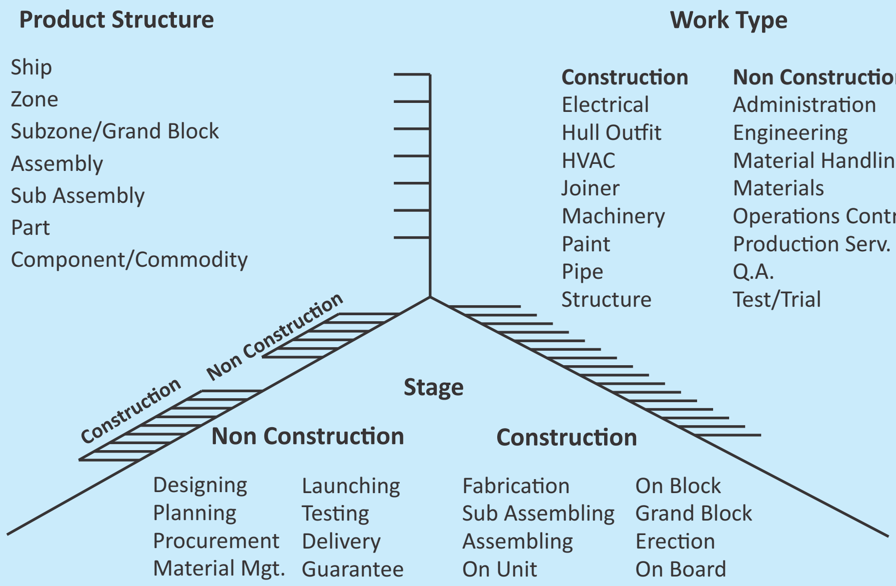
(iii) by quality, e.g., grade of workers required, grade of facilities required, etc.

(iv) by kind of work, e.g., marking, cutting, bending, welding, blasting, bolting, painting, testing, cleaning, etc. and

(v) by anything else that creates a manifestly different work problem.

(d) *Stage* -A division of the production process by sequences e.g. sub-steps of fabrication, subassembly, assembly, erection, outfitting on-unit, outfitting on-block, and outfitting on-board.

**Fig. 2: Product-Oriented Work Breakdown Structure System**




## 5 Modular Construction

5.1 Henry Kaiser's introduction of *Group Technology* for the Liberty ships (to achieve benefits normally associated with production lines) lead to development of modular assembly for shipbuilding business during WWII bringing about an industrial rev·olution within the industry. Using the logic of Group Technology, Dr Hisashi Shinto of Ishikawajima-Harima Heavy Industries Co. Ltd. (IHI) developed and refined the PWBS that helped IHI to build over 2,000 ships during 1960 to 1970. Since then this concept has been employed by various shipbuilding houses in different forms (Agarwala, 2014) and is mainly aimed at any one or a combination of the equipment level, the compartment level and/or the platform level.

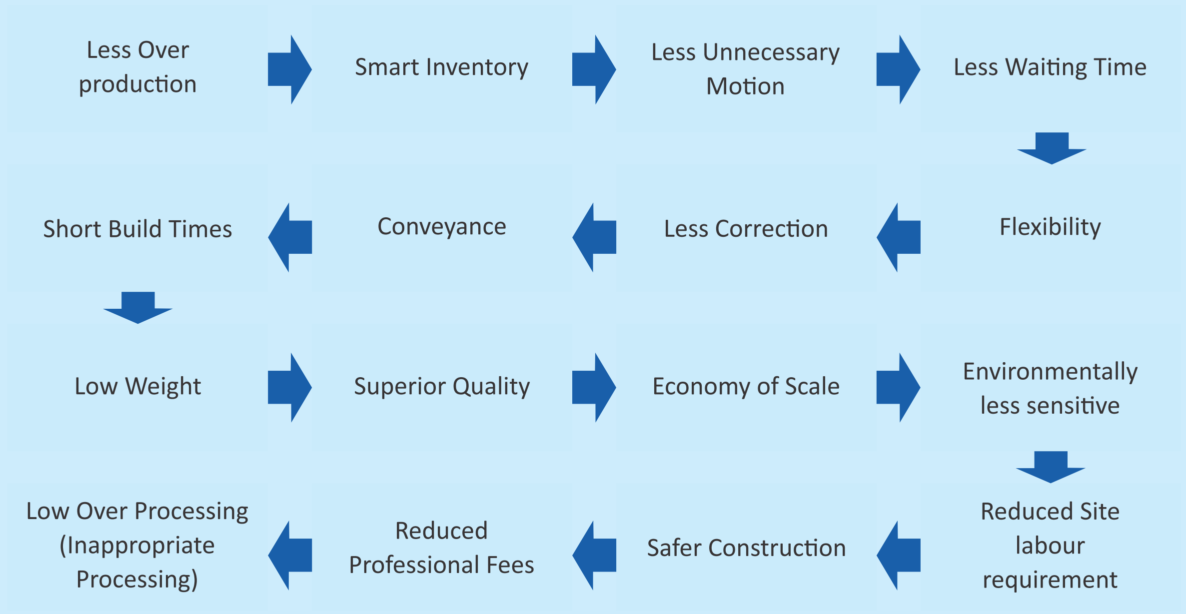
5.2 Use of modular construction is not as simple as it sounds. The true benefits of this type of construction can be achieved only if specialised construction facilities along with carefully designed and laid out outfitting facilities that dovetail with the build strategy exist. In addition, a design that incorporates equipment disposition, system designs, zoning of ship systems and block definitions that are commensurate with the infrastructure and modular construction philosophy of the yard are considered essential.

5.3 Using the PWBS system, each component is manufactured at specialised locations, called workstation, that have the requisite tools, machinery and workforce to improve manufacturing efficiency. This process permits easier planning, higher efficiency due to repeated work, availability of manpower of different trades, and a steady work load at the workstation.

## 6. Why use modular construction

6.1 The modular-build strategy may be prophesied by a country for political reasons, say, to provide work, to maintain a shipbuilding industrial base, to access skills available only at another shipyard, to overcome capacity constraints or just to reduce costs. Largely, the benefits of modular build are seen in every stage of the life of a ship (see Fig. 3). These include:

### Fig. 2: Product-Oriented Work Breakdown Structure System




8.2 New Construction Benefits.

(a) Reduced construction period, hence reduced overhead cost and reduced impact of inflation

(b) Higher efficiency from learning

(c) Higher opportunities for smaller businesses

(d) Provide a larger supplier base and a possible improvement of quality

(e) Possibility of more products in the available funds

(f) Allows easy corroboration of material requirements between zone and system, there by allowing correct estimation of material required

8.3 Ship Maintenance Benefits.

(a) Easy removal from onboard and repairs in shop-floor

(b) Less costly to upgrade, repair or replace

(c) Faster turn-around time to repair/ replace modules

(d) Even faster turn-around with Swap-out/ Swap-in scenario of selected modules

(e) Increase fleet operation time due to reduced time in yard

8.4 Ship Operations Benefits

(a) Provides more flexibility for a standard ship platform

(b) Allows more focus of purpose for specific operating requirements

(c) Minimizes need for incorporating unnecessary systems

## 9. Challenges for Use of Modular Construction

9.1 Challenges are natural in a manufacturing system. Those for modular construction include:

(a) *Deciding the appropriate level of design*. Usually at the design phase the ship has no definition of modules or zones. However, building blocks need to be defined at their interfaces, rather than by their internals to allow for necessary changes, which is a major challenge.

(b) *Defining a module is critical*. To do so, one needs to keep the *modular technical architecture* in mind that may include outfit and equipment modules, hull assembly blocks, outfitted hull blocks, and/ or outfitted panel assemblies. These module blocks should be designed with similar volume, weight and shape in order to distribute work evenly during fabrication and assembly levels while allowing maximum down-hand welding.

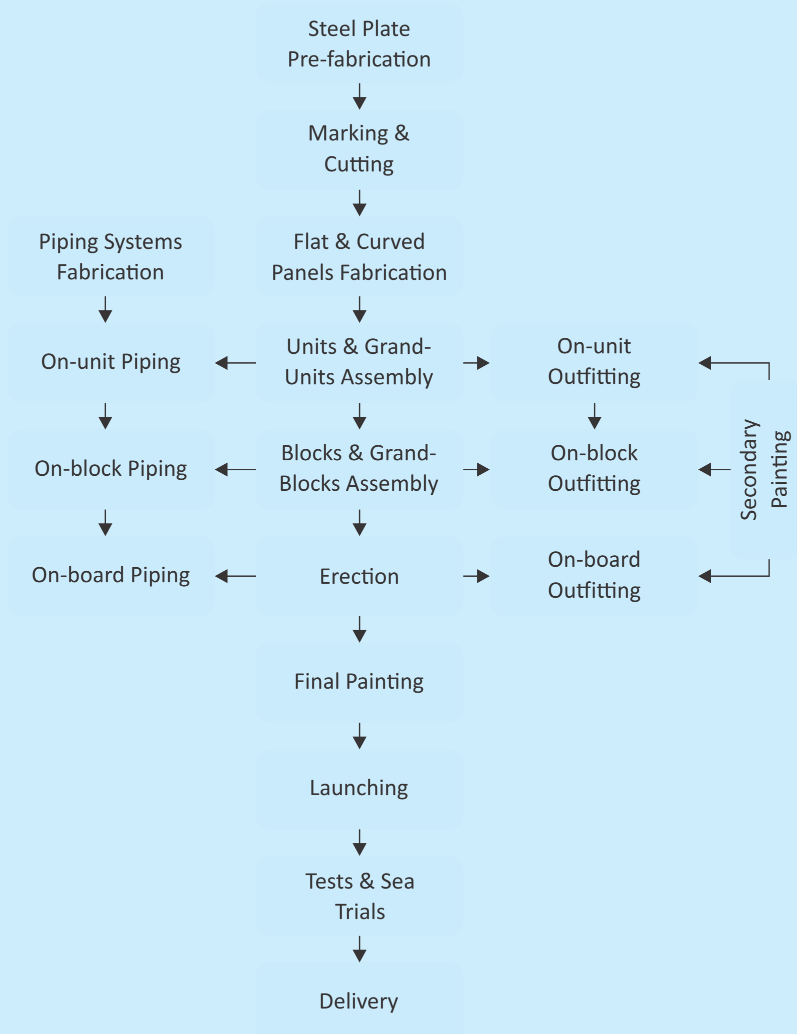
(c) *Need for detailed design to the extent feasible*. To allow transformation of a basic design to a zone-oriented design as demanded by modular construction, the detailed design needs to be completed before construction begins. This would allow accurate progress reporting, cost recovery, forecasting of balance work and required resources.

(d) Modular construction requires better engineering, quality assurance and a higher level of design standards to minimize interferences and disconnects.

## 10. IHOP

10.1 As modular construction received acceptance of the industry and greater professional works of block construction started to get subcontracted, a greater level of outfitting was possible to be undertaken at the workshop by the contractors. With a variety of outfitting needed to be undertaken that included steel (penetrations, cable trays, cable pipes, foundations, brackets for fittings, etc.), hull, machinery, deck, interior, and electrical, there was a tendency of encountering delays, rework and sub-optimization due to a lack of coordination and insufficiently detailed planning. These problems were pronounced in complex vessels. This necessitated the need for a detailed planning to account for the needs of all involved parties and provide a more structured guidance to them to perform their work. The traditional approach of outfitting was replaced by the world's most productive shipbuilders with the integrated hull construction, outfitting and painting (lliOP) management technique with a workflow as seen in Fig. 4.

**Fig. 4: Work flow in IHOP (Mossad et. al., 2014)**




10.2 The concept of IHOP as described in the Design for Production Manual (DFP, 1999)focuses on the need to undertake more overlapping work rather than in sequence. Such an approach allows more efficient organizing of different trades to work together. It requires unprecedented collaboration between all departments of the shipyard to achieve integrated planning through discussion, trade-offs and ultimately mutual consent. The process is considered as the second phase of GT application that aims to bring about integration between all the fabrication processes.

10.3 The IHOP and PWBS (both GT applications) are considered as two sides of the same coin. The PWBS is used to classify and arrange the fabricated parts, subassemblies and assemblies while the IHOP applies the zone-oriented scheduling to control the work flow on the various work process so that interim products will be completed according to the production schedule. These interim products will be merged according to the schedule before the final erection of the ship. The workflow of IHOP can be completed not only by a single shipyard, but by several shipyards that participate in the production processes.

10.3 **Advantage of using IHOP**. Shipyards that have experimented successfully with IHOP find increased productivity, reduced costs and hence the advantages of IHOP can be listed as:

(a) Reduced schedule on the building berth

(b) Improved quality and repeatability of units and modules

(c) Improved organizational communications at all levels of the yard

(d) Better managerial measurements of performance and cost

(e) Reduced overall man hours per ship

(f) Better working environment that allows maximizing the down-hand installation and reduces waste

(g) Better working conditions as the work now is undertaken in workshop that allows heating, better lighting and ventilation

(h) Easier transportation and accessibility of the material and tools to the work site

(j) Lesser need for repair painting

(k) Reduction of scaffolding and other supporting work

(l) Better balancing of outfitting work

(m) Small disturbances due to other workers

(n) Reduction in rework because the vessel is divided and subdivided into blocks.

(p) Easy supervision of work Better control of temperature, humidity and vertical plane for paint works

10.4 **Challenges for use of IHOP**. The challenge for implementing such a planning are:

(a) The need of a ship model that accounts for outfitting components

(b) The need to understand and customise the PWBS system according to the shipyard based on the available workstations

(c) Increased cost associated with the initial design, new production facilities or workstations and the transportation equipment required to move the constructed unit/ block to the construction ways

(d) Design and production of block is started earlier than normal and hence changes, if any, at a later date are difficult and costly

(e) The block division and size is restricted by the outfitting design

(f) An increased block weight affects the transport

(g) Accuracy requirements for the block installation is higher than otherwise

(h) There is a higher risk of broken equipment due to transportation

(j) The labour and material costs get committed much earlier

**11. Where is the World Moving to?**

11.1 In order to understand where the shipbuilding and the associated technology are moving to, we categorise both of them in five different generations of development as seen in Table 1.

**Table 1: Shipbuilding and Technology over the years**

| Generation | Shipbuilding | Technology |
|---|---|---|
| 1 (early 1960s) | • Construction was piece by piece, with building on open inclined building berths<br>• Shipyards had multiple berths employing a large workforce<br>• Steel hull were launched and towed to a quay for outfitting<br>• Outfitting and steel facilities and their trades were widely separated | • Use of low capacity cranes and very little mechanisation.<br>• Outfitting largely undertaken onboard ship after launch<br>• Operating systems were basic and manual.<br>• Yard is characterised by the most basic equipment, systems and technologies |
| 2 (late 1960s and early 1970s) | • Method of construction changed to a unit or block building philosophy<br>• The number of building berths reduced to two or three<br>• Much of the assembly work was carried out in large buildings<br>• A limited amount of outfitting was completed prior to launch<br>• Steel and outfit facilities remained separated with outfitting shops generally located adjacent to an outfitting quay | • Use of larger cranes and a degree of mechanisation<br>• Computing applied for some operating systems and for design work<br>• Movement towards modular construction to reduce built-periods |
| 3 (late 1970s) | • The separation of steel and outfit facilities continued<br>• Assembly of steel blocks became mechanized<br>• Process lines were introduced for rapid steel assembly<br>• Blocks became larger, construction times reduced and the number of building locations reduced<br>• Level of outfitting prior to launch increased. There was some pre-outfitting of blocks | • Seen in the fully re-developed shipyards in the US, Europe, South Korea and Japan<br>• Introduction of IHOP<br>• Use of large capacity cranes, a high degree of mechanisation in steelwork production<br>• Extensive use of computers in all areas |

| Generation | Shipbuilding | Technology |
|---|---|---|
| 4<br>(the 1980s) | • Essentially steel and outfit facilities remained separated<br>• Automated assembly of steel increased<br>• Multiple process lines combined under a single roof creating a factory style environment<br>• Blocks became much larger and the level of pre-launch outfitting was maximized<br>• Modularization of outfitting was used in all outfit intensive areas of the ship<br>• Construction cycle times reduced. A single high throughput construction point was normal | • A single dock, with good<br>• environmental protection, short cycle times, high productivity, extensive early outfitting and integration of steel and outfit<br>• Use of fully developed CAD/CAM and operating systems |
| 3<br>(in the 1990s) | • Shift to a product oriented philosophy<br>• Previous generations focused on increasing efficiency and reducing cycle times<br>• Shipyards focused on a very narrow product range and develop customized facilities for that range<br>• This generation exploits the premise that a wide variety of end products can be constructed from different aggregations of standard interim products<br>• A total ship approach is adopted and steel and outfit are fully integrated<br>• Product ranges are greatly increased and the learning curve on a new vessel type is dramatically reduced | • Use of automation and robotics in areas where they can be used effectively, and by integration of the operating systems, such as the effective use of CAD/CAM/CIM<br>• Use of modular production philosophy in design and production<br>• Introduction of lean technology in shipbuilding<br>• Use of efficient, CAM control and by fully effective quality assurance<br>• Focus on – state-of-the-art use of technology and industry-leading business processes, facilities, systems, management and workforce |

## 12. Conclusion

12.1 With cost cutting becoming an essentiality for the shipyards to stay in business, shipbuilding has moved away from the traditional method of straight line construction to modular construction. This has been aptly supported by various management techniques such as TQM. The resulting methods of modular construction, integrated hull construction, outfitting and painting (IHOP) and the developing lean construction technique have allowed companies to become leaner and more productive. Though the efforts required on the part of the shipyards to achieve the desired results of the TQM methods is high, many of them have succeeded in doing so.

12.2 Based on literature available, the accrued advantage in outfitting using IHOP is a 20% reduction in build time, a 52% improvement in man-hours, 54% reduction in overhead cost and 18% reduction in material costs (for Yarrow Shipbuilders Ltd.). Similarly, the time required for manufacturing a one-ton of raw material (m.h/cgt) has reduced by about 34.5%, while the cost of one compensated gross tonnage (Cost/cgt) has reduced by about 17.16% which are all encouraging. Such techniques have also reduced the physical construction space required by shipyards thereby changing the entire dynamics of shipbuilding.

It is thus essential that if a shipyard is to be competitive while achieving a high productivity, it needs to adopt TQM and GT. Though some shipyards feel that they are following GT, in actual they are not. What they are using is the WBS classification and coding which is not GT. GT can be used if a shipyard wants to utilize facilities like automated pipe shop, Computer Aided Process Planning and/or robotics. There is hence a need to create a clear understanding of how GT actually works and how it can be actually used to improve productivity in shipbuilding.

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# INDIGENOUS SHIPBUILDING IN INDIA – CHALLENGES AND WAY AHEAD

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**1. Introduction**

1.1 India is a country with a rich maritime tradition spanning over 4,000 years. This maritime tradition is deeply imbibed in the psyche of our coastal population and manifests itself in their customs and practices. In Indian mythology, the ocean is considered as the primordial source for creation of the universe. The Indian seaboard had always witnessed peaceful maritime activity, with trade as the prime driver. Indian folklore, ancient Indian texts and Buddhist Jatakas, all allude to the fact that the Indus Valley Civilization of Mohenjodaro, Lothal and Harappa thrived due to maritime activity between ancient India and the countries of Africa, Arabia, Mesopotamia and the Mediterranean.

1.2 The Indus valley Civilization was known to use boats around 3000 BC. It was also well known for their skills in constructing boats and sail ships. Lothal in Gujarat, which was part of their civilization, appears to have been the boat-building centre, as it could get building materials from the Gujarat forests. Five anchors made of stone have been found at Lothal.

1.3 Lothal also had the world's first dock, which was trapezoid-shaped measuring approximately 214m x 36m built before 2000 BC. The archaeological findings from this civilization reveal that there was a vibrant and dynamic maritime network, using a variety of watercraft, during the 2nd millennium BC. A double-ended vessel, with a crescent-shaped hull, probably made of reeds bundled with lashing is observed in a stone seal from Mohenjodaro. A graffito from the same place represents a vessel with a mast and steering oars or side rudders at the stern of the ship, while a terracotta boat model from Lothal represents a square-stern vessel with a sharp bow, with fittings for rigging.

1.4 Before recorded history, the fishing community living along the coast of south India had built boats by tying wooden logs together with coconut coir rope. In the Tamil language, 'tied wood' is known Kattu Maram, and these boats known as Kattumaram are popularly used for fishing even today. It is from this name that the modern day terminology of catamaran has been derived.

1.5 Thus, India has an age old history dating as early as 3000 BC in the manufacture of boat hulls and an in-depth know-how on this subject. This art of manufacture of the boats started to fade when the Mughals invaded India. In order to restore ship building in India, there is a requirement to study the ship building practice in India and implement required corrective actions in a time bound manner.

1.6 India requires a vibrant and strong shipbuilding industry for economic as well as strategic reasons. For a country that is predominantly peninsular in nature with a coastline of 7516.5 km and 1197 islands, India's shipbuilding capabilities have not kept pace with its economic development, market demand and human resource potential.

1.7 This is specifically more important from the national security point of view since the Indian Ocean Region is of great importance to India. To ensure that India attains its rightful position in the region, she needs to take steps for meeting the challenges through proper use of its economic capability, political stability, social order and military potential. Towards this, possession of an indigenous ship building capability is of utmost importance to counter any threat emanating from the seas.

1.8 **Aim.** The aim of this paper is to analyse the present state of the Indian shipbuilding industry and suggest a way ahead towards further bolstering it further.

1.9 **Scope.** There are various reasons due to which the Indian shipbuilding industry is not able to presently flourish to its full potential. Therefore, the scope of the paper is restricted to understanding the economics of Indian shipbuilding and suggesting a tangible way ahead for the industry to develop.

**2. Economics of Shipbuilding**

2.1 The Indian shipbuilding is mainly centred around 27 shipyards comprising of eight Public Sector and 19 private sector shipyards. The shipyards between them have 20 dry docks and 40 slipways with an estimated capacity of 281,200 DWT. A major share of this capacity is held by the eight public sector yards. Private shipyards though more in number are severely limited by capacity and size of ships they can build.

2.2 A ship can be considered as a floating/ moving platform with space to carry cargo or war payload depending upon the role. Therefore, ships are fitted with various equipment pertaining to systems such as propulsion, cargo handling, weapons etc. Building a ship starts with the fabrication of ship's hull in dry-dock or a launch way and outfitting it with various equipment and systems in outfitting basins. Hence, shipbuilding requires a supply of diverse type of raw materials. Constructing a commercial ship requires around 300-400 types of raw materials and equipment, which vary depending upon the type of the ship being constructed. In the terms of cost, value of all the raw material and equipment would be around 60% - 70% of the total cost of the vessel. A ship builder has to purchase these raw materials and equipment from various industries, and therefore, a shipyard can be regarded as a mother industry which takes raw material from all other ancillary/ small industries and puts them together. The shipyard, here, is described as a mother industry because, money flows out from the shipyard to these industries in exchange of the products and services provided by them.

2.3 In order to understand the Indian shipbuilding perspective, the basic business of money transaction cycle needs to be understood. The first financial transaction takes place between the ship-owner and the shipyard, where the owner gives a part of the money agreed upon as price for the ship, which the shipyard will deliver in approved time duration. The shipyard in turn distributes a part of this money to the various ancillary industries, which in return deliver the raw materials and equipment to the shipyard. While drawing a similarity with the automotive industry, these ancillary industries which deliver the material and equipment to the shipyard are termed as the tier-I industries. These tier-I industries source their raw materials from several manufacturing firms, which are termed as tier-II industries. Flow of money from tier-I to tier-II industries in exchange of materials also takes place. In addition, the shipyard, the tier- I and the tier-II take support of the following sectors:-

(a) Manufacturers of capital equipment to set up infrastructure.

(b) Financial services such as banking and insurance.

(c) Support services such as water and energy in the form of gas, power, etc. to facilitate factory operation.

2.4 Money flows to the human resources working in the shipyards, the tier-I and the tier-II industries, as remuneration for their labour efforts. The money which reaches the people enables them to purchase various consumer goods and services from the ecosystem. This results in circulation of money in the ecosystem, which is essential for the economic development and growth of a nation.

2.5 On comparing a shipyard with the automobile sector there are some subtle differences that are enumerated below:-

(a) Shipbuilding industry is labour oriented. Therefore, there are more skilled job- opportunities that could be created in this sector.

(b) The cost of a ship and an automobile cannot be compared. The cost of a ship is very high and therefore, the amount of money that can be transferred to the ancillary industries per unit vessel is very high for shipbuilding.

(c) However, the number of ships built worldwide are far less than the number of automobiles manufactured in a given time duration. Therefore, for this to develop as a mother industry, it is important for the volume of ships to be built to increase exponentially for the ship building industry and the ancillary industry to reap the cost benefit.

**3. Ancillary Industry in Indian Shipbuilding**

3.1 The ancillary industry supporting commercial shipbuilding in India is at a very nascent stage. Even though, there is a fair amount of indigenisation in the Indian Warship building, the efforts in the commercial shipbuilding is poor. There is a very low percentage of indigenously sources raw materials used on commercial shipbuilding. However, in leading shipbuilding nations such as Korea and China, this is around 40-80%. Each of these nations is trying to maximize the percentage use of indigenous items, because it is the only means by which the cost of the input material could be reduced and sustain the shipbuilding industry.

3.2 In India, the ancillary industry supporting commercial shipbuilding has been neglected as the volume required by the shipbuilding industry is low and indigenisation is not cost effective. However, the ancillary industry that provides raw material for defence shipbuilding is relatively better developed. There are several Indian vendors manufacturing defence shipbuilding equipment. This is because the Indian Navy is focusing on indigenization and supporting the ancillary industry. Therefore, commercial shipbuilders can trap the services of these ancillary industries. Only if the ancillary industries are supported, will they be able to deliver quality goods at a cheaper price, which will eventually reduce the cost of shipbuilding ships.

**4. Economic Inequality: Indian Shipbuilding**

4.1 In the present Indian scenario, there is economic inequality in the shipbuilding sector on multiple fronts like taxes on procurement of raw material, payment of income tax, taxes on sale of ships, etc.

The disadvantages that the Indian shipbuilders presently experience in terms of government taxation in comparison with some of the rising ship building nations are discussed in the succeeding paragraphs.

4.2 **Corporate Tax (CT).** In India, corporate tax on the overall profit generated by a firm as on Mar 19 is 30% for a company with turnover of more than INR 250 crores. In China, the equivalent of this tax, which is known as 'Enterprise Income tax', was removed and made 0% when the Chinese shipyards were fiercely competing to establish themselves in the international market in the first decade of this century. After the Chinese shipyards captured the international market, this tax was gradually increased. In addition, many segment of shipbuilding have been notified as 'encouraged sectors', which has enabled companies to set-off a minimum of 50% of total investment against the 'Enterprise Income Tax' within 05 years of commencement of production. Additionally, provincial governments like the Zhejiang province have allowed the shipbuilders to deduct the amount invested in domestically produced equipment from the company's income tax that accrues to the province.

4.3 **Goods & Services Tax (GST).** All sales of ships attract GST of 5% (code 8906 - Other vessels, including warships and lifeboats other than rowing boats) for domestic customer where as it is not in vogue in case of an export order. This means that if an Indian shipyard sells a ship to an Indian shipping company for INR 100 Crores, the shipyard will have to pay a GST of 5% which is transferred to the customer's account (which works out to be around INR 5 crore). However, if the same ship is sold to a foreign company, then the shipyard does not have to pay this, which makes selling of ships to a foreign shipping company lucrative for the Indian shipyards. Therefore, in a competitive market, shipyard would pass on some percentage of this extra amount paid as GST to the customer (ship-owner) eventually. However, this discount is not available to the Indian customer. This could be one of the reasons why an Indian buyer prefers to place an order with a foreign shipyard, even if Indian shipyards have idle capacity.

4.4 **Tax on Capital Goods for Setting Up Infrastructure.** Capital goods imported for the purpose of setting up or upgrading the shipyards incur custom duty of 26 % which increases the initial investment costs.

4.5 **Cost advantages in South Korea and Chinese Shipyards due to Better Taxation.** Indian shipyards face the following handicaps when compared with their counterparts in China and Korea:-

(a) Differential impact due to statutory taxes and levies as discussed above.

(b) Differentials on account of financial charges, such as bank guarantee (BG) charges, insurance charges and interest on working capital (WC) and capital expenditure. The Working Capital (WC) loan for a shipyard is currently around 5-7 % more than the competing countries. Shipbuilding cycles are long and the time duration between each stage payment is high. The reduction in interest rates on WC could bridge the gap between the supplier credit period and inflow of stage payment.

(c) Differentials on account of import such as sea freight, clearing, forwarding and other external factors, such as discount on bulk purchase, forex rate etc.

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## 5. Shipbuilding Subsidy

5.1 In the past, in order to overcome the cost and price disadvantages that an Indian ship-builder faces in the international competitive market, the Government of India had introduced a subsidy scheme for shipbuilding in 1993 for duration of 5 years and extended twice with certain modifications. During the last phase (2002-07) of this scheme, the private shipyards were also included. Under this scheme, the Indian government would refund 30% of the contract price to the shipyard; this facilitated the shipyard to bid at a lower price in the international market to secure a shipbuilding order. This scheme existed till 14 Aug 07 and thereafter the subsidies have not been extended. Details of the Indian subsidy given in the past is tabulated below:-

**Details of Subsidy Schemes Implemented by the Government of India**

| Year | Scheme | Applicability |
|---|---|---|
| 1993 | 30%subsidy on the price of an ocean-going vessel. This policy was for a duration of 5 year. | Public sector shipyards |
| 1997 | The subsidy policy was extended for 5 years, substituting loans at concessional rate by arranging loans through External Commercial Borrowing (ECB). | Public sector shipyards |
| 2002 | 30% subsidy applicable to export ship orders and domestic ocean- going vessels of 80metres and above. This policy was applicable for a period of 5 years and expired on August 14, 2007. | Public sector and private sector shipyards |

5.2 It is pertinent to mention that subsidy has been provided by all the countries that have focused on the shipbuilding industry. Even in India, the shipbuilders association, and the Inland waterways Authority of India (IWAI) are of the opinion that the subsidy scheme, which was discontinued in 2007, should be reinstated. The MoS in its document 'Maritime Agenda 2010-2020' has also recommended that the subsidy scheme should be provided for the shipbuilding sector.

## 6. Economic Benefit to Human Resources

6.1 The shipbuilding industry, in addition to facilitating the flow of funds provides employment to people in various sectors such as shipyard, the tier-I and tier-II industries, the capital goods manufacturing sectors and the service sectors. As shipbuilding is highly labour-intensive it provides greater opportunity for employment. A shipyard supports a large pool of talented/ skilled human resources and approximately 20% of the total cost of building a ship goes toward paying the human resources employed in the shipyard.

6.2 The shipbuilding industry has the potential to employ diverse categories of human resources across a broad educational spectrum viz. school pass-outs, diploma holders, graduates, post graduates to doctorates. It can employ men and women for both blue and white collared jobs in different field of specialization such as skilled technicians, technical engineers, management specialists, information technologists (IT), financial and commercial. A shipyard also provides employment and business opportunities for subcontractors and vendors. The Indian shipbuilding industry has the potential to additionally generate employment for 2.5 million persons (0.5 million in direct employment and 2 million indirectly) in the coming years, in the core sector of shipbuilding and the ancillary industry.

6.3 In a country like India, where adequate human resource is available (India being the second largest populated country in the world), it is important that this resource is gainfully utilised. The shipbuilding industry provides an excellent platform for employing the valuable human resource as well as uplifting the standard of living of this human resource. In addition to employing people, shipbuilding facilitates circulation of money through the people associated with this industry. This facilitates growth and development of the human resource as well as the economy of the country.

**7. Shipbuilding Ecosystem and GDP**

7.1 It is an established fact that circulation of money (Velocity of Money) is essential if wealth is to be generated. Therefore, towards the growth of a nation, flow of money is very essential. The shipbuilding industry has the potential to facilitate flow of money across a plethora of manufacturing industries, and the manufacturing sector has the potential to cause steady, sustained and inclusive growth of the national economy. In addition, shipbuilding is linked to the financial services and energy sectors.

7.2 Another interesting feature of shipbuilding is that this industry brings in valuable foreign exchange into a country. Presently, around 80% of the orders being executed by the Indian shipyards are for export. The sale/purchase deals of all export orders of ships are undertaken in USD/Euro. Therefore, it can be said that the shipbuilding industry as on-date is an export industry. Shipbuilding, as an export-oriented industry can lead the rest of the economy towards modernization.

7.3 As shipbuilding has the potential to circulate large amounts of capital, it facilitates the growth of the economy and thereby the GDP of a country. Towards this, the number of ships manufactured in India should be high and they should source around 80% of their raw material from the Indian ancillary industry. One of the challenges towards achieving this is that the Indian shipyards need to have adequate shipbuilding orders.

7.4 It is very important to note that various leading shipbuilding countries such as Korea and China have their shipbuilding industry contributing in a major proportion of their national GDP. China presently manufactures 90% of the world's containers. The throughput of cargo and containers at China's ports has been the largest in the world for the past five years (2015 -2019), with an annual growth rate of 35%. However, in case of India, contribution of shipbuilding industry is minimal. There is a potential to increase the contribution of shipbuilding towards the national GDP.

**8. Recommendations**

8.1 With the potential India possesses as a shipbuilding nation, economic benefits of a robust shipbuilding industry, a conducive policy framework and institutional support systems would go a long way in India's endeavours to emerge as a vibrant shipbuilding nation. Towards this end, countries such as Brazil, Philippines, Vietnam, South Korea and China among others have put in place strong policy framework and support systems that have contributed significantly to these countries' emergence as vibrant and growing shipbuilding nations. Learning from such experiences would prove to be beneficial in development and expansion of India's own shipbuilding industry. Accordingly, broad strategy and recommendations in this are elucidated in succeeding paragraphs.

8.2 **Tax regimes and SEZs.** All ships including dredgers imported by Indian owners from abroad are fully exempted from customs duty. Hence the existing shipbuilding industry is totally unprotected. In fact customs duty of the order of about 35% is imposed on all capital equipment required for shipbuilding even though this measure does not protect any industry in India. There is therefore a need to accord export status for building ships which are built in India for Indian owners. Both existing and future shipyards should be considered as SEZ. Such a status should also be accorded to any other ancillary industry that may come up to enable the shipbuilding industry to grow in clusters. Investment will then be structured and will flow in the right direction without affecting the existing units. A favourable structure of taxes and duties is essential to provide equal market opportunities for Indian shipyards and ancillary industries with respect to their competitors. The economic disadvantage that an Indian shipyard faces due to various taxes being levied needs to be removed in order to aid the Indian shipbuilding industry to proceed forward. A level playing field between the indigenous and foreign vendor is essential.

8.3 **Subsidy.** Shipbuilding skills take a long time to nurture and develop, and industries take time to be set up. Hence the subsidy scheme needs to be extended for at least the next 10 years so that Indian shipbuilding fully establishes itself in the global arena.

8.4 **Industrial Clusters.** Setting up of shipbuilding ancillary industrial clusters in the vicinity of the shipyards is the need of the hour. This would facilitate the Indian shipyard to have the option of sourcing its raw material from the most cost-competitive vendor and aide development of tier-I and tier-II industries. The following subsidies/ features are recommended:-

(a) Land made available to the shipbuilding industry near sea ports at a concessional rate.

(b) Availability of concessional power and energy/ subsidies for solar powered plants, so that the manufacturing cost reduces.

8.5 **Single Window Clearance.** The industry is presently subjected to multiple checks and clearance from both the Central and the State governments. From being an extremely dynamic as well as cyclical industry, return on investment/ capital needs to be ensured by avoid procedural delays and in allowing smooth expansion of capacity. The main deterrent of multiple clearances which delay a project must be removed. Hence environmental clearance, clearance for allocation of land and its development, clearance for power and water requirements and security clearance of the location apart from the long term fiscal climate must be established through a single window.

8.6 **Specialized Marine Financing Institution and Marine Finance Scheme.** Setting up of a specialized financing institution/ marine finance scheme could also provide the much needed boost to the shipbuilding industry. In Malaysia, in line with the country's Strategic Plan 2020 for the shipbuilding and ship repair industry, Bank Pembangunan Malaysia Berhad (BPMB) actively supports the shipbuilding industry through a marine finance scheme providing medium and long term financial support to domestic shipyards.

8.7 **Exploring Potential Demand from Overseas Market.** An important strategy to provide a boost to India's shipbuilding activities as also India's exports could be matching India's export capability with demand existing for ships in emerging markets. A case in point would be exploring specific markets in Africa, which are major importers. India's exports of ships and boats to Africa had witnessed a sharp rise from US$ 11 mn in 2002 to touch US$ 951 mn in 2010, accounting for as much as 23% of India's global ship exports. However, despite rise in Africa's global ship imports from US$ 16.5 billion to US$

18.5 billion, India's exports to the region have witnessed a contraction. In this direction, an important strategy could be putting in place credit lines to identified potential markets in Africa, which would serve to enable such countries to increase imports from India, while also generating much needed assured orders for Indian shipyards. For instance, in the case of China, China Exim Bank has extended credit line to shipping companies in Ethiopia, Brazil and Iran, to help generate construction and exports orders for domestic shipyards in China.

8.8 **Reduce Charges of Financial Services.** The current charges on various financial services are relatively high in comparison to its competitors and could be lowered. The recommendation in respect of the financial services is reduction in the Working Capital (WC) loan. This loan currently is hovering around 12%. Since shipbuilding cycles are long and the time duration between each stage payment is high, the interest rates on WC can be reduced so as to bridge the gap between the supplier credit period and inflow of stage payment from the customer. The interest rate for WC in the other competing countries is in the range of 6-7%.

8.9 **Technology Upgradation Through Joint Ventures.** An important measure to upgrade technology in the shipbuilding industry could be joint ventures with major shipbuilding companies/ shipyards. For instance, the Hyundai-Vinashin shipyard, a joint venture between VINASHIN of Vietnam and Hyundai Mipo Dockyard, is now rated among the most modern, as also one of the largest ship repairing yards in South East Asia.

8.10 **Conclusion.** The shipbuilding industry has its own distinctive features as compared to other industries in the country. It is unique in a way that it has to sell first and construct later, unlike the auto industry or others, where one manufactures first and sells later. Further, shipyards get orders only if they are credible (deliver quality ships on time) and it can be credible only after successfully executing consistently under international competition. Further, it has to be globally competitive against the best yards in the world. Unfortunately, the shipyards are faced with very stiff taxes, tariff, duties, and financing charges as compared to foreign yards. Unlike other manufacturing industries the product takes years to deliver and requires high cost finances over a long period. This weakens the competitiveness of the industry. In order to propel the Indian shipbuilding industry, the financial/ economical recommendations to be implemented have been discussed in the paper. The shipbuilding industry can improve the economy of a nation, only with a high volume of shipbuilding output along with sourcing the raw material indigenously. Towards this, a favourable economic ecosystem is essential. In addition, the shipyards need to perform to the best of their ability, so that they can deliver quality ships on time which will bring in more orders. The recommendations deliberated above will go a long way in providing the required boost to the Indian shipbuilding industry and to India in return.

**Disclaimer**

Contents of the paper are personnel views of the authors and do not reflect the policy or position of the Indian Navy or Government of India.

# HULL FORM OPTIMISATION AND BUBBLE SWEEP-DOWN MITIGATION IN NAVAL VESSELS

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**1. Abstract**

1.1 Naval vessels and research vessels fitted with sonar have always found it difficult to position them correctly for a better sonar performance and optimised hull resistance. It is always a trade off between sonar performance and speed of the vessel. Very often, the positioning is done by past experience and some limited physic cal model test bubble sweep down studies. This paper describes some of the design and analysis effort made to improve sonar capability through minimizing bubble sweep-down interference with consideration of over-all ship resistance. Computational fluid dynamic (CFD) analysis is used to determine their effect on bubble sweep down near the transducers. A new bubble diverter bow design is analysed for mitigating the bubble sweep down phenomenon.

**2. Introduction:**

2.1 Oceanographic research vessels are fitted with acoustic sonar transducers at the bottom keel region - usually at the forward 1/3 length of the vessel. For a ship underway, atmospheric air gets mixed naturally with the surface water in the presence of wind and waves. Bubbles get entrapped in the region within the draft of the vessel and flow in the stream past the vessel. Literature shows that the bubbles are formed in the upper regions (made worse by the pitching motion) below the surface. When they flow immediately below and in the region of the sonar transducer resulting in bubble sweep-down phenomenon, they directly interfere with the acoustic transmission and deteriorate the functioning of the sonar transducer. Degradation of performance of the acoustic transducers seriously limits the mission capability of the vessel. This is a major concern and there is no complete remedy in sight for the avoidance of the bubble formation in the flow stream.

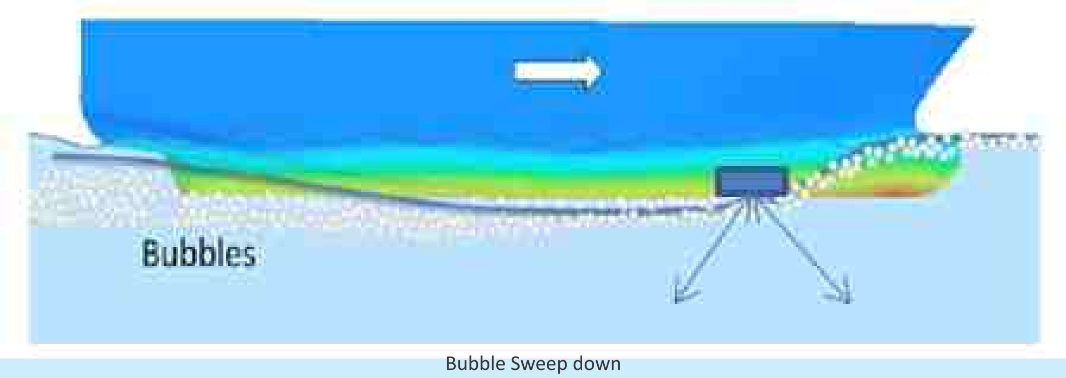
2.2 Currently this issue is mitigated by keeping the underwater transducers in a separate structure below the keel as an appendage. Based on its shape and installed location, bubble sweep over the transducer face is avoided to some extent with penalty on added resistance.

2.3 For new build vessels, an attempt is made to re-design the hull geometry in the forward region and the creation of an effective bubble diverter bow. A new modified bow form is proposed to help in deflecting the stream lines away from the location of the sonar transducer. The strategy in the approach here is to design the bow region to control hydrodynamic flow such that the bubble entrapped water of the upper surface layers can be strategically ensured to flow side-ways of the hull or at the bottom side-ways well away from the location of the sonar transducer.

**3. Bubble sweep down phenomenon and ship speed:**

3.1 Two phenomena drive the bubble sweep-down process. The first one is the formation of the bubbles and the second is the bubble transport. Bubble formation occurs continuously at the ocean surface, mainly due to wind and waves and their interaction with the ship structure. The density of bubbles and depth of bubble penetration are proportional to wind speed and vessel speed. Bubble sizes vary from 20 microns to 200 microns and are concentrated around the ship hull with in 4 to5 m depth from the surface water.

An analysis of some of the oceanographic research vessels built around the world shows that a typical speed of 10 to 12 knots favours the mission requirement of bottom and side survey, though there are vessels with higher speeds. At slow speed (below 4 knots) machinery and ambient noise were the main source. At medium speeds (between 4 and 11 knots) hydrodynamic flow noise was the main source. At higher speeds (above 11 knots) noise due to cavitation was the main contributor to the acoustic signature. Different noise sources are controlling the acoustic signature for different speeds. It is evident that ship speeds above 10 knots in calm water and 8 knots in higher speeds, bubble sweep down is present and hence the noise. The sonar transducers fitted at the bottom are affected by bubble sweep-down which is a widely known phenomenon.




Bubble Sweep down

3.2 **Numerical Simulation and Streamline study on hull form to trace bubble sweep down:**

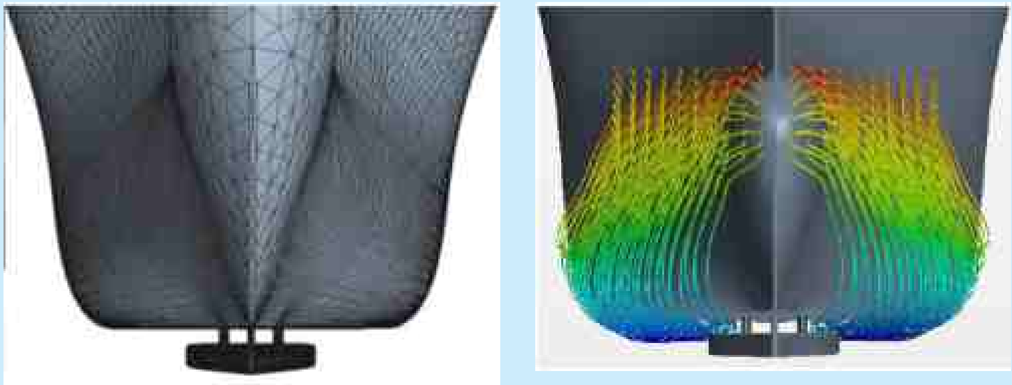
3.3 Bubbles in general follow the streamlines and it is established that any bubbles originating at the bow has tendency to flow down the ship. Any under-water sensor array should not be placed in the way of the streamlines carrying the bubbles. Streamline study is considered a reasonably good approach to trace the approximate path of bubble transport.

**4. Solution for conversion design**

4.1 It is necessary to address the merits and characteristics of existing known design efforts to alleviate the problem of bubble sweep-down in the path of the bottom mounted sonar transducers. These design efforts have been primarily in the form of modified bottom shapes and have acquired different names. The success of the design has to be accounted with simultaneous assessment of the penalty on resistance. Depending on the design shape and location, the resistance penalty and flow diverting characters vary. Three common modifications in shape viz.,gondola, flush mounted and cowcatcher (which have been explained earlier in the literature study) are assessed here for their merits. The results are presented based on flow line traces and the extent to which the designs have helped in steering the streamlines from the bubble locations away from the sonar transducer location.

**5. Gondola**

5.1 The Gondola, houses the sonar transducer array, is a bottom appendage and is connected to the hull through struts. The dimensions of the scientific equipment decide the height of the Gondola structure. The extent to which the Gondola structure requires to be lowered (length of struts) depends on the streamline analysis, which ensures that streamlines pass through the gap between the Gondola and the hull. However, if the submergence of the Gondola is deeper, while the bubbles may steer clear of the sonar transducer, the additional structure of the Gondola will add more to the resistance. Hence a trade-off is to be obtained to fix the dimensions.



Streamline pattern around Gondola

5.2 Results from the flow simulation through CFD indicate that the streamlines emanating from the free surface to a point 1.5m below pass through the gap between the hull and the transducer assembly with more turbulence around the struts area.

**6. Flush Mounted Arrangement:**

6.1 In this arrangement as the name implies, the array structure containing scientific components is maintained flush with the keel at the centreline of the ship. It is to be expected that the smooth shape offers minimum disturbance to the flow with resulting low resistance due to the appendage.

6.2 The results of flow simulation from CFD indicate that the streamlines emanating from the free surface to 1.5m below, are partially effectively diverted towards the sides as desired in the design, and partially pass over the bottom surface.

**7. Cow Catcher:**

7.1 The Cowcatcher configuration consists of a U-shaped structure bending inward resulting in a reverse angle slope in the transverse sections as well as at the leading edge. This is also attached to the hull through flush mounted configuration.

7.2 The results of flow simulation from CFD indicate that the streamlines emanating from the region from free surface to 1.5m below are diverted towards the sides. The streamline pattern around the hull and appendage is shown in Fig.

| Sl. No | Shape of sensor arrary | Added weight | Added resistance | Flow diverting effect |
|---|---|---|---|---|
| 1 | Gondola | High | High | Very good |
| 2 | Flush mounted | Low | Low | Fair |
| 3 | Cow catcher | Low | Medium | Good |

Assessment of various shapes of sonar array

| Resistance at design speed and draft - CFD Results | | | |
|---|---|---|---|
| SL. No | Shape of sensor array | Rt (N) | Added resistance |
| | Original bulbous bow hull | 70.2 | 0 |
| 1 | With Gondola | 84.0 | +19.7% |
| 2 | With Flush mounted | 76.8 | +9.4% |
| 3 | With Cow catcher | 78.0 | +11.1% |

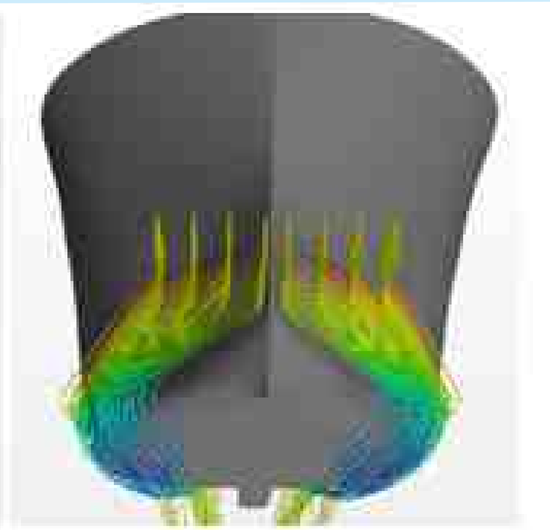
Resistance comparison of various shapes of sonar array

Considering the combined effect of adverse resistance and flow diverting characteristics, the Cowcatcher is the better option among the three.

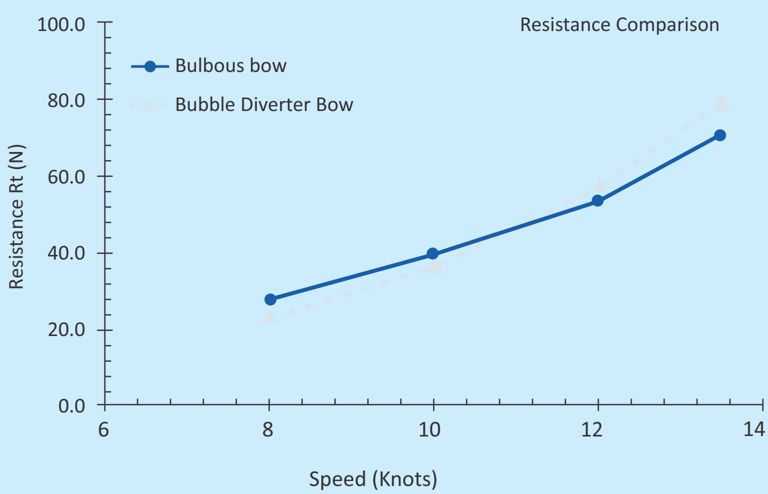
**8. Solution for New Design**

8.1 The objective here is the control by diversion of the trace lines of fluid emanating from the bow region, which may contain bubbles. An accentuated U-shape at underwater bow cross sections can aid delay of flow to the bottom. Based on these leading considerations the hull form is now modified to obtain a bubble diverter form. The rationale behind the shape design is to delay the tendency to flow under and to widen the streamline traces for those fluid particles mixed with bubbles emanating at the critical depth between 0.3m and 1.2m below the surface at the bow. Hence the road map to improvement of the hull form is to achieve the bubble diverter form without the bulbous bow shape as a function of geometric parameters. The evolved hull shape, by analysis, achieve the twin objectives of bubble sweep-down mitigation with least penalty on resistance.

Bubble Diverter Bow (BDB) Hull form



Streamline pattern around BDB




8.2 Currently research vessels are designed with or without bulbous bow. In both the cases streamlines originating from the bow tend to go deeper under the hull and closer to the sonar array installation region (centreline of ship). To overcome this problem, most of the sonar manufacturers recommend installation of the transducers in the forward 1/3 length between perpendiculars of the hull. The study here has validated this aspect. The bubble diverter bow form has superior bubble sweep-down mitigation characteristics. For a general-purpose research vessel, 8 to 11 knots is a generally preferred operational speed range. For this speed range, the bubble diverter bow emerges as a good choice with a balance between resistance and bubble sweep down. It is superior even to the conventional hull form with bulbous bow.

**9. Summary and Conclusion :**

9.1 When research vessels are made by conversion process from other vessel types, most of the time, the sonar array is mounted below the hull as an appendage as a mitigation technique. Whereas for new build vessels, instead of tweaking the hull form with appendage, it is appropriate to modify the forward part of hull shape to divert the flow towards the sides of the vessel (away from the sonar installation in the centre line of the vessel). This research study has resulted in a new improved design based solution namely, Bubble Diverter Bow form. The assessment involves computer aided surface development of the hull form, flow simulation past the hull using computational fluid dynamics, validation studies and observation of the trace lines of particles emanating from the bow region and potentially carrying bubbles. At every stage of analysis, flow diverting character has been monitored along with resistance. The development of the bubble diverter bow form is reported as a new solution to bubble mitigation for oceanographic research / survey vessels and can be considered for any vessel by thorough hydrodynamic investigation at the design stage.

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[2] M. Palaniappan and V. Anantha Subramanian, "Hydrodynamic design for mitigation of bubble sweep down in sonar mounted research vessels", *International Shipbuilding Progress* 64 (2017) 101-126, DOI 10.3233/ISP-170139.

[3] M. Palaniappan, M.S (By Research) thesis, "Hydrodynamic study for Bubble sweep down mitigation in Oceanographic Research Vessels", 2017, Department of Ocean Engineering, IIT Madras.

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# ABB ABILITY™ MARINE REMOTE DIAGNOSTIC SYSTEM RELEASE 5.2: SOFTWARE AND HARDWARE TECHNOLOGY UPGRADE, NEW FUNCTIONALITY, SIMPLIFIED COMMISSIONING, SCALABLE INFRASTRUCTURE FOR IT SERVICE CENTRES

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R&D Product Manager

1. After fundamental improvements and changes in the back-end and server side functionality, in 2016 the RDS system has been subject to major modifications related to its presentation layer. In order to fulfill requirements of 'common ABB Marine Onboard User Interface' look and feel, a totally new design of the RDS main view was introduced. ABB Marine graphical designers worked closely with system users to create a visual design that will inherit the best functionalities from the previous RDS release and deploy them according to the new philosophy of user-machine interaction that is to be common for all types of onboard systems delivered from ABB (e.g. automation, voyage optimisation and diagnostics). The iterative process of discussions, specification and incremental implementation allowed building the new RDS UI with focus on user satisfaction and ergonomics. On the technology side, communication between data server and presentation layer has been improved drastically by introducing fast and ultra-light messaging protocol. Graphical elements are based on world's best UI frameworks such as Telerik and SCICHART. Main features of new RDS User Interface are as follows:

(a) Consistent presentation of information from the level of equipment status and analytics results through detailed alarm and event description,to the level of time series trends and high frequency sampled signal transients and loggers

**New RDS UI**

(b) Two different ways of aggregating information, e.g. by asset types (drives, motors, generators) and system types (e.g. portside drive train, power system, etc.)

(c) Status Panel with three levels of drill-down navigation allows user to quickly assess the condition of monitored equipment in real time

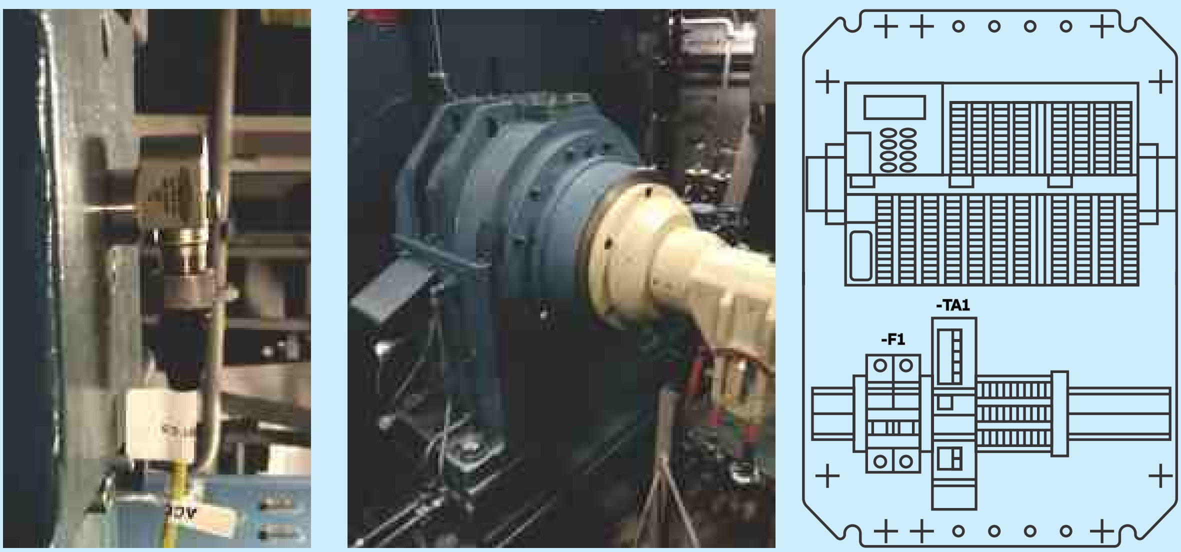
(d) Alarm Panel and Trend Panel with detailed alarm list and advanced plotting controls facilities fast fault tracing – a core feature for internal, ABB users of the system

(e) Embedded roles-based mechanism governs presentation of certain information only to privileged users

(f) No software engineering required to redesign the content of Status, Alarm and Trend panels

(g) Optimised for wide screen displays

**Condition monitoring**




(h) Information presented onboard in the Status Panel is replicated on the RDS section of ABB Fleet Portal to provide consistent notification to both offshore and onshore customer teams.

(j) The status panel is only visible onboard for customers with Service Level 3 – RDS Prediction

**2. Condition monitoring of rotating equipment**

2.1 The Diagnostics for Machine (D4Machines) package has been greatly improved with two main areas of development:

(a) Introduction of a new data acquisition hardware solution for online condition monitoring of critical rotating machinery.

(b) Piloting a new concept of Modular Tool – multi-sensor data acquisition tool for condition monitoring of LV rotating equipment

2.2 Ad (1) The online solution for condition monitoring of critical machinery received a new hardware platform for signals acquisition. Proven and widely tested in various industries and application, the ABB AC500 based, highly specialised data acquisition components have been chosen and integrated with the RDS system. With its pilot deployment onboard PGS Ramform Hyperion, the new concept proved to be fully operational. Similar to previous release of D4Machines concept, measurements from AC500 CMS system are trigged by RDS under precisely defined operating conditions to normalise the calculation results. Some of the raw readings and end results are automatically sent to our Service Center databases to feed periodic reports. The main highlights of the new release are as follows:

(a) AC500 Condition Monitoring Package consisting of PM592 CPU and FM502 input module form new RDS data acquisition unit

(b) The system facilitates signals collection from up to 16 I/O channels acquired simultaneously with maximum 50 kHz sampling frequency

(c) Input channels re-configured 'on-the-fly' by RDS systems typically read signals from accelerometers (IEPE) and +/− 10V voltage signal out

(d) Extendable with standard, 16-channel AI module for additional hard-wired input signals such as temperatures

(e) Installed inside the RDS marine cabinet forms a portfolio of four different options fitted for normal and extreme condition of installation, depending on the vibration level of the machine and the installation location of the cabinet

2.3 Ad (2) Year 2016 brought significant effort in further product development and market introduction of ModularTool – a cost effective hand-held solution for RDS condition monitoring of LV rotating equipment. Conceptualised and researched in previous years, the tool was successfully integrated with the RDS system in 2016. All analytics provided with the tool are deployed in the onboard RDS system and launched automatically each time it is connected to RDS PC.

2.4 Acoustic, vibration, magnetic and tachometer recordings acquired by the tool are processed with the number of specialised algorithms to give high level indication about the condition of the motor bearings, rotor and mechanical installation. Pilot installation of prototype device was done in January 2017 onboard the PGS Ramform Hyperion and received very good feedback from end customer.

2.3 **RDS Cyber Security Enhancements**

(a) Fully compliant with ABB cyber security requirements

(b) Encrypted traffic from ship to shore using ABB's technology Remote Access Platform (RAP)

(c) DSAC and hardening for onboard RDS infrastructure

(d) Firewalled from ship network - the vessel's network is secured from outside (Internet) by a firewall which is by default configured only to allow for traffic required for ABB Remote Access Platform and set up to pass only dedicated predefined data connections and block all other traffic

2.4 **Enhanced Portfolio of Monitored Assets and Analytics**

(a) Connector to ACS880 drives

(b) Turbochargers monitoring and analytics

(c) Infrared temperature monitoring and diagnostics for MV power systems

(d) Integration with ABB 800xA and Asset Optimiser

(e) Prediction algorithms for MV drive water cooling system

### 3. Improved IT Serviceability

3.1 For internal users and RDS IT maintenance teams in particular. RDS version 5.2 comes with new functionalities that simplify and accelerate the process of RDS software upgrade and reconfiguration. With several years of experience on remote troubleshooting and maintenance of RDS, what proved to be particularly troublesome for our IT team were 2 types of operations:

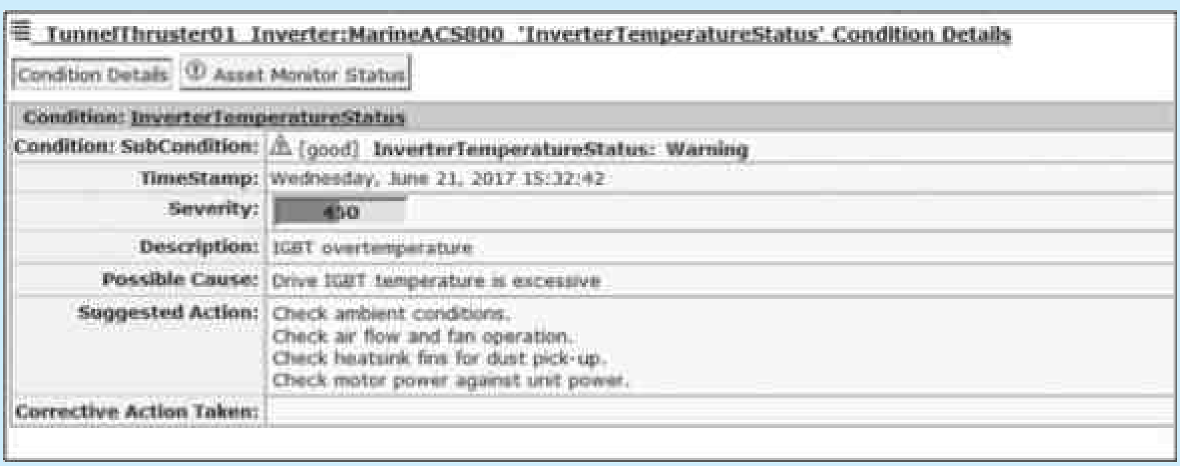
(a) Update of software typically requiring transfer of the entire RDS installer, reaching more than 100MB in size

(b) Reconfiguration of RDS using configuration screens

3.2 Both above activities, perhaps trivial tasks when working on a local desktop computer, become a challenge if the remote connection to onboard RDS stations is using a very weak satellite connection with very limited broadband capacity. In those cases, a single click of mouse to change the configuration may take dozens of seconds and the transfer of installation files, if possible at all, may take several days.

3.3 The first problem was solved by changing the release and build philosophy of RDS. From version 5.2, each and every maintenance or production release of the software comes with the pair of full .msi installer .msp patch files. As a result, in order to upgrade the software version between minor versions, transfer of a maximum 2MB file onto the site is needed, or 50 times less than previously required.

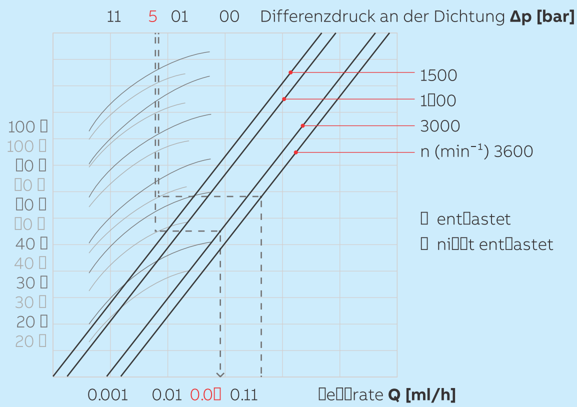
**Enhanced portfolio of monitored assets and analytics**



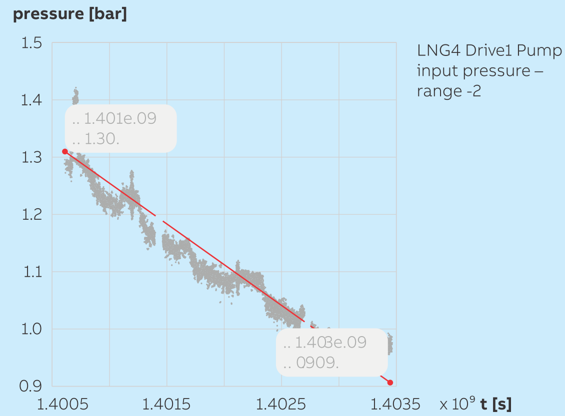

### 4. New Diagnostics Functionalities in RDS 5.2

4.1 Continuous innovation on existing solutions and newer products delivered to customers requires RDS to constantly adapt to market needs and provide state-of-the-art monitoring solutions that match equipment installed onboard the most sophisticated vessels. Additional drives have been incorporated into the already existing D4Propulsion diagnostics package, including ACS1000, ACS800, ACS880 and DCS800 used in DC grid projects. In order to provide better condition monitoring of circuit breakers and contactors, a new client library based on IEC61850 MMS protocol is being developed to interface RELION protection relays installed in MV switchboards, which will significantly increase the volume of signals being recorded, and will enable further advanced analytics. For example, monitoring the total number of opening/closing cycles, load of operations, short circuits and faults, etc., will help to determine the life expectancy of a circuit breaker.

**Left: Natural leakage mapping**




**Right: Pump input pressure drop**

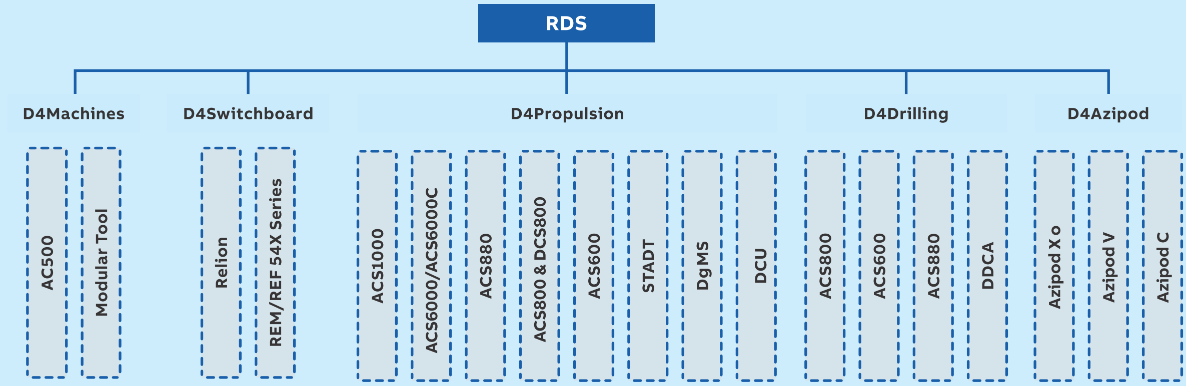



4.2 Thanks to the modular approach of standardised modules connected to different equipment, RDS is able to expand its diagnostics portfolio and regularly adapt to brand-new equipment. With currently >45 different diagnostics solutions installed in about 600 automation PCs, ABB is able to remotely monitor approximately 100 vessels with service contracts.

### Hardware and platform upgrade

The increasing amount of assets being monitored, and higher-end diagnostics solutions with onboard edge analytics, require more resources from the automation PCs and panel PCs running RDS software. Within 2017, all computers will be delivered with an increased 8GB RAM memory (previously 4GB RAM) with 64-bit Windows 10 operating system. These upgrades not only contribute for better performance and user experience, but also extend the serviceability of the equipment and eliminate hardware constraints that could limit future software development activities.

**RDS modular concept of diagnostic solutions**



# IMPROVED CFD METHOD FOR SHIP RESISTANCE PREDICTION: LARGE EDDY SIMULATION MODEL

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## 1. Abstract

1.1 Usage of Computational Fluid Dynamics for prediction of ship resistance has increased tremendously in the last decade. For warships, estimation of hydrodynamic characteristics in the concept design stage helps the designer and the organization to take critical decisions with regards to hull form and propulsion systems. The traditional RANS methods for viscous flow estimation around a body are slowly being replaced with advanced methods. Large Eddy Simulation (LES) is one such method that is gaining usage across the industry for higher accuracy within practical limits. This paper attempts to discuss the LES methods and its usage. Further, a comparison of RANS and LES method for drag prediction of flow around a circular cylinder has been undertaken and results are presented.

## 2. Introduction

2. Ship resistance estimation in the early concept phase is an essential procedure in the ship design spiral. Essentially, resistance, propulsion, and manoeuvring fall under the ship hydrodynamics umbrella and are driven by the fundamental fluid dynamics principles. Numerical methods for prediction of resistance and flow around the hull exist and have been widely in use since the advent of computers. Computation methods have given increased insight in favourable hull form characteristics, and it is generally accepted that the numerical methods have reduced the requirement for extensive model testing as the maximum portion of the hull form refinement is undertaken using computational pre-optimization [1]. From the 1980 Gothenburg international workshop on numerical prediction of ship flows, the study of flow around the ship has increased in pace wherein international communities are working with standardized model hull forms and compare numerical and experimental methods for prediction of the flow characteristics [2].

## 3. Review of Numerical Methods

3.1 Essentially, the ship resistance prediction using computational methods decomposes into two components:-

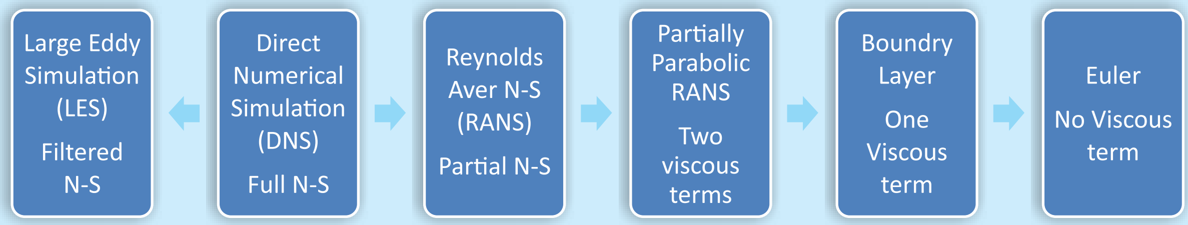
(a) The inviscid process to study the wave generation in the whole domain around the ship

(b) The viscous flow, occurring in the relatively narrow region around the hull and in the wake (and is considered unaffected by wave making)

3.2 Such a separate treatment helps in simplifying the computational problem where the wave making phenomenon can be calculated using coarser discretization and simpler methods. Prediction of inviscid flow for studying the wave making resistance phenomenon is undertaken using Panel methods. The solution of viscous flow computation is undertaken using methods based on the Navier-Stokes (N-S) equation.

3.3 Solving the Navier-Stokes equations for flow around the ship has been discussed by Larsson et al. wherein for a full-scale ship, the order of grid points required turns out to be 1021 to study the smallest eddies (of the order of 0.1 mm) in the turbulent boundary layer. In general, the grid points that are used during the concept stage studies are nearly 106-109. Assuming linear scaling for computational time to number of grid points, one can understand the high computational cost. Hence, instead of solving the Navier-Stokes equations without modifications (DNS methods), some assumptions and modifications are taken which incorporate neglecting the details of the flow. This is undertaken to achieve manageable computational times. The classification methods and their underlying simplifications, used in viscous computational; hydrodynamics are shown in Fig. 1.

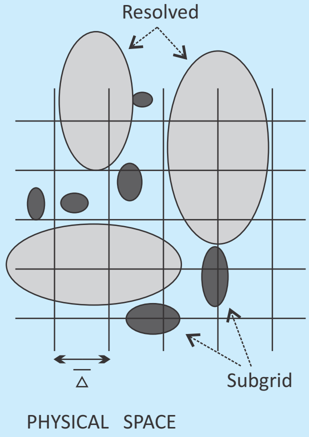
**Fig 1: Classification of methods used in viscous computational hydrodynamics**




In the RANS (Reynolds Averaged Navier-Stokes) methods, all turbulent fluctuations are removed, and N-S equations are solved only for the mean flow. Additional unknowns appear in such equations (called Reynolds stresses), and turbulence models are incorporated to solve for those quantities.

3.4 Large Eddy Simulation (LES) methods model the smaller eddies and compute the mean flow and large eddies. For this method, N-S equations are modified with a low pass filter to remove eddies smaller than the filter width. The low pass filter is characterized in terms of wave number. In this process, the non-linear terms will give rise to additional unknowns, which require modelling using separate equations. The equations are known as "subgrid scale models". A schematic view of the subgrid scale resolution in physical space is shown in Fig. 2.

**Fig. 2: Schematic view of resolution and modelling –**



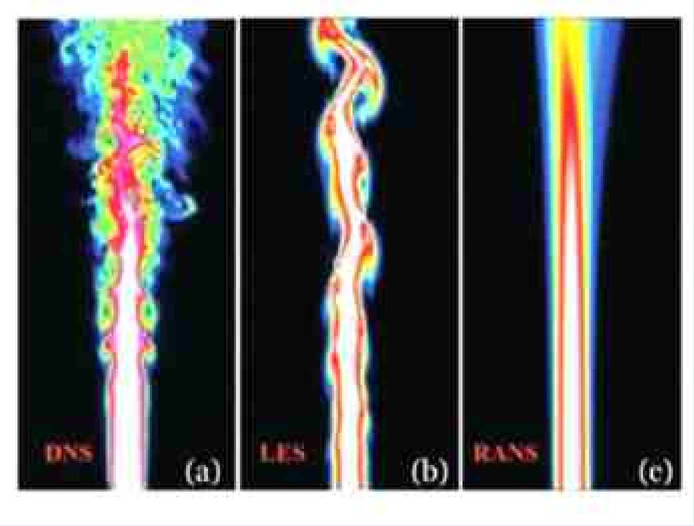
"Subgrid scale models" attempt to describe the unresolved flow on the resolved flow using the resolved flow variables. These models can be characterized as functional or structural depending on the methodology the model uses to mimic the unresolved flow.

**4. Brief on LES Method**

4.1 LES method was first proposed in 1963 by J. Smagorinsky to study the atmospheric boundary layer flow. The underlying principle is the elimination of small-scale flow physics not resolved on the computational grid leading to resolution of large scale flow physics and modelling of unresolved small scale models using subgrid models. For practical engineering systems, the use of LES usually requires large grids. Methods include wall-resolved or wall-modelled LES for wall bounded flows.

4.2 LES presents an approach that allows for higher fidelity than RANS methods and at a lower computational cost compared to Direct Numerical Simulation methods. A comparison of simulation of jet flow using DNS, RANS and LES is given in Fig. 3. The governing equations for LES are shown below.

**Fig. 3: Comparison of results of Jet Flow simulation**




$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \qquad (1)$$

$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial}{\partial x_j}(\bar{u}_i \bar{u}_j) = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\frac{1}{Re}\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\right] - \frac{\partial \tau_{ij}}{\partial x_j} \qquad (2)$$

$$\tau_{ij} = \overline{u_i u_j} - \overline{u_i}\,\overline{u_j} \qquad (3)$$

where $u$ is the velocity component of the resolved scales, p is the corresponding pressure.

4.3 The filtering procedure provides the governing equations for the resolvable scales of the flow field. Although the continuity equation (1) of the resolved quantities is equal to the original unfiltered one, the filtered momentum equation (2) includes an additional term for the non-resolvable sub-grid scale stresses, which results from filtering the non-linear convective fluxes. describes the influence of the small-scale structures on the larger eddies. Only this effect has to be modelled by a sub-grid scale model [5].

For one-equation SGS model, the eddy viscosity is calculated from equation (4):

$$\mu_{T,a} = \rho_a C_k \Delta k_{sgs}{}^{1/2} \quad (4)$$

where $k_{sgs}$ represents the SGS kinetic energy, as show in equation (5), which is obtained by solving or transport equation for $k_{sgs}$,

$$\frac{\partial}{\partial t}(\rho_r \alpha_r k_{sgs}) + \nabla(\rho_r \alpha_r u_r k_{sgs}) = -\nabla\left(\alpha_r \frac{\mu_{eff,r}}{\sigma_k} \nabla k_{sgs}\right) + \alpha_r (G_r - C_g \frac{k_{sgs}{}^{3/2}}{\Delta} \quad (5)$$

where, G is the production term, defined as equation (6):

$$G_r = \mu_{T,a|\overline{S_{ij}}|} \quad (6)$$

The value of model constants ($C_\varepsilon$ =1.05 and $C_k$ =0.07) in equation are considered on the basis of recommendation by Davidson [5].

4.4 Different LES methodologies exist and are used. These include Detached Eddy Simulation (DES), Delayed DES (DDES), Improved Delayed DES (IDDES), Implicit LES (ILES) and Two Scale LES (TSLES). In the Detached Eddy models (DES and its subvariants), an unsteady RANS model is used as a built in wall model. This is in conjunction with bending function transitions into a conventional LES model outside of the near wall region. ILES is based on the observation that the leading order truncation error from finite volume discretization schemes is of the same general form as that of conventional subgrid models. TSLES is based on a combination of a conventional LES and a one-dimensional DNA in the wall normal direction [6].

4.5 For ship resistance estimation, traditionally potential flow models and Taylor wake fields were used. RANS models have gained popularity in the last 30 years however, as only mean flow is computed explicitly and statistical turbulence models provide information on effect of turbulence on mean flow, calibrated turbulence model for ship hydrodynamics are required for underestimation of the size of separation, recirculation regions and underestimation of turbulent kinetic energy in wakes. Hence, the usage of LES, DES and other hybrid methods has started gaining popularity in marine ship flow problems.

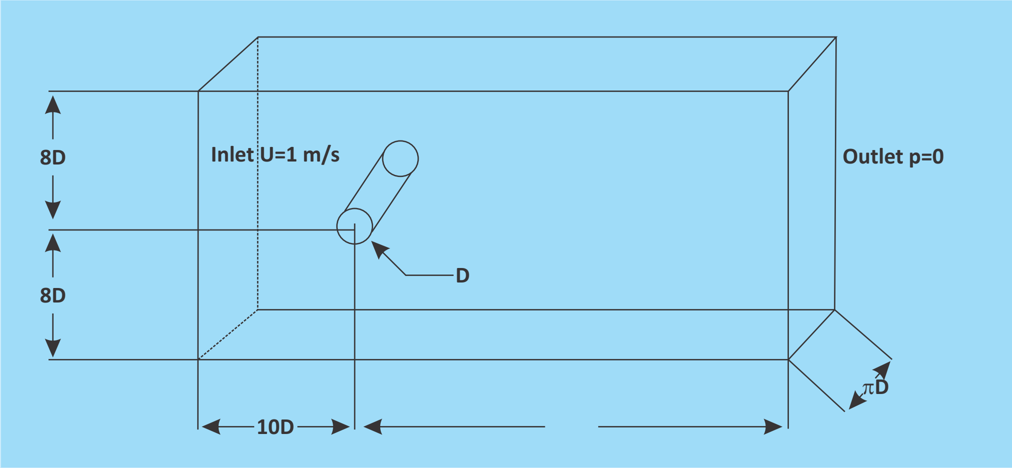
4.6 Pattendsed et al. [7] discussed the developments in use of LES for ship hydrodynamics. Further, they undertook study of flow field in the stern region for KRISO Very Large Crude Carrier (KVLCC) tanker model using PIV and compared the results with CFD predicted results. The authors brought out that when the studies on the model were undertaken during Gothenburg 2000 workshop, RANS models had difficulty in modelling the turbulent kinetic energy in wake area. The results of LES model for flow around stretched cylinder (similar to the aft of ship model) highlighted that resolution of wake flow was possible.

**5. Current Study**

5.1 The present study is to simulate the flow past a circular cylinder at a Reynolds number of 3900, which is based on a free-stream velocity and the cylinder diameter. Unsteady flow past a cylinder in 2D and 3D (Re=3900) was computed using large eddy simulation (LES) in commercially available CFD software. The study included the prediction of drag and lift coefficient, and pressure distribution around the cylinder. During the simulation, the one-equation subgrid scale (SGS) model was applied.

5.2 Fig. 4 depict the computational domain used for the study. The diameter of the cylinder model is 1 m. Fig. 5 and Fig. 6 are the mesh views of the cylinder, used for RANSE and LES study respectively. The number of cells used for RANSE and LES study are shown in Table 2. For 3D LES model, y+ <1, and the first layer height was calculated to be about 1 mm.

**Fig. 4: Computational Domain [7]**




For 3D RANS model, y+ was taken as 100, thus first layer height was calculated to be about 10 mm.

**Fig. 5: Meshing for 3D RANS**

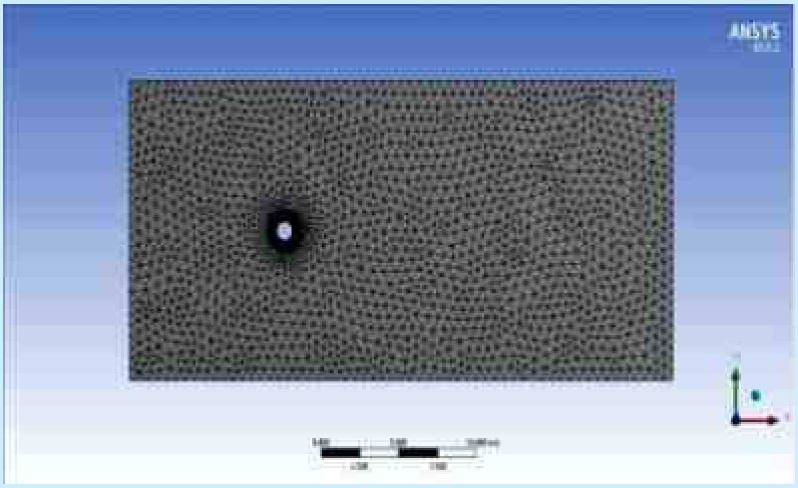
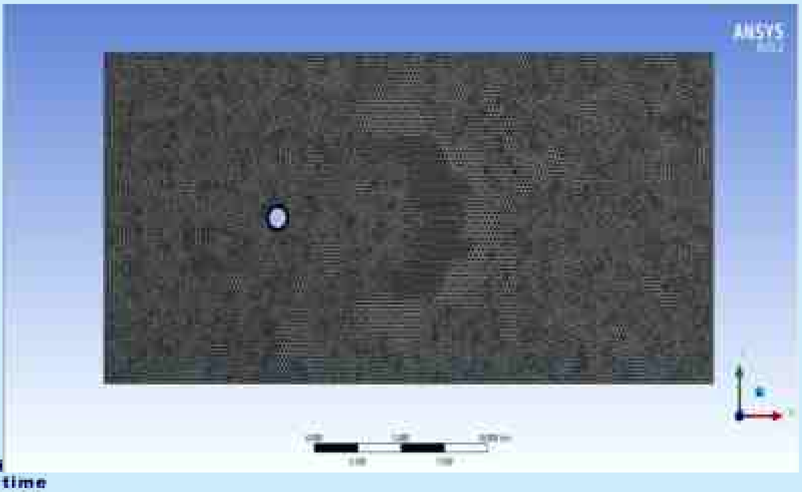



**Fig. 6: Meshing for 3D LES**



5.3 The segregated implicit solver is used for all simulations. Second-order implicit temporal discretization is adopted. For the RANS simulation, second order UDS is used for the equations of turbulent kinetic energy and turbulent kinetic energy dissipation rate, as well as the energy equation. QUICK is used for the momentum equation. For the LES, bounded central differencing scheme (B-CDS) are employed for momentum equations. Solvers used for the current study is shown in Table 1. The time duration of the flow was of 5 seconds with a time-step of 0.5 seconds. The convergence criteria for the simulation was kept at 10E-6.

**Table 1: Solvers used for CFD study**

| Study | Pressure velocity coupling | Spatial Discretization Momentum | Transient Formulation |
|---|---|---|---|
| RANS 2D | SIMPLE | Second order | Second order Implicit |
| RANS 3D | SIMPLE | Second order | Second order Implicit |
| LES 3D | PISO | Bounded Central Differencing | Bounded Second order Implicit |

## 6. Results and Discussion

6.1 Results indicate that LES One-equation SGS model provides better agreement in force coefficients and pressure distribution than above mentioned RANS turbulence model. Besides, effect of span wise discretization to numerical results is also investigated, showing that medium grid is fine enough to yield accurate results compared to the fine grid, which is very computationally expensive. Validation study is undertaken with results of Han Liu et al. [8]. The authors studied the flow past cylinder model using a three dimensional geometry. The current study includes 2-D geometry and 3-D geometry results for flow past cylinder using RANSE and 3-D LES study for the same problem. Two models of meshes were used for study; a coarse mesh and a fine mesh. The results are as shown in Table 2 and the CFD estimated results are shown in Table 3. Table 3 also brings out the number of cell elements used for study. Total wall clock time taken for each simulation to run is given in Table 4.

6.2 Error percentage with respect to the experimental data [7] is given in Table 5. The computational system used for these simulations was a 12 Core, 64 GB configuration. This gives us an understanding of the time duration required for LES simulations.

**Table 2: Published Results [8]**

| Comparison of Drag Coefficient – Cd | | | |
|---|---|---|---|
| Exp | 0.98±0.05 | | |
| | Coarse | Medium | Fine |
| LES | 1.1075 | 1.0524 | 1.0447 |
| RANS(k-Ɛ) | | 0.7446 | |

### Table 3: CFD Results for Drag Coefficient

| Study | No of elements | No of nodes | Cd |
|---|---|---|---|
| RANS 2D SIM 1 | 15098 | 29286 | 0.87859 |
| RANS 2D SIM 2 | 8303 | 14754 | 0.65839 |
| RANS 3D SIM 1 | 246723 | 495275 | 0.83277 |
| RANS 3D SIM 2 | 144882 | 340750 | 0.81158 |
| LES 3D SIM 1 | 165093 | 828613 | 1.0189 |
| LES 3D SIM 2 | 172485 | 502691 | 0.96367 |

### Table 4: Time Taken for Each Simulation to Run

| Study | No of nodes | Time taken for each simulation to run |
|---|---|---|
| RANS 2D SIM 1 | 29286 | 877 sec |
| RANS 2D SIM 2 | 14754 | 606 sec |
| RANS 3D SIM 1 | 495275 | 1832 sec |
| RANS 3D SIM 2 | 340750 | 1540 sec |
| LES 3D SIM 1 | 828613 | 2450 sec |
| LES 3D SIM 2 | 502691 | 1896 sec |

Graph of comparison between the time taken for each method to run is shown in Fig. 7.

**Fig. 7: Comparison between the time taken for each method to run**

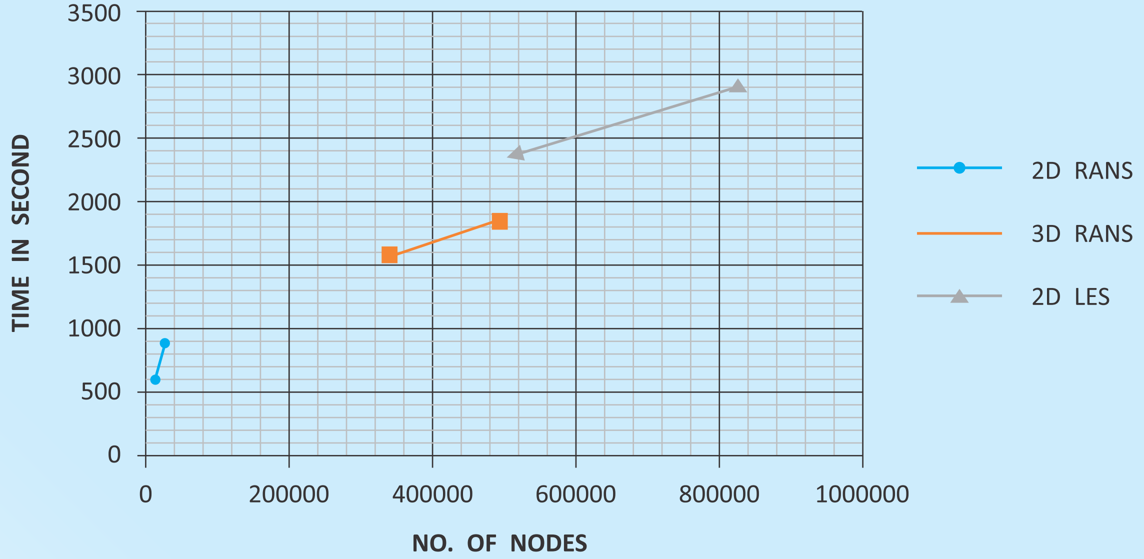


**Table 5: Error % with respect to experimental data**

| Study | Obtained Cd values | Error % w.r.t. Experimental Data from Ref [7] |
|---|---|---|
| RANS 2D SIM 1 | 0.87859 | 10.34796 % |
| RANS 2D SIM 2 | 0.65839 | 32.81735 % |
| RANS 3D SIM 1 | 0.83277 | 15.02347 % |
| RANS 3D SIM 2 | 0.81158 | 17.18571 % |
| LES 3D SIM 1 | 1.0189 | -3.96939 % |
| LES 3D SIM 2 | 0.96367 | 1.666327 % |

Velocity contours for RANS and LES study for RE 3900 is shown in Fig. 8 and Fig. 9 respectively. The LES contours provide a rich insight of the velocity pattern around the cylinder.

**Fig. 8: Velocity distribution around cylinder in RANS for Re=3900**

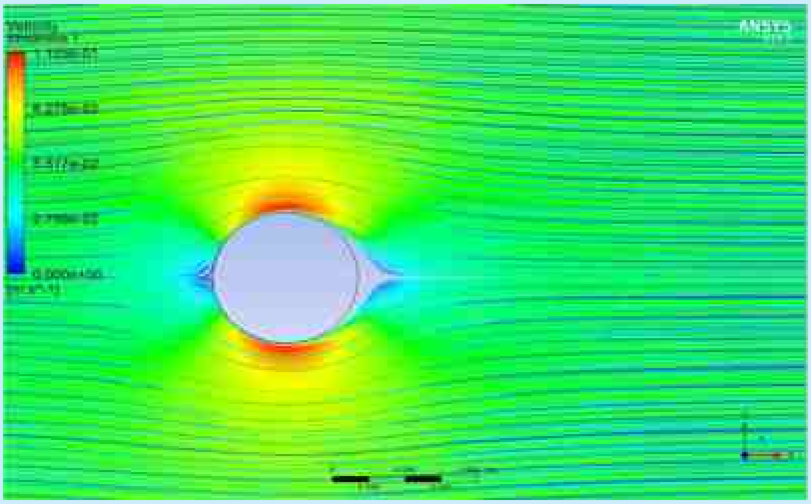
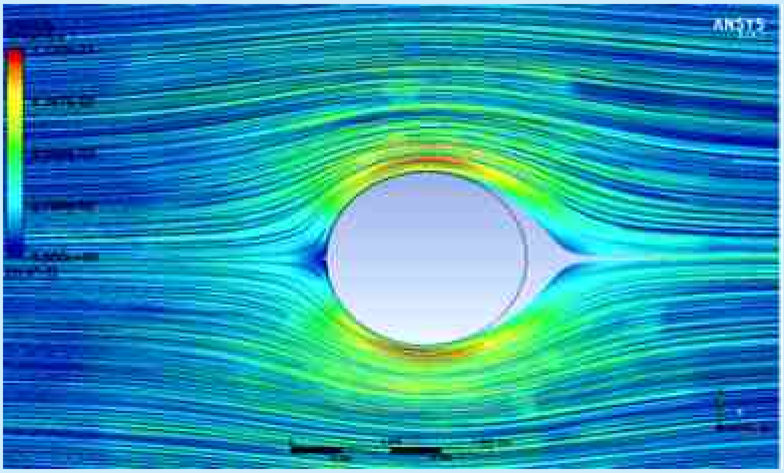
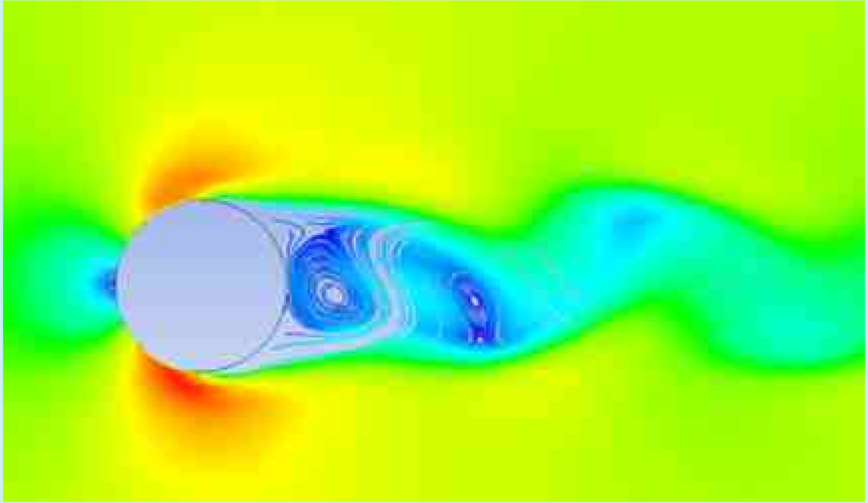


**Fig. 9: Velocity distribution around cylinder in LES for Re=3900**



6.3 Further, the authors took a case with a very high Reynolds number flow to show how LES simulation can give better contours and a good understanding of how fluid would behave around the body profile. This is very beneficial in the case of complex flow conditions (especially marine applications) where visualization of eddies and vortices is important.

**Fig. 10: Velocity distribution around cylinder in LES for Re=10000**



## 7. Conclusion

7.1 Unsteady flow past a cylinder (Re=3900) was computed by large eddy simulation (LES). One-equation SGS model was applied, whose results were validated against experimental data. Results show that the one-equation SGS LES model predicts the force coefficient and the mean stream-wise velocity better than the RANS (k-epsilon) models. For investigation of span wise discretization, it can be seen that if restricted by time and machine condition, medium grid is accurate enough to yield good results. In this study, it has been shown that LES although computationally costly, gives more accurate values for drag coefficient. With the increase in computational capabilities, it is recommended, as found out in the literature review, that LES simulations can be incorporated in design stages for marine applications.

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# INCORPORATION OF WATERTIGHT INTEGRITY TESTING SYSTEMS ON FUTURE INDIAN NAVAL SHIPS DURING DESIGN

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## 1. Introduction

1.1 A ship floats due to the upward buoyant force generated by displacing water equal to its weight, according to the Archimedes' principle. To stay afloat, a ship needs to maintain an adequate amount of watertight volume below its waterline. The watertight integrity of a ship is critical to its ability to float as any compromise in the Water Tight Integrity of the ship can sink, capsize or severely impede the vessel. This watertight integrity onboard IN ships is estimated for watertight sections/ clusters using Air Pressure Tests (APT).

1.2 **Air Pressure Test**. It is the standard procedure carried out onboard Indian Naval ships for assessing watertight integrity of underwater compartments, tanks or clusters of multiple compartments. Ships in the IN are categorized according to their ages. In the newer ships, all the watertight compartments are air pressure tested once in a four year period by ship staff in the presence of a Trials Unit. In the older ships, the periodicity of conduct of Air Pressure test of all the clusters reduces to two years. This test is undertaken by the hull department onboard an IN Ship. Conduct of an Air Pressure Test trial during sailing induces fatigue in the crew due to motions. Therefore the test is attempted in the limited time available at harbour.

## 2. Present Methodology For Evaluating Watertight Integrity

2.1 The procedure followed for Air Pressure Testing of compartments or cluster onboard Indian Naval Ships is as follows:-

(a) **Pressure Test**

(i) A test pressure of 150 mm water gauge is applied and pressure source isolated. The pressure drop, if any, is monitored.

(ii) Any drop in pressure should not exceed 13 mm in 10 mins.

(iii) Where the drop exceeds 13 mm in 10 mins, a search pressure of 0.14 kg/cm sq. is applied to search for leaks.

(iv) The normal test pressure of 150 mm water gauge is then repeated until the pressure drop obtained is below 13 mm WG as above.

(b) **Vacuum Test**

(i) The vacuum test is normally carried out prior to the pressure test for compartments with easy access, i.e doors, and hatches, and not in compartments accessed by bolted manhole covers.

(ii) A test vacuum of 150 mm water gauge is applied and vacuum source isolated. The vacuum level should then be monitored.

(iii) Any drop in vacuum gauge reading should not exceed 13 mm in 10 mins.

(iv) Where the drop exceeds 13 mm in 10 mins, a search vacuum of 610 mm water gauge is applied and defects located using soap water on the outer side.

(v) Post-liquidation of all leaks, the normal test vacuum of 150 mm water gauge is then repeated until the pressure drop obtained is below 13 mm WG as above.

2.2 Ship staff undertakes in-house trials to identify defects, prior to offering compartments to a trials unit. Once the in house trials are successful the trials unit is called onboard for witnessing the test.

**3. Disadvantages of Present Methodology**

3.1 The disadvantages of the present methodology are brought out below:-

(a) Ventilation trunkings of compartments or clusters need to be sealed for a long period prior to and during the Air Pressure Test trials and the final Air Pressure Test.

(b) Watertight Integrity cannot be proved or established prior proceeding to sea.

(c) Manpower extensive i.e. a number of personnel are involved in this evolution.

(d) The department responsible for this task has a manhour deficit of about 2800 Manhours (approx.) on the old IN Ships (including Hull Maintenance Parties and Ventilation Maintenance parties). These tests are a major contributing factor to that deficit.

**4. Proposed Methodology**

4.1 The proposed APT will be undertaken using the ships compressed air system. The system will comprise of ship's compressor, air bottles, reducers, low-pressure air lines, pressure gauges, and remotely controlled flap valves.

4.2 Equipment required for the proposed methodology of Air Pressure Test are:-

(a) **Air Compressor.** An air compressor situated in the machinery space of the ship will be required to charge the air bottles of the APT system.

(b) **Air Bottles.** Air bottles will be required to hold the compressed air and supply compressed air for the APT of compartments/clusters.

(c) **Reducers.** High pressure to low-pressure reducers will be required to reduce the pressure of the air held in air bottles and supply the low-pressure air to compartments/clusters for attaining the requisite pressure in the compartment.

(d) **High-Pressure Air Lines.** High-pressure air lines will be required to supply high-pressure air from the compressor in the engine room/machinery spaces to the air bottles situated above the clusters. The high-pressure lines will also be used to supply the reducers after the air bottles.

(e) **Low-Pressure Air Lines.** Low-pressure air lines will be required to supply low-pressure air from the reducers into the compartments/clusters.

(f) **Pressure Gauges.** Pressure Gauges will be required to monitor the air pressure at the following locations:-

(i) After the compressor.

(ii) Before the Air Bottles.

(iii) After the air bottles and before the reducers.

(iv) After the reducers and before the compartments/clusters.

(v) In the compartment cluster at least two locations

(g) **Relief Valves.** Relief valves will be needed in the following locations:-

(i) At the Reducers

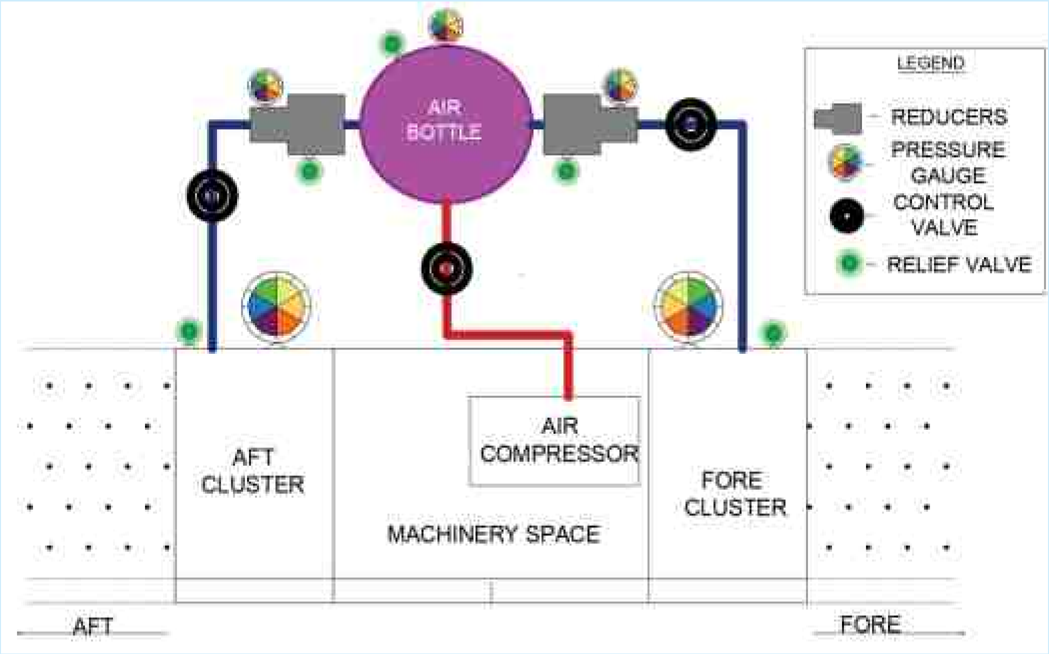
(ii) After the Air Bottles

(iii) At the Air bottles

(iv) Outside the compartments at least two locations.

(h) **Solenoid operated Quick Closing Valves.** These valves will be required to remotely operate all the valves connected in the compartments from a location outside, to ensure a watertight closedown for air pressure testing and effective isolation of flooding in case of flooding.

**SHIP'S LONGITUDINAL SECTION**




**5. Advantages of Proposed Methodology**

5.1 The advantages of the proposed methodology would be:-

(a) **Operational Flexibility.** The watertight integrity of every compartment of a ship can be checked prior sailing. This is a mandatory requirement and this gives a better evaluation of a ship's ability to float prior to proceeding to sea.

(b) **Reduction in required Manhours.** The man-hours required for undertaking the air pressure test of a compartment reduces drastically using the proposed approach.

(c) **Minimum Ventilation Isolation.** The isolation of the compartments from the ships ventilation system is also for a minimum duration.

(d) **Benefits and operational flexibility would outweigh the initial cost.** The initial cost of the system in a ship would be high. However, when compared with respect to the operational flexibilities achieved and the reduction in manhours, the benefits would clearly outweigh the cost.

## 6. Future Advancements

6.1 As advancement to this concept, the whole system of compressed air supply and closure of ventilation openings using Solenoid Operated Quick Closing Valves can be integrated into the Integrated Platform Management System of a ship enabling the command to establish the WT Integrity of a section before sailing or as required. This would only require the hatch of the designated compartment/ cluster to be closed locally for the trial. Such a capability would effectively establish the safety and ability to float to the ship's command.

## 7. Conclusion

7.1 The paper evaluates various factors in the existing methodology for the conduct of air pressure test onboard ships and proposes a viable solution in way of an Integrated Air Pressure Testing System which would mitigate all the drawbacks of the present methodology. The proposed methodology, however, has to be incorporated into the design phases of a ship. This system if incorporated could provide operational flexibility to the command and also would require minimum manhours in undertaking an APT.

## Disclaimer

Contents of the paper are personnel views of the authors and do not reflect the policy or position of the Indian Navy or Government of India.

# POLICY INITIATIVES FOR GROWTH OF INDIAN MERCHANT SHIPBUILDING

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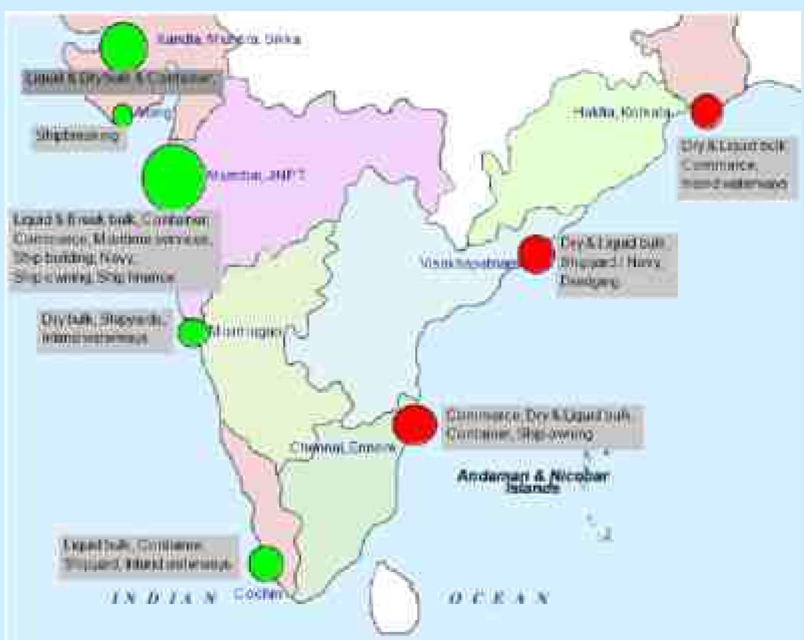
**1. Introduction**

1.1 Nearly 95 per cent of India's foreign trade in terms of volume and more than 65 per cent in terms of value is through sea routes. Currently, about 10 per cent of India's trade is carried by ships with an Indian Flag while the ships manufactured in India carry even less cargo. India's emergence as a major economic power would mean greater integration in terms of trade with the rest of the world, requiring huge shipping tonnage. Activity wise distribution at major Indian ports is represented in Fig. 1. To ensure the safety of our vast coast line, the naval requirement of sophisticated and modern vessels is also growing rapidly. Therefore, shipbuilding is highly important from a civilian as well as defence perspective.

**Fig. 1: Activity wise distribution at major Indian ports**




(Source: Srinjoy Dasgupta, Chief Engineer (Mercantile Marine); EPGP, IIM Indore)

1.2 After a brief introduction on Indian shipbuilding industry, the paper describes various objectives to be achieved through these industries. Achievement of these objectives is based on the goals set by the shipbuilding industry. This in turn is a function of the challenges encountered by this industry. In order to overcome these challenges and enhance the growth and efficiency of shipbuilding in India, various initiatives/ policy changes, both by the government and by the industry itself are required to be implemented. A few of them are described at later (para 6) in this paper. Finally, the paper draws out its conclusion that Indian shipbuilding industry has immense potential which needs to be tapped.

With the increase in maritime trade, there will be a growing requirement to build more number of warships in tandem with merchant ships so that safety and security of maritime trade is ensured.

**2. Shipbuilding Industry**

2.1 Shipbuilding essentially involves the assembly, construction and modification of ships in a specialized facility known as shipyards. These shipyards build ships for commercial as well as for defence purposes. The shipbuilding industry has two main sub-sectors: shipbuilding and ship repair. The shipbuilding industry is a significant consumer of raw material and generates substantial employment opportunities. It relies heavily on supplies from key elements of industrial infrastructure such as steel, forging and casting, marine machinery, machine tools, construction equipment's, control gears, etc. The supply industry / ancillaries to the shipyards are extremely important in the whole value chain, and with technological advances, their role has increased significantly. The development of the shipbuilding industry typically has a positive multiplier effect on the economy by triggering growth in other manufacturing / services sectors. Other countries such as Japan, South Korea and China have all focused on a strong and vibrant shipbuilding industry. Vietnam, Turkey and Malaysia are in the process of building strong capabilities as well.

2.2 With the opening of the Indian economy to globalization, there has been a sound increase in handling of cargo traffic at Indian Ports. India's share in global exports has increased from 0.7 per cent in 2000 to 1.7 per cent in 2015 (Source: WTO). At the time of independence, there were about a dozen shipyards around Kolkata and Mumbai which rose to around 45 shipyards in the late seventies. At present, there are 31 shipyards, out of which 8 shipyards are in the public sector and the rest are in the private sector. The demand for ships, semi-submersibles and port auxiliary vessels viz. new shipbuilding activities as well as ship-repair activities is projected to grow in view of rising cargo traffic from/ to India in the coming years. The government has also announced "Manufacturing Plan - Strategies for Accelerating Growth of manufacturing in India in the 12th Five-year Plan and beyond". The erstwhile planning commission lists "Shipbuilding and Ship Repair" as one of the key sectors of strategic importance. There are 34 dry docks for repairing ships in India both in public and private sector as per data recorded. These dry docks include the 12 dry docks operated by 08 major ports. The major ports which have no dry dock facilities are JNPT, New Mangalore, Chennai, Ennore, and Haldia Dock Complex of Kolkata Port.

**3. Shipbuilding Subsidy Scheme**

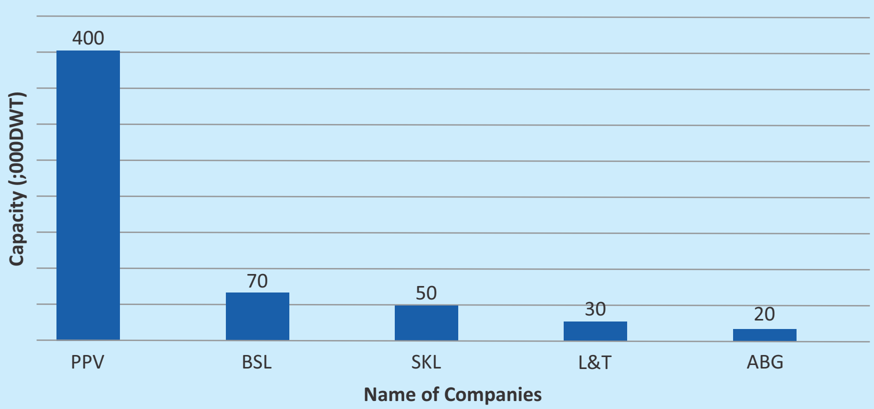
3.1 The Indian government has publicized a Rupees 4000 crores Shipbuilding Financial Support Policy for ten years to encourage local shipbuilding. Financial support will be provided to Indian Shipyards equal to 20 per cent of the lower of "Contract Price" or the "Fair Price" of the individual ship built by them for a span of at most 10 years launching from 2016-17. This rate of 20 per cent will be reduced by 3 per cent once a year for three years. The quantum of financial benefit of a vessel will be the product of the appropriate rate of financial benefit prevailing on the date of contract and the least contract price or the fair price when changed into Indian Rupees. Provided that, at the time of the release of financial benefit, if the actual payment received for a vessel is lesser than the contract price, such payment will restore the contract price in the formulae for estimation of the financial assistance. In the beginning, the Indian government had unfolded shipbuilding subsidy scheme for all shipyards of India on the 25th October 2002. The scheme concluded on the 14th August 2007. The government decided in March 2009 to make a disbursement for shipbuilding subsidy for shipbuilding agreement signed up to 14th August 2007 for which budgetary readiness was made up to 31st March 2014. Among the 228 shipbuilding contracts signed in the course of 2002-2007, subsidy amounting to Rs. 1142 crore has been paid out for a building of 121 ships. A new shipbuilding financial benefit policy has been publicized for orders secured during April 1, 2016 to March 31, 2026. The subsidy was focused at pitching the distortions of the domestic economic environment which impact native shipbuilders adversely over and above aiming the impact of indirect and also direct promotion provided to the shipyards in overseas.

**Table 1: Shipbuilding - Total subsidy disbursed in term of Public Vs Private sector in India (Rupees in crore)**

| Year | Public Shipyards | Private Shipyards | Total |
|---|---|---|---|
| 2002-03 | 25.36 | Nil | 25.36 |
| 2003-04 | 10 | Nil | 10 |
| 2004-05 | 15 | Nil | 15 |
| 2005-06 | 101.53 | Nil | 101.53 |
| 2006-07 | 110.52 | Nil | 110.52 |
| 2007-08 | 169.96 | 19.28 | 189.24 |
| 2008-09 | 131.71 | Nil | 131.71 |
| 2009-10 | 107.4 | 71.8 | 179.2 |
| 2010-11 | 70.91 | 128.19 | 19.1 |
| 2011-12 | 5.77 | 116.65 | 122.42 |
| 2012-13 | Nil | 220 | 220 |
| 2013-14 | Nil | 179 | 179 |
| 2014-15 | Nil | Nil | Nil |
| 2015-16 | Nil | Nil | Nil |

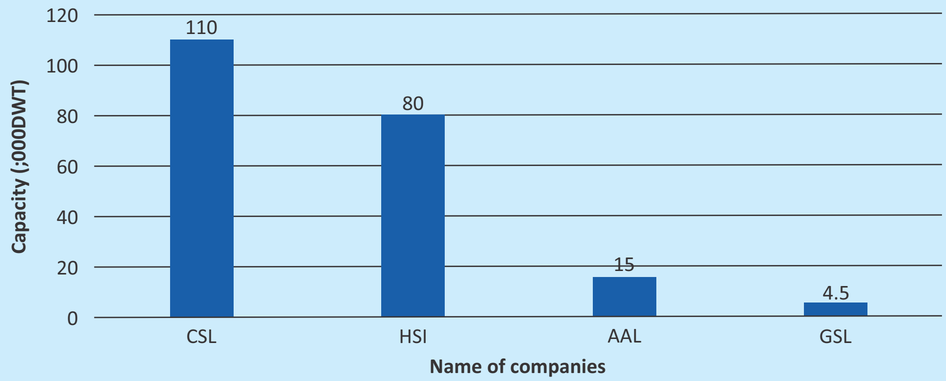
(Source: International Journal of Civil Engineering and Technology (IJCIET)

**Fig. 2: Current Shipbuilding Capacity of Private Sector in India**




(Source: International Journal of Civil Engineering and Technology (IJCIET))

Fig 3: Current shipbuilding capacity of Public Sector in India




(Source: International Journal of Civil Engineering and Technology (IJCIET))

**4. Objectives to be achieved**

4.1 The main objectives to be achieved in the shipbuilding industry is based on the goals set by them in medium and long range aspects of vision which will enable them to build a concrete plan of action. Few of them as set by the Planning Commission of India are:

(a) To achieve 5 per cent share of the global shipbuilding market by 2020.

(b) To be self-sufficient in ship repair requirements of the country and to emerge as a dominant ship repair centre displacing Colombo, Dubai, Singapore and Bahrain.

(c) To achieve a share of 10 per cent by 2020 in the global ship repair industry.

(d) To develop a strong ancillary base for shipbuilding/ ship repair in the country by 2020.

(e) To generate additional employment for 2.5 million persons (0.5 million direct and 2.0 million indirect) by 2020 in the core shipbuilding as well as the ancillary and supporting industry sector.

(f) To develop strong R&D facilities and design capabilities for commercial shipbuilding.

**5. Challenges**

5.1 The major key challenges pertaining to the industry and as well as the current status of the projects as follows:

(a) The average annual deliveries over the period of 2010 to 2020 are expected to be in the range of 80-100 million DWT. Hence, Indian shipbuilders would have to achieve delivery capacity of approx. 4-5 million DWT by 2020 in order to achieve the 5 per cent market share by 2020. As against this, the current deliveries of the Indian shipyards stand at 0.25 million DWT.

(b) The ship repair industry worldwide is estimated to be around USD 12 billion (approx. Rs 55,000 crores) but currently India has less than 1-2 per cent share with revenue of approx. USD 170 million in 2009-10 (Rs 734 cr.)

(c) India is currently heavily dependent on import of critical ancillaries for its shipbuilding sector. On an average 65 per cent of the value of the ship is derived from ancillaries, of which Indian shipyards import almost two thirds.

(d) In 2010, Indian shipyards employed approx. 31,800 people with an employment multiplier of over 6.

(e) When it comes to do business in India, one must be ready to entertain a complex set of levies and duties. Shipbuilding industry is not an exception till date. It attracts a complex set of levies and duties. The differential rate of duties and taxes between India and other nations leads to additional cost burden for Indian shipyards.

(f) Octroi, CST, VAT, excise, service tax and corporate tax are some of the levies applicable to shipyards. Several shipbuilding nations have relaxed these levies to encourage shipyards. For example, China refunds VAT completely on domestic sale of ships whereas in India VAT is refunded only on inputs.

(g) Shipyards are required to provide bank guarantees to protect the ship buyer. These guarantees include performance guarantee (for timely delivery), refund guarantee (for stage payments) and post-construction guarantee (towards defects). In China, the government provides sovereign refund guarantees for certain class of vessels, thus removing any related burden on the shipyard. In Korea, shipyard financing has matured and the evolved mechanisms drive the cost lower. However, in India, financial institutions do not have a focus on the shipbuilding sector and there is no support from the Government to reduce the charges as in the case of Korea. As a result, the cost of bank guarantees in India is higher than competing countries.

(h) A typical shipyard requires a working capital of around 25-35 per cent of the cost of the ship during the entire production period. The interest rate on the working capital in India averages 10.5 per cent. On the other hand, the interest rates presently offered to shipbuilding yards overseas are considerably lower at around 5-6 per cent in Korea and around 4-8 per cent lower in China.

(j) India currently lacks design capabilities and most of the concept designs are being sourced from a pool of global designs. Many Indian shipyards have set up their small design centres and some independent design centres have also been established, but broadly, the country is purchasing conceptual design from foreign firms and doing detailed engineering within the country. Another major challenge to the growth of shipbuilding industry is lack of proper professional education and research and development facilities in the country. The growth of Indian Register of Shipping has not been as it should have been and it is yet to receive the status of a full member of IACS. The other Research and Development laboratories, such as, NIO, NIOT, NSTL, NPOL, which are not under Ministry of Shipping are doing all right.

## 6. Way Ahead

6.1 In order to meet the above requirements, the following strategies may be put into use as a part of a trial basis and check the feasibility study whether the suggested measures can be applied practically to the industry in order to find the corrective measures to enhance the strategies of the building capability of the ships. Some of them are as follows:

(a) A policy statement in clear terms should be pronounced conveying the commitment of the government to undertake various priority measures in the sector.

(b) In 2002, the government introduced a Shipbuilding Subsidy Scheme that provided 30 per cent subsidy applicable to ocean going vessels, for shipyards both in public and private sector. The scheme came to end after five years in August, 2007. Some form of adequate financial/ fiscal incentive would need to be considered in order to facilitate the industries to achieve critical mass.

(c) Infrastructure status to shipbuilding: Granting infrastructure status would assist the indigenous shipbuilding industry to utilize the tax benefits available to the infrastructure sector and also avail credit at comparatively lower rates for investment in the technological development, infrastructural facilities and modernization.

(d) Purchase preference for Indian built, Indian flagged vessels and Indian shipyards in government/ Defence purchase: Globally, countries have aggressively promoted the use of locally build vessels by local shipping companies. NMCC has also recommended facilitating greater carriage of Indian trade by Indian built ships, and consequently developing domestic shipbuilding capabilities.

(e) Offset scheme for government procurement: The ancillary industry in India is neither developed nor matured as compared to other shipbuilding markets in the world primarily because of low volumes of the Indian shipbuilding industry. This has, in turn, severely impacted the cost structure of home-grown companies, rendering them un-competitive in international markets. It should be mandated that during the purchase of any ship from a foreign yard, the foreign yard would have to source a certain amount of marine engineering goods from India. This can create a steady stream of orders for domestic marine engineering companies and help develop capabilities in the sector.

(f) The offset policy in defence sector should insist on systems and sub-systems as units for consideration for meeting offset requirements. Defence procurement from foreign suppliers should be conditional on greater domestic manufacturing content as well as on technology transfer.

(g) Need for State Maritime Policies: In order for the efforts to boost Indian shipbuilding to be successful, the industry needs to get adequate support from the maritime states of the country. It is the states that would have to help implement these policies to support and develop the industry. In this context, development of state maritime policies and state maritime boards is extremely important. Gujarat Maritime Board (GMB) has recently come up with its own shipbuilding policy. The policy is aimed to develop Marine Shipbuilding Parks (MSP) and clusters to create ancillary base for the industry and help reduce costs to the shipbuilders by sharing costs such as common infrastructure, logistics etc. Other states should also be encouraged to have similar enabling policies so as to help develop shipbuilding industry. Such policies would provide clear directions to the shipbuilding industry and confirm the commitment of State governments on long-term basis.

(h) To examine the issue of incidence of taxes that disadvantages the domestic industry.

(j) A renewed thrust is required to develop education and training facilities, and R&D infrastructure. This would also include promoting applied R&D to facilitate the development of basic design as well as standardization to encourage series production. For this purpose, the government's financial support would be required.

(k) An efficient intermodal system is vital to the success of a port as it supports the seamless movement of cargo across all modes - ship, rail, and truck. In fact, a government report says that due to poor port infrastructure and productivity, India's trans-shipment cargo is handled at South Asian hubs like Colombo or Singapore, which costs Indian ports around USD 230 million in revenue annually.

(l) The 'Make in India' initiative offers tremendous opportunities in the maritime sector, particularly in the shipbuilding and ship repair industry. The government's shipbuilding policy provides a boost by encouraging Indian shipyards to bag foreign orders in a more aggressive manner and meet the requirements of Indian ship-owners. A cost-effective and skilled manpower base, established steel industry, technology know-how and an increased demand in domestic shipbuilding could enhance India's global shipbuilding share from one per cent to five per cent by 2020. The Indian Navy too is giving a strong push to the Make in India initiative as it strives for self-reliance in the production of warships. Other Indian shipyards have developed investment plans and accessed capital markets to play an increasing role under the Make in India programme.

(m) The Indian maritime sector needs to be constantly on the lookout for technologies and advancements that help save cost and deliver more for less. A major way could be through partnerships and collaborations with successful maritime clusters especially in areas of ship design, automation, and technology. Such collaborations can improve efficiency and enhance competitiveness. Also in view of the regulations to control emissions from ships set by the International Maritime Organization, there will be a growing need to collaborate for environment-friendly technology & solutions, such as LNG powered vessels. The other key area that could benefit from partnerships and technological assistance of maritime countries will be training & development of manpower to bring the frontline workforce up to speed on world-class manufacturing techniques and processes. The academia can also look at establishing university partnerships to encourage innovation, knowledge sharing, and transfer.

(n) In order to avoid telescopic approach, adopting a Joint Venture method i.e. "multi shipyard-modular block build strategy" which will help in resolving the constraints of the infrastructure of the shipyard. This will enable to have a good partnership between public and private sector companies and creates competitiveness in the field. A consortium approach can be exercised at a multi -national level by Indian shipbuilding industry by signing a memorandum of Understanding(MOU) with different foreign companies like Northrop Grumman (USA), Hyundai Heavy Industries (South Korea), Rosboron Export (Russia) etc. which will enable the public and private sector shipyards to have a transfer of knowledge on manufacturing practices, augmentation of infrastructure facilities & designing capabilities that can further lead to significant changes to the existing policies on shipbuilding industry and pivot way for the contribution in shipbuilding.

## 7. Conclusion - A promising future

7.1 Given the present scenario, India appears to be among the major economies in the world. India will require a vibrant and strong maritime industry for economic and strategic reasons. There are many factors conducive to the development of a robust and sustainable maritime sector. It can be convincingly concluded that India is on the cusp of major maritime revolution which will play out over the next couple of years. This growth in maritime environment would, in parallel require similar all round development and growth of warship building to safeguard our interests in the maritime trade zones and routes. This hand in hand development would ensure and fulfil our maritime vision and objectives.

## 8. References

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[2] Ministry of Shipping, Government of India *www.shipping.nic.in*

[3] Indian Ports Association, *http://ipa.nic.in*

[4] Special Economic Zones in India, Government of India, *http://sezindia.nic.in*

[5] Directorate General of Shipping, *http://www.dgshipping.com*

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# A SCIENTIFIC APPROACH TO LAYOUT DESIGN – THE CASE OF SHIP'S GALLEY

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**1. Abstract**

1.1 It is common knowledge that ergonomic consideration in layout design increases not only efficiency but also adds to the overall safety. However, implementing this knowledge in layout design of a warship has never been a priority for a naval architect who has other core issues like strength, stability, speed, survivability, stealth, and fire power as his primary concern. Considering the near continuous use of a galley onboard warships, the presence of heat generating equipment, as also fire prone material (such as oil, cloth rags, etc.) and the typical nature of the Indian cuisine, makes galleys one of the most hazardous compartment onboard a warship. Added to this is the risk posed by a constant man-machine interface in a highly constrained and harsh working condition (heat, smoke, etc.). This necessitates the galley to be one of the most ergonomically designed compartments, especially, as this has a direct influence on the vessels safety.

1.2 In this study, exploratory research framework, which is characterized by flexibility and versatility with respect to the methods employed, is adopted. To begin with, secondary data which includes literature survey, open domain internet based, national as well as international standards, and internal policy directives were collected and analysed. Based on the understanding of the problem, a multi directional approach for collecting primary data was employed. Accordingly, focus group discussion, in depth interview, questionnaire based survey, photography and videography were employed to collect data from eight related organizations spanning over 90 professionals, 1500 photographs and over 120 minutes of video. These data were than systematically analysed using layout planning tools like relationship chart, flow analysis, link analysis, task analysis and NASA TLX workload estimation. A typical galley layout which provides an efficient and safe work environment is developed and various recommendations are proposed.

**2. Keywords**-Data collection technique, layout planning, link analysis, task analysis.

**3. Introduction**

3.1 Any successful design which eventually emerges as a design trend necessarily emanates from a need. Recognizing this need of a user is the primary condition for any successful design. This design should solve a problem that the user is facing, which implies that the product should be useful to the user. User feedbacks received in the form of DFRs and various Flag Officer Sea-training (FOST) observations, when systematically analysed indicate deficiencies with respect to ergonomics (human factor) and many were related to layout planning and design. While it is no denying the fact that layout design not only increases efficiency but also adds to the overall safety, however implementing this knowledge in layout design of a warship has never been a priority for a naval architect who has other core issues like strength, stability, speed, survivability, stealth, and fire power as his primary concern. Layout design requirements can be primarily categorized into either functional in nature or statutory (regulatory as indicated in standards and regulations). To arrive at a most optimal layout design which takes into consideration all these aspects, design constraints, both functional and statutory has to be systematically analysed.

3.2 The demand for providing quality and hygienic food on a near continuous basis in limited time coupled with space constraint and harsh working environment (heat, smoke, etc.) makes the ship's galley one of the most difficult places to work onboard. Further, presence of a wide range of heat generating equipment and various fire prone material (such as oil, ghee, etc.), also makes galley one of the most hazardous compartment. In addition, being positioned lowest in the organizational ladder, the users of the galley (chefs and stewards) are ill equipped for and hence not involved in any form of decision making w.r.t the ship's galley equipment selection and its layout. In view of the influence that a galley design can have on the working efficiency of the ship's crew, it was considered appropriate to undertake a comprehensive study which has scientific rigor by obtaining credible and actionable data from wide range of sources, both within the Navy and from similar industries like the railways, airlines and various Indian and foreign OEMs. In this paper we broadly discuss the approach to layout design which includes data collection and analysis. Simultaneously we apply this concept in the layout design of a ship's galley.

## 4. Research Methodology and Data Collection Technique

4.1 The framework for conducting the study was to carry out Exploratory Studies. The objective of exploratory research is to explore or search through a problem or situation to provide insights and understanding. Exploratory research is characterized by flexibility and versatility with respect to the methods because formal research protocols and procedures are not employed. Rather, it enables generation of new ideas and insights as they proceed. Once a new idea or insight is discovered, the direction of the study can be reoriented. This new direction is pursued until its possibilities are exhausted or another direction is found. For this reason, the focus of the investigation may shift constantly as new insights are discovered.

4.2 In the present case, to begin with, secondary data (literature survey, open domain internet based, you-tube video) were collected and analysed first. Based on the understanding of the problem, a broad plan was made to arrive at a consensus for collecting primary data. After evaluating various options for collecting primary data, it was concluded that for a better design solution, a combination of primary data collection technique would have to be used. Accordingly, a focus group discussion, in-depth interview, questionnaire-based survey, photography and videography were considered. Each technique of collecting data is discussed in the subsequent paragraphs.

## 5. Focus group

5.1 A focus group[1] is an interview conducted by a moderator in a non-structured and natural manner with a small group of respondents. The moderator leads the discussion. The main purpose of focus groups is to gain insights by listening to a group of people from the relevant domain about issues of interest to the investigator. The value of the technique lies in the unexpected findings often obtained from a free-flowing group discussion. Focus groups are the most important qualitative research procedure. They are so popular that many marketing research practitioners in the private industry consider this technique synonymous with qualitative research. Focus group discussion was conducted with cooks and stewards at INS Hamla and onboard frontline warships where the respondents were more than 15.

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[1] *Carter Mcnamara, "Basics of Conducting Focus Groups," www.managementhelp.org/evaluatn/focusgrp.htm; Richard A. Krueger and Mary Anne Casey, Focus Groups: A Practical Guide for Applied Research, 3rd ed. (Thousand Oaks, CA: Sage Publications, 2000).*

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### 6. In-depth Interview

6.1 In-depth interview[2] is another method of obtaining qualitative data. An in-depth interview is an unstructured, direct, personal interview in which a single respondent is probed by a skilled interviewer to uncover underlying motivations, issues, attitudes, and feelings on a topic. As a part of the in-depth interview, Officer-in-charge catering school, mess secretaries of Officers Mess, Officers Institute, and Commanding Officers of various warships were interviewed. The chief chef of IRCTC Maharaja Express also provided valuable inputs.

### 7. Survey based Questionnaires

7.1 The survey method of obtaining information is based on questioning[3] relevant respondents. Respondents were asked a variety of questions regarding issues related to the galley and their design. Gathering information directly and in a standardized form from cooks and stewards through the use of structured questionnaires, in which the questions are the same for all the interviewees, renders it possible to make inferences regarding the population as a whole. The questionnaire which contained approximately 20 questions were distributed among 60 cooks and stewards selected through non-probability, convenience sampling techniques from various naval warships.

### 8. Activity sampling

8.1 Activity sampling is a method of data collection which provides information about the proportion of time that is spent on different activities. The method was originally developed for use by work study practitioners,[4] to help them determine exactly how time was utilized during industrial tasks. The intention of activity sampling is to produce a measure of what proportion of time is spent performing each of several identified activities. Subsequently, such data can be used as the basis of efforts to reduce unnecessary tasks, or to understand which task elements constitute the greatest proportion of the workload. In order to design an activity sampling exercise effectively, there are four issues which must be considered, namely the classification of activities, the development of a sampling schedule, information collection and recording, and the actual analysis of activity samples.

### 9. Photography and videography

9.1 The media used for design can be divided in two categories, visual and verbal. The role of visual reasoning in the thinking process was clarified by Ferguson.[5] He proposed that much of the creative thought of the designers of the technological world is nonverbal, not easily reducible to words; its language is an object or a picture or a visual image in the mind. Design tools, for example, sketch; drawing, photograph and video are some of the effective tools for visual reasoning and are widely used in creating technological artefacts. Accordingly, a large number of videos and photographs were taken from galleys of different ships in order to uncover the nonverbal information. This assisted in developing understanding about the various constrains and onsite problems faced by the galley staff due to inadequacies in either the design itself or during the process of equipment selection and their integration as a system at the construction stage.

9.2 Large amounts of data, both quantitative and qualitative, were collected from eight related organizations spanning over 90 professionals, 1500 photographs and over 120 min of video using

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[2] *David Stokes and Richard Bergin, "Methodology or 'Methodolatry': An Evaluation of Focus Groups and Depth Interviews," Qualitative Market Research: An International Journal, 9(1) (2006): 26–37;*

[3] *Powell, E. T., & Hermann, C. (2000). Collecting evaluation data. Retrieved August 18, 2009, from http://learningstore.uwex.edu/pdf/G3658-10.pdf*

[4] *Christensen, J.M. (1950) The Sampling Technique for use in Activity Analysis. Personnel Psychol., 3, 361–368.*

[5] *Ferguson, Eugene S. "The mind's eye: Nonverbal thought in technology (http://cgt101.tech.purdue.edu/info/art01_Ferguson_1977.pdf) ". Science 197.4306(1977):827*

various techniques discussed above. While quantitative data has been analysed using certain statistical techniques to arrive at the final findings, qualitative data analysis[6] uses words as the units of analysis and is guided by fewer universal rules and standard procedures. The goal in qualitative research is to decipher, examine, and interpret meaningful patterns or themes that emerge out of the data. The key findings and recommendations arrived at through systematic layout planning and design, were utilized to arrive at an ideal galley layout design solution. In the next section we look at the framework used for a layout design.

**10. Layout Design**

10.1 Systematic Layout Planning[7] facilitates layout design and planning. It provides a framework of procedures, and a set of conventions for identifying, rating, and visualizing the elements involved in planning a layout. Layout design philosophies are task (collection of activities) based. In the specific case of a galley layout, the task and hence the activities, is driven by the menu. The lunch/ dinner menus onboard different ships were analysed and over 250 different types of activities, which are involved, were identified. These activities form the core of galley design, right from equipment selection to layout design. Central to any layout design philosophy is using the most appropriate techniques to find optimal solution to six key questions. Techniques which have been extensively used to analyse data gathered from different sources and the associated questions which are being answered are listed below.

(a) Location strategy - Where should the ship's galley be located?

(b) Space allocation strategy - How much space is required for the galley?

(c) Relationship matrix - Which interdependent space should be located where?

(d) Flow analysis - How well are these interdependent spaces connected?

(e) Task analysis[8] - What equipment do I require in the galley?

(f) Link analysis[9] - Where to locate various equipment inside the galley?

**11. Location Strategy**

11.1 Def. Stan. 08-144 indicates that a galley should be located within the citadel, preferably aft of midship. It should be efficiently grouped, preferably, at the same deck level as an integrated complex such that the galley, the dining halls and the wardrooms are easily accessible from the accommodation areas. Ease of flow of stores from various provision stores to galley is vital and hence these should be either on the same deck or in the same vertical plane (WTB) and served by a 'Vertiflo' or connecting lift. Further, where it is impracticable to locate a servery/ pantry and the galley on the same deck, a food lift above/ below the galley must be provided. Officers' galley/ pantry should be located away from the ships galley in a different WTB and should be designed to serve as an Emergency Feeding Station. Galley boundaries should preferably be integrated with the ships primary bulkhead. Galley and all stores must be made gas tight to make it a vermin proof boundary.

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[6] *Naresh K. Malhotra, Marketing Research- An Applied Orientation Sixth Edition, Georgia Institute of Technology, Pearson Education, Inc., publishing as Prentice Hall, 2010*

[7] *R Muther & L Hales, Systematic Layout Planning, 4th Edition, Mir Publications, USA*

[8] *B.Kirwan and L.K.Ainsworth, A Guide To Task Analysis, (Synergy) UK Taylor & Francis Ltd*

[9] *Chapanis, A. (1959) Research Techniques in Human Engineering, Baltimore: Johns Hopkins.*

## 12. Space allocation strategy

12.1 Six key factors dictate the amount of space required for a galley and these are:

- Strength of the ships company
- Activity analysis of chefs
- Number of dishes per meal
- Ready use storage requirement
- No. of chefs at a given point of time
- How each group of crew to be served

12.2 Representing mathematically the above space constraint, the area required for a galley can be calculated as:

$$Total\ area = \sum_{n=1}^{number\ of\ equipment} (width_n\, depth_n) + \sum_{m=1}^{number\ of\ racks} (width_m\, depth_m) + \sum_{u=1}^{number\ of\ work\ table} (width_u\, depth_u) + \sum_{v=1}^{number\ of\ activity} \frac{(width_v\, depth_v)_{*m}}{v} + m(occupancy) + access + wastage$$

The above expression can be easily converted into an excel sheet and for a crew of approximately 250, it is seen that approximately 58 m2 area is ideally required for a galley. This space allocation duly considers the following aspects:

**Fig. 1: Space allocation calculation**

| CALCULATION OF AREA FOR SHIPS GALLEY | | | | | | | |
|---|---|---|---|---|---|---|---|
| EQUIPMENT/FIXTURES/AREAS | area (sq m) | Quantity | Total area | Priority | Total 1 | Total (1+2) | Total (1+2+3) |
| Potato peeling machine | 0.308 | 1 | 0.308 | 1 | 0.308 | 0.308 | 0.308 |
| Dough kneading machine | 0.56 | 2 | 1.52 | 1 | 1.52 | 1.52 | 1.52 |
| Pulverizer | 0.675 | 1 | 0.675 | 1 | 0.675 | 0.675 | 0.675 |
| Wet grinder | 0.4971 | 1 | 0.4971 | 2 | 0 | 0.4971 | 0.4971 |
| Veg cutting machine | 0.18 | 1 | 0.18 | 2 | 0 | 0.18 | 0.18 |
| Meat cutting machine | 0.15 | 1 | 0.15 | 2 | 0 | 0.15 | 0.15 |
| Onion/potato slicing machine | 0.42 | 1 | 0.42 | 3 | 0 | 0 | 0.42 |
| Food processor | 0.38 | 1 | 0.38 | 3 | 0 | 0 | 0.38 |
| Vegetable mincing machine | 0.3777 | 1 | 0.3777 | 3 | 0 | 0 | 0.3777 |
| Vegetable wheel grinder | 0.3777 | 1 | 0.3777 | 3 | 0 | 0 | 0.3777 |
| Masala grinder | 0.48 | 1 | 0.48 | 2 | 0 | 0.48 | 0.48 |
| Combi steamer | 0.645 | 1 | 0.645 | 1 | 0.645 | 0.645 | 0.645 |
| Conventional oven | 0.645 | 1 | 0.645 | 2 | 0 | 0.645 | 0.645 |
| Microwave oven | 0.1837 | 1 | 0.1837 | 2 | 0 | 0.1837 | 0.1837 |
| Dosa making machine | 1.1214 | 1 | 1.1214 | 3 | 0 | 0 | 1.1214 |
| Chapati making machine | 1.11 | 1 | 1.11 | 3 | 0 | 0 | 1.11 |
| Deep fat fryer | 0.405 | 1 | 0.405 | 3 | 0 | 0 | 0.405 |
| Cooking range | 0.8265 | 3 | 2.4795 | 1 | 2.4795 | 2.4795 | 2.4795 |
| Tilting pan | 0.64 | 2 | 1.28 | 1 | 1.28 | 1.28 | 1.28 |
| Rice boiler | 0.81 | 1 | 0.81 | 2 | 0 | 0.81 | 0.81 |
| Water boiler | 0.15 | 1 | 0.15 | 1 | 0.15 | 0.15 | 0.15 |
| Locker | 0.04 | 1 | 0.04 | 2 | 0 | 0.04 | 0.04 |
| Work table | 1.4 | 1 | 1.4 | 1 | 1.4 | 1.4 | 1.4 |
| Hand rack | 1.45 | 1 | 1.45 | 1 | 1.45 | 1.45 | 1.45 |
| Waste basket | 0.175 | 2 | 0.35 | 1 | 0.35 | 0.35 | 0.35 |
| Garbage disposal | 0.45 | 1 | 0.45 | 1 | 0.45 | 0.45 | 0.45 |
| Sink/Wash place for vegetables | 2.1 | 1 | 2.1 | 1 | 1.8 | 2.1 | 2.1 |
| Sink/Wash place for utensils | 0.98 | 1 | 0.98 | 1 | 0.98 | 0.98 | 0.98 |
| [illegible] | 0.21 | 1 | 0.21 | 2 | 0 | 0.21 | 0.21 |
| [illegible] | 0.64 | 3 | 1.92 | 1 | 1.92 | 1.92 | 1.92 |
| Vegetable chiller | 0.42 | 1 | 0.42 | 3 | 0 | 0 | 0.42 |
| Cooked food [illegible] | 0.377 | 2 | 0.754 | 1 | 0.377 | 0.754 | 0.754 |
| Local Control box with MCB | 0.1625 | 1 | 0.1625 | 1 | 0.1625 | 0.1625 | 0.1625 |
| EP Fixed Switch key | 0.12 | 4 | 0.48 | 1 | 0.48 | 0.48 | 0.48 |
| E/T Rat repellent | 0.014625 | 4 | 0.0585 | 1 | 0.0585 | 0.0585 | 0.0585 |
| Area required for cook | 2.5 | 5 | 12.5 | 1 | 12.5 | 12.5 | 12.5 |
| Dry storage | 2.88 | 1 | 2.88 | 1 | 2.88 | 2.88 | 2.88 |
| Fresh storage | 1.88 | 1 | 1.88 | 1 | 1.88 | 1.88 | 1.88 |
| [illegible] | 5% | 1 | 5% | 1 | [illegible] | [illegible] | [illegible] |
| Occupancy | 0.5 | 4 | 2 | 1 | 2 | 2 | 2 |
| Access | 30% | 1 | 30% | 1 | [illegible] | [illegible] | [illegible] |
| Work space/activity | 2.5 | 1 | 2.5 | 1 | 2.5 | 2.5 | 2.5 |
| Wastage | 10% | 1 | 10% | 1 | [illegible] | [illegible] | [illegible] |
| Total minimum area | | | | | [illegible] | [illegible] | [illegible] |

(a) Certain galley equipment has higher priority.

(b) Veg and non-veg area are demarcated clearly.

(c) The requirement of Ready Use storage considered is typically what is used on a frigate.

(d) The compartment form factor and nature of compartment outfitting influences net volume available.

## 13. Relationship Matrix

13.1 A relationship matrix shows which activities have a relationship with others. It rates the importance of closeness between them and supports the rating with coded back-up reasons. It can be algorithm or relationship chart based. These measures make the relationship chart one of the most highly practical and effective tools for layout planning. If n is the number of spaces being evaluated, n (n+1)/2 number of relationship can be evaluated, which would be near impossible otherwise. The procedure for relationship analysis would involve identifying spaces, list the spaces on a relationship chart, determine the desired relationship for each pair of space as per level of closeness, list out reason(s) therefore, analyse the filled chart and get approval. In the case of a ship's galley, as shown in Fig. 2, 15 spaces are interlinked and accordingly using the relationship chart (15*16/2 =) 120 relationships were evaluated. This is an excellent tool when large number of space is to be located and there are far too many conflicting relationship requirements. For the complete ship where the number of compartments can exceed 450, an algorithm can be used to develop the relationship matrix.

**Fig. 2 : Relationship matrix**

| Val. | Closeness | Colour | No of Rating |
|---|---|---|---|
| A | Absolute Necessary | Red | |
| E | Especially important | Yellow | |
| I | Important | Green | |
| O | Ordinary | Blue | |
| U | Unimportant | Black | |
| X | Not desirable | Brown | |

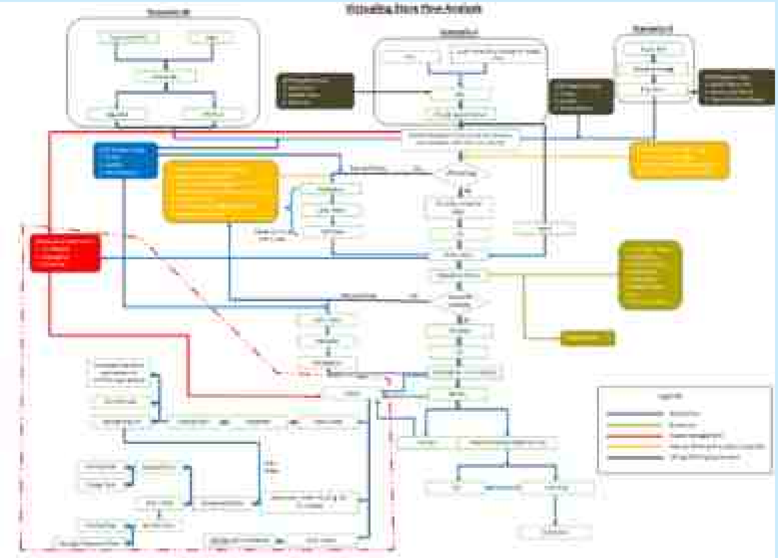
| Code | Reason |
|---|---|
| 1 | Flow of material |
| 2 | Frequency of flow |
| 3 | Supervision or control |
| 4 | Flow of people |
| 5 | Team Work |
| 6 | Hygiene and Safety |
| 7 | Management requirement |


13.2 This analysis brings out the importance of co-locating Junior Sailors (JS) servery and the provision store closest to the galley. Further, the provision store lift should be conveniently connected to the galley. Ward room pantry/ galley should be in a different fire zone as that of the ship's galley. Senior sailors' servery and dining hall can be positioned across the passageway opposite the galley. It is advisable to conveniently locate a WC near the galley/ dining hall complex. Finally, away from the galley, but convenient to scullery, a garbage point must be provided. Location of catering office has no bearing on the relationship matrix.

## 14. Flow analysis

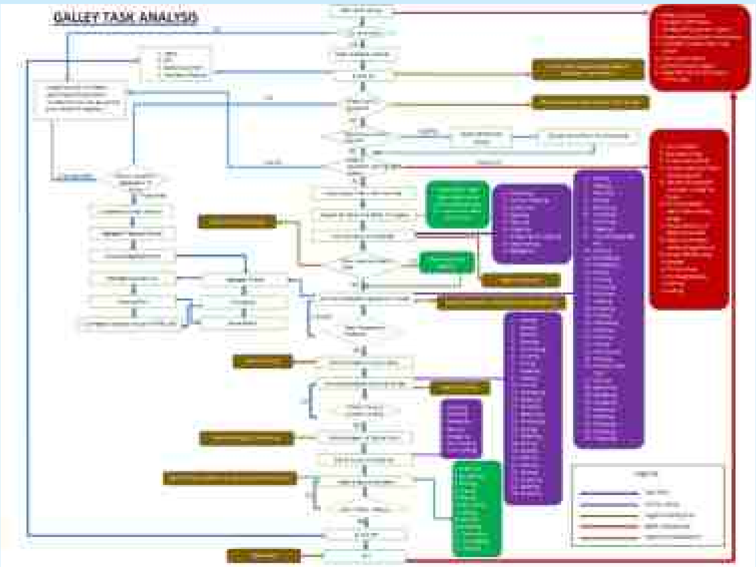
14.1 The flow analysis evaluates the ease of movement of material, man and information for a given layout design. Considered to be the key contributor and the first step towards ergonomic compliance, it should be carried out during the early stage of the design spiral before the end of the Preliminary design, and finalised during the Functional design. It is a process which tracks the flow (of material) from cradle to grave. For galley design, stores loading points (cradle) to garbage/ waste/ WC/ vomiting (grave) has been analysed. Further, all possible scenarios which include when the warship is alongside, at anchorage or at sea doing RAS have been evaluated. The flow diagram (see Fig. 3) shows a typical flow analysis for a frigate class of ship for various scenarios.

**Fig 3: Galley flow analysis**



## 15. Task Analysis

**Fig. 4: Galley task analysis**




15.1 Task analysis[10] covers a range of techniques used by ergonomists and designers, to describe, and in some cases evaluate, the human machine and human-human interactions in systems. Task analysis can be defined as the study of what an operator (or team of operators) is required to do, in terms of actions and/ or cognitive processes, to achieve a system goal. Task analysis is therefore a methodology which is supported by a number of specific techniques to help the analyst collect information, organize it, and then use it to make various judgements or design decisions. The application of task analysis methods provides the user with a 'blueprint' of human involvements in a system, and building a detailed picture of that system from a human perspective. Such structured information can then be used to ensure that there is compatibility between system goals and human capabilities and organization, so that the system goals will be achieved. It leads to more efficient and effective integration of the human element into system design and operations, in three principal areas:

(a) Safety: identify hazards, analysis of human errors, accident investigations

(b) Productivity: where to automate processes, determine staffing requirements

(c) Availability: keep downtime within acceptable limits

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[10] *Kirwan, B. and Ainsworth, L. (Eds.) (1992). A guide to task analysis. Taylor and Francis*

15.2 The entire domain of galley task analysis is shown in the Fig. 4. It covers aspects related to safety, hygiene, work flow, listing of core activities and provides ergonomic check points. This thus considered the most critical factor in equipment selection and flow of work. Some of the findings of the analysis, which impacts equipment selection and layout design, are:

(a) Need for reviewing the arrangement for RU lockers and its design.

(b) Review arrangement of securing for sea.

(c) Food safety in terms of hygiene.

(d) Ease of movement of man and material including escape arrangement.

(e) Adequacy of hand tools.

(f) Equipment design and usage to increase efficiency.

(g) Adequacy of waste management system onboard for MARPOL.

(h) Need for having an arrangement for storing in-process food item.

(j) Utensils sizing and its standardization.

(k) Improve diffuser design for better dispersion of air.

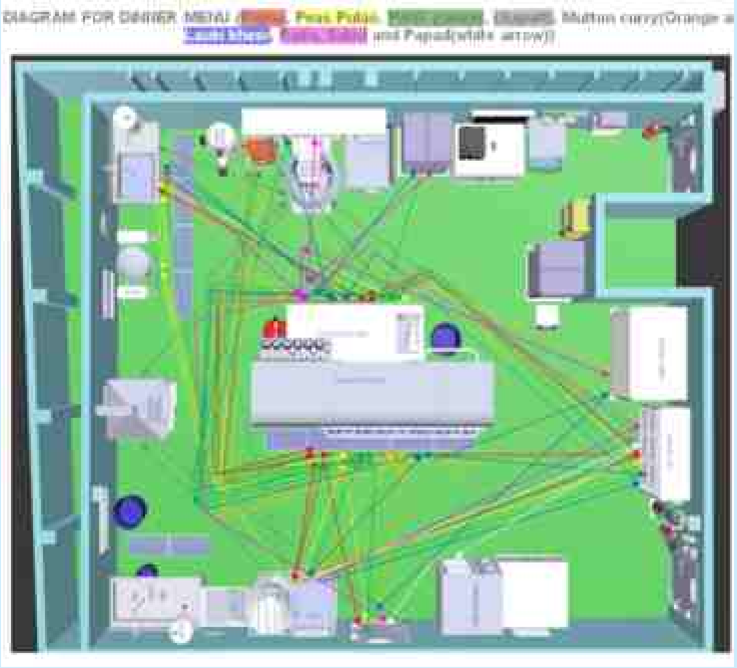
(l) Serving arrangement in the servery.

(m) Equipment ownership issues influencing maintenance and downtime.

**16. Link analysis**

16.1 Link diagrams[11] are a powerful ergonomics tool [Kantowitz and Sorkin 1983] wherein on a diagram of a proposed layout, a link or connection is drawn between different elements. Link diagrams can be used to reduce the distance that people or information must move. This can improve the arrangement of a shopfloor, office, etc. Fig. 5 shows the application of this technique to a ship's galley. Links are drawn with their width showing the frequency of movements during the preparation and cleanup for a typical meal.

**Fig. 5: Link Analysis of Ship's Galley**



16.2 The design objective here is to reduce the length of the high frequency links. And as the galley is used by more than one person, crossovers should be reduced. The key object of a link diagram is to use the line width to help show link importance, minimize the length of important links and eliminate crossovers.

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[11] *Chapanis, A. (1959) Research Techniques in Human Engineering, Baltimore: Johns Hopkins.*

Some of the key findings of the analysis which should be factored in a galley layout are as follows:

(a) Preparation area should be located near the RU storage area.

(b) Work bench should be so located to act as an interface between the preparation area and cooking area.

(c) Maximum concentration of work flow is in an around the workbench and hence should be centrally located.

(d) Food (raw/cooked) flow and garbage/refuse flow should never cross.

(e) Masala RU storage should be located near the cooking range.

(f) Certain regular use equipment should be strategically located. This includes the tilting pan, potato peeler, kneading machine and combi-steamer.

(g) Separate washbasins for washing vegetable and that for soiled utensil are essential.

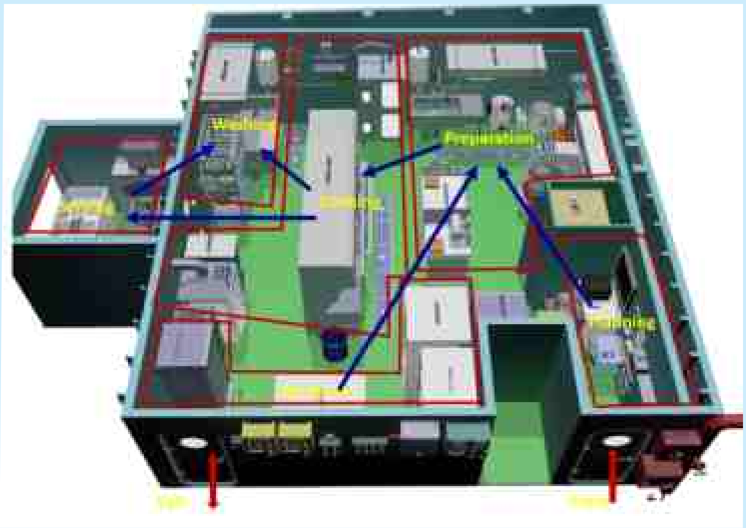
(h) Utensil rack should be located near the wash basin.

**17. Key findings and recommendations**

**Fig. 6: Ideal Galley Layout**

17.1 Based on this systematic analysis, an ideal galley layout, as shown in Fig. 6, should adequately address some of the core issues discussed here. Poor waste management including improper design of drainage system compromise hygiene and food safety and hence needs to be urgently addressed. Also in view of space constraint there is a need for rationalization and standardisation of galley equipment including various cook tools. Lack of OEM support and inferior quality has renders few galley equipment non-operational within few years of commissioning of the ship. Further, view inadequacy of exhaust design the performance of the galley exhaust is sub optimal in most cases. And finally, galley layout designed by the shipyard in consultation with the OEMs does not factor in layout ergonomic including food safety and the requirement of escape. Some of the recommendations of the study are to minimize waste generation on board through improved packaging and pre-processing of ration at BVYs, better management of food waste through integrated food waste management system and disposal of food waste in compliance with MARPOL. To control pests, vermin proofing of galley and store boundaries must be undertaken. Also free standing of all equipment to facilitate easy cleaning, sealing all crevices, air tight packaging of ration, and provisioning of human friendly pest control devices must be considered to address the issue holistically. Further, considering the nature of cooking in a ship's galley, hood design and exhaust fan sizing should be carried out by an agency which has the requisite knowhow about kitchen exhaust. Also, dual speed exhaust fans, improved baffle type filters and better diffusers may be introduced for effective exhaust. Equipment like the induction cooking range, tilting pans and advanced combi-oven should be included in the galley equipment list. Better cook tools act as a productivity enhancer. Presently most of the cook tools are locally purchased as the same are not included in the procurement list. High standard commercial cook tools, like colour coded knives for different purposes, whisk, etc. to be included in the galley TSP for centralized procurement. Most importantly, galley design should consider ergonomic aspects and should include carrying out task and link analysis of the layout prior approving the final layout.

**Fig 7 : Area Demarcation for Efficiency and Hygiene**



A galley model shown in Fig. 7, incorporates every aspect of ergonomic which includes clear demarcation of different areas like ready use storage, preparation, cooking and washing which promotes hygiene and food safety. The layout is so designed to so as to facilitate intuitive work flow as indicated by the blue arrow. This minimizes work effort and better accessibility which in turn promotes ergonomic design in line with concepts followed in commercial galley both in shore establishment as well as merchant marine like the cruise liners. Concurrently, all these aspects are being incorporated in the galley TSP to ensure meticulous implementation on all future projects.

**Disclaimer**

Contents of the paper are personnel views of the authors and do not reflect the policy or position of the Indian Navy or Government of India.

# ADVANCEMENTS IN MODULARITY TO ENABLE MISSION CONFIGURABLE WARSHIP CONSTRUCTION IN INDIA

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"Engineering or technology is all about adapting the power of science to make life better, reduce cost and to improve comfort and productivity."

- N R Narayana Murthy

**1. Abstract**

1.1 The paper undertakes a study on the concept of "adapting mission configurable" warship construction in India. This method of construction could prove to be a major milestone in the technological advancements of modular warship building in India. The mission configurable construction methodology is a plug and play technique that ensures role modification/ role enhancement of a ship, thereby proving the ship to be a multi-dimensional, role intensive asset. This paper also highlights the various merits of considering the mission configurable warship construction in India.

**2. Introduction**

2.1 The conventional means of construction of warships is a process of 'weld-as-you-go' approach adopted by many of the shipbuilding yards for construction of warships and submarines till recently in India, however the same proved to be laborious over a period of time with increased manhours and multiplying modifications, leading to cost overruns due to lack of planning at the early stages of construction. However, the tides of change have brought in the method of "modular construction", which is a reliable and faster method of construction of warships [1]. The modular construction is the process by which various sections of a ship are pre-fabricated and welded together to enable a faster approach. This methodology is currently being used for the next in-line seven frigates of P-17A class which are to be built by M/s Mazagon Dock Shipbuilders Ltd and M/s Garden Reach Shipbuilders and Engineers Ltd [2]. In order to improvise on the current procedure being adopted, the modularity can be refined to suite the mission configurable warship construction so as to change the capability of the ship based on the role for which it will be deployed. This mission configurable warship technique can be used in R&D for developing of various weapon and sensor modules to integrate it to the existing hull form.

**3. Aim**

3.1 This paper aims at examining the prospects of design/ construction of mission configurable warships as the next major breakthrough that the Indian shipbuilding industry is to lay focus upon.

**4. Scope of the Paper**

4.1 The scope of the paper is as highlighted under:-

(a) Modular construction in India.

(b) Modular construction - World over.

(c) Challenges - modular construction in India.

(d) Mission configurable warship construction.

(e) Merit - Flexible mission configurable warship construction.

**5. Assumptions Made**

5.1 The basic assumptions being made in the paper are that the modular construction of warships in India has attained sustenance in order to accept the flexible methodology being adopted. Further, majority of the design has achieved 80-90 per cent design maturity prior commencement of construction.

**6. Modular Construction in India**

6.1 Modularity, which in broader terms can be explained as dividing a large segment of systems related to a platform into smaller, self-sufficient parts which are subsequently combined to form a final unique product [1]. This method of construction is more complex as the design algorithm is raised to a much higher level in terms of completeness.

6.2 In India, modular construction has begun spreading its roots with India contracting its seven P-17A class of frigates to M/s MDL and M/s GRSE in the recent past [2], which are being constructed using modularity. The construction is divided into the large and small scale functional modules, wherein the large pre-outfitted sections are those which are joined together to establish the hull form and the small scale functional modules comprise of the wiring, piping, venting, etc. that can be undertaken prior joining the sections. This method of modularization enables reduction in construction time as well as costs. However, difficulties with regard ensuring of perfect fit exists while considering the allowable tolerances between the two sections as per the designer's margin. Over the past few years, modularity has only matured in terms of the basic assembling of sections with pre-fabricated and pre-outfitted sections and has not yet been flexible in incorporating growth margins to facilitate any major role modification/ upgradation [2].

**7. Modularity adopted the world over**

7.1 Though India has recently initiated construction of warships through modularity, the methodology of modularization has already advanced the world over. For example, the United States of America has brought about revolutionary modifications to the general usage of modular construction of ships, this features enable morphing a ships capability over time to match the evolving requirements by balancing the ships service life in comparison with the evolutionary changes being adopted. The various advancements that are proven to be effective in terms of time consumption and cost cut downs are [3]:-

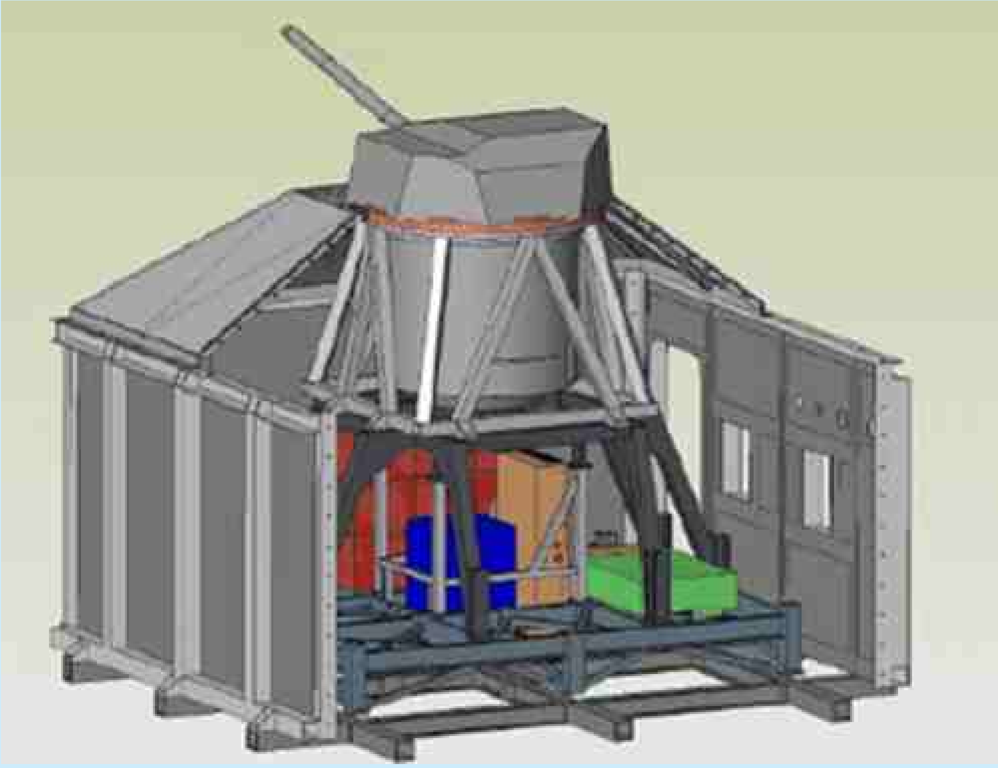
(a) **Parallel Mid Body.** Inserting of parallel mid bodies for the newly constructed ships, wherein the bow and stern would remain stagnant and the parallel mid bodies is included containing the application specific systems, like the insertion of AIP (Air independent propulsion) plug into an otherwise conventional submarine. However, this method has till date been extensively used for merchant vessels only in the USA.

(b) **Mission Modules.** Introduction of mission modules that compose of mission systems and support systems that is fully operable for a plug and play condition as shown in Fig. 1.

Fig. 1: Module Consisting of Mission Components and Support Systems

(c) **Interface up-gradation.** Development/ upgradation of the weapon station modules (see Fig. 2) by converting the ship specific interface to adapt to the general purpose interface standards.

Fig. 2: Weapon Station Module



(d) Flexible infrastructure consisting of an open structure to consider various feasibilities of ergonomically arranging the available space within these structures consist of the foundation track to be bolted to the deck and fittings/ adapters and associated fasteners to attach equipment and other components to the foundation track.

### 10. Challenges - Modular Construction in India

10.1 Modular construction is being adopted across the globe for faster construction of ships. India too has adopted the same for construction of most of its new to be inducted warships and submarines. Yet warship building in India suffers from the following limitations:-

(a) Huge initial capital investment for construction of the requisite hull form to accommodate the desired role/ mission capabilities of the vessel. The hull form is to be designed taking cognizance the fast evolving equipment fit in today's world.

(b) The insufficient levels of local industry support in ancillaries, lack of compatible indigenous systems like the propulsion and power generation systems, wherein the new design or repair assistance is extensively sought from the non-indigenized firms.

(c) The stumbling blocks in the road to designing followed by capacity limitations of the shipbuilders and the long gestation periods between design and construction culminate into a fixed mission ship with obsolete equipment fit.

(d) The snags in the finalization of the equipment/ weapon fit prior initiation of construction of the vessel is also a long lead issue as the weapon system India desires is not available for purchase, the alternate offered is exorbitantly priced and what is affordable is invariably not required. The ideal solution to this is the local availability of weapon systems, which will ensure maintainability, timely upgrades, however they are either unavailable or do not meet the desired result. Therefore, India is left with no alternative but to import and also prolong use of existing armament by process of life extension, constrained with improper/insufficient spares and testing methods.

### 11. Flexible Mission Configurable Construction

11.1 Flexible warship designs are often described as "plug-n-play" or "Legos". This method in a broader sense is the ability of a ship/ submarine to adapt to universal or alternate mission statements with the benefit of increased capability/ role modification, which thereby reduces high investment on the basic hull construction. Flexibility is one form that can be designed into the architecture of a system to provide options to designers, engineers, manufacturers, and end-users alike in order to accommodate the uncertainty in the future, So as to ensure that the designers put an option in and the consumers could execute an option on it. This reduces the cost and enhances competition in the open market as new companies can provide new capabilities with innovative design as long as the interface is standardized.

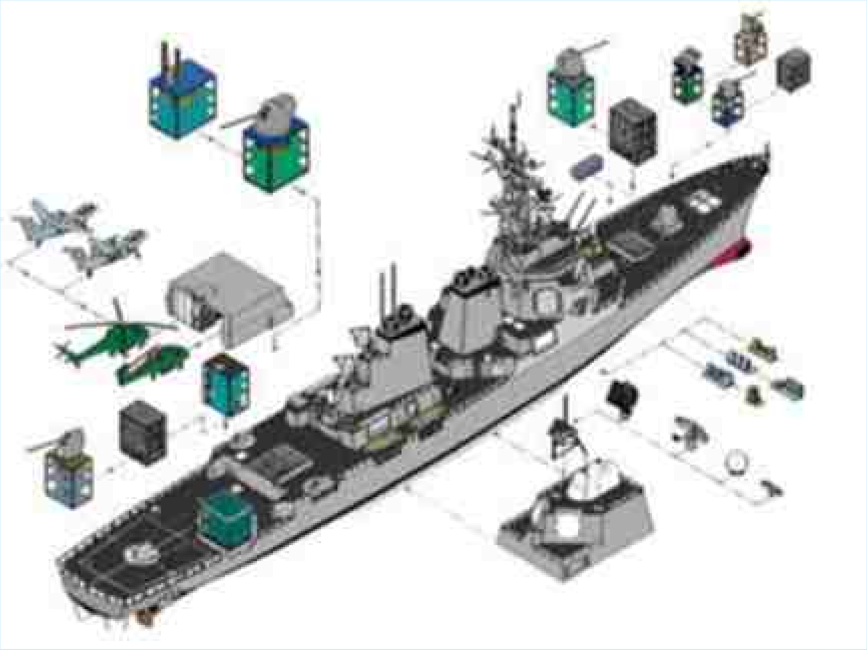
11.2 A concept termed SCAMP abbreviating to scalable, common, affordable, modular platform has been designed by a team of American and Hellenic Naval Officers at MIT [4] as a design project starting with the idea of reducing acquisition cost by decoupling combat systems for Hull Maintenance and Equipment .The project team has successfully designed a model which has been longitudinally divided into four independent potential variants, each one meeting all the standard design and stability criteria. The team has also studied its pros and cons in comparison with the Arleigh Burke class destroyer and the internal space and volume has grown over 40 per cent of the existing design.

### Fig. 3: Comparison of the Arleigh Burke class destroyer and SCAMP

| Key Performance Parameter | DDG 51 | SCAMP (5-module) |
|---|---|---|
| LOA [m] | 154 | 175 |
| Beam [m] | 20 | 20 |
| Draft [m] | 9.4 | 5.58 |
| Full Load Displacement [MT] | 9,042 | 8,915 |
| VCG Service Life Allowance [m] | 0.256 | |
| Weight service Life Allowance [MT] | 1,218 | |
| Internal Arrange-able Space [m²] | ~7,000 | ~11,000 |
| Internal Volume [m³] | ~30,000 | ~36,000 |
| Installed Propulsion Power [MW][16] | 78 | 10 |
| Installed Electrical Power [MW] | 7.5 | 60 |
| Propulsion Type | Mechanical | IPS |

11.3 In a conventional design, the entire warship is optimised for one specific combat role to perform one defined mission. The combat systems are integrated once and shipboard inter-system functions are developed and perfected to enable effective functionality of the role. In a mission configurable warship, however, different parts of the ship and combat systems can be taken on and off the ship and upgraded multiple times as shown in the Fig. 4. This facilitates the ultimate challenge of role modification/ enhanced capability for the same hull model.

### Fig. 4: Various flexible modules



11.4 In order to achieve this state of flexibility, the modular construction of warships is to develop total ship open system architecture with access to standardized interface modules to ensure operability of the entire platform. Intelligent design of the hull and support structure is significant in case of a flexible design so that structural considerations do not hinder potential capability upgrades. The process for designing a flexible warship is to functionally partition the ship into functional element zones, wherein, each functional element zone is a volume of the ship that provides space, structural support, and services for one major function located therein independently. Examples of functions that might be provided by this method of the functional element zone include: weapons; exterior communications (the mast with the communication systems); aviation; habitability etc. [5]. The stage at which every individual system functions independently with or without the existence of the surrounding systems of the platform, the flexible mission compatible warship construction is said to be operable and functional [5].

**12. Merits of undertaking the Flexible mission compatible warship construction**

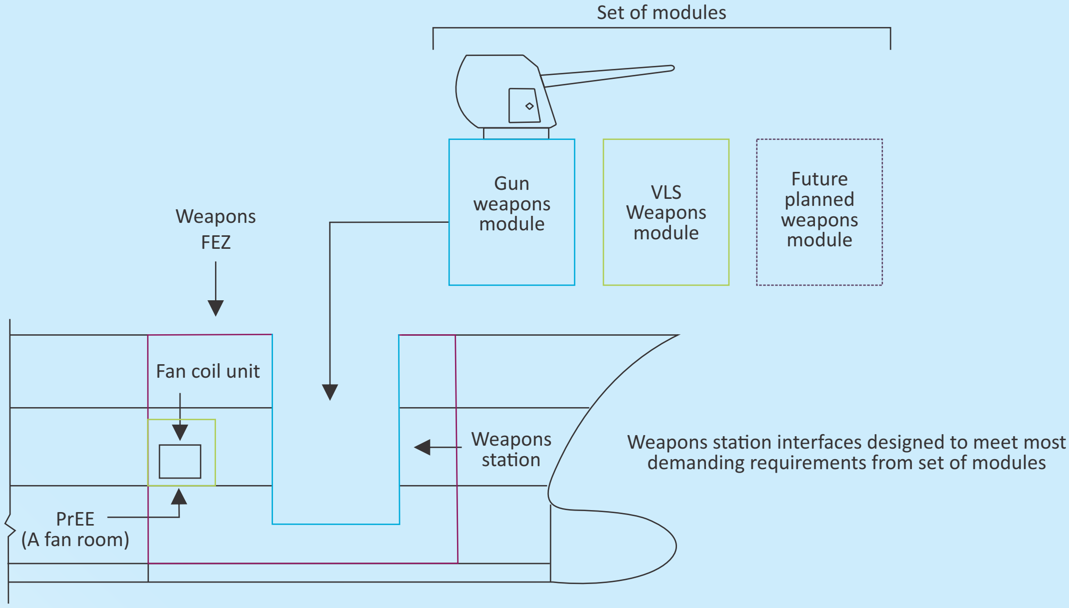
12.1 This method of warship construction can prove to be economical due to the major outlined reasons as under:

(a) The primary benefit is the enhanced mission effectiveness/ role modification at lower investments. This enables lower maintenance cost and effective modernization as per the mission statement.

(b) The initial cost and time overruns for construction of a dedicated ship's hull is mitigated and is replaced by the cost saving method of flexible access routes, alleyways and standard interface modules without any major modifications to the hull. Standardization reduces the numbers of parts and facilitates easy replacement of systems.

(c) Through the use of standard interfaces as shown in the Fig. 5 [5], flexible ships enable new technologies to be deployed earlier than on a traditional design that would require retrofitting. Due to the design-for-modernization features, flexible warships can be modernized in significantly less time than a traditional ship. This reduces the midlife modernization philosophy as the flexible ships are overhauled at regular intervals to incorporate the modern system fit.

**Fig. 5: Standardized Modules to Enable Modernization**



## 13. Challenges in adapting to the Flexible mission compatible warship construction

13.1 A developing nation like India with the world's fastest growing economies has inched cautiously towards accomplishing many of its milestones. However, weighing the pros and cons is the quality of the wiser and thus, though flexible mission compatible warship construction is considered to be the best and biggest milestone India could achieve, the challenges that could arise are also elaborated as under:

(a) The major challenges that could be encountered, pertains to the distribution of weight and the stability of the vessel. Addition of a module or a set of mission components should not compromise the basic sea-going ability of the vessel. In order to sustain this, the ships are to be constructed with adequate/ allowable growth margins and sufficient ballast spaces.

(b) The propulsion system of the ship is a hindrance, as standardization of propulsion of the ship across the various mission statements is not a viable solution. The same cannot be effective during a war scenario due to increased top weight leading to reduction in design speed of the vessel [6].

(c) The placement of equipment within the ship and within a space, the method of connecting the system/ equipment (e.g., bolts, welds, cables, service connections, etc.), distribution of services (e.g., electrical power, cooling, HVAC), and adjacency to support equipment.

(d) Upgradable/ expandable associated systems like power modules to facilitate the compatibility of the modules being integrated with the platform.

## 14. Conclusion

14.1 India has adopted the modular methodology of warship building on a full-fledged note only in the recent past. As the milestone of implementation of modular construction has been achieved to a far extent, India as a nation with one of the fastest growing economies should focus upon inching ahead to adopt the 'adaptable mission configurable' warship construction. This method aids in delivering a ship equipped with the futuristic capabilities and access to role modification unlike the role bound platforms ageing with every growing day. This method of warship construction requires standardisation of most of the major mission contributing systems/ equipment and designing of the hull form to incorporate this standard equipment fit. In today's state of affairs though India cannot adopt to this methodology, at least the initiation of R&D in the field of mission configurable warship construction will yield desired results a decade hereon.

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# "IOS OPEN PLATFORM" TO IMPLEMENT MARITIME BIG DATA


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1. As shipping evolves into a "Big Data" industry, ClassNK and its subsidiary Ship Data Center Co., Ltd. (ShipDC) are supporting the maritime community by providing the platforms to reap the benefits in partnership with the consortium partners in Japan.


**2. Key Words**. Big data; Internet of Shipping; Ship Data Centre


**3. Introduction**

3.1 ClassNK and its subsidiary Ship Data Center Co. Ltd. (ShipDC) have investigated how the industry can utilize the so-called big data, teaming up with shipping companies, shipbuilders, suppliers, ICT companies, and other related parties. For sharing the data in the industry, shipping companies, as the data source, have pointed out the necessity of a common rule for data property and distribution as well as a secure data center. Responding to these needs, ClassNK and ShipDC have designed a scheme in which shipping companies are able to provide the data with less concern, and data users in the industry can utilize for development and improvement of their products and services.

3.2 The paper describes the above-mentioned scheme of "IoS Open Platform (IoS-OP)" consisting of the data center with various functions to encourage the data use and "the common rules" to store, exchange, utilize the data, as the model of data sharing and distribution in the industry.

**4. The Era of Data**

4.1 Big Data has been called "the oil of the 21st century" to emphasize the wide spread of data flow brought about by the new era of digitization. 'Internet of Things' is expected to comprise between 20-40 billion devices by 2020 depending on who is doing the forecasting, but keeping pace with data flows is certainly likely to be challenging.

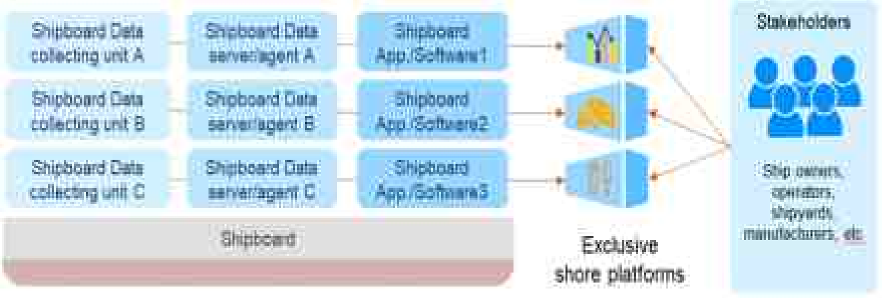
4.2 Once considered a very "low data" industry, the maritime industry is now vigorously waking up to the new digital age. Thanks to rapid advances in the development of information and communication technologies, it is now possible to collect large volumes of data on a diverse range of items related to ship operations. The information acquired from sensors of equipment, machinery and any other onboard devices can be recorded as digitalized data. The generated data connected to the internet as IoT can be accumulated as Big Data, which can be the basis of digitalization in the maritime industry. Remote access monitoring, condition-based maintenance, data analytics and forecasting are significantly improving and optimizing numerous functions in operations and ship management. As a result, the international shipping industry is beginning to embrace the tangible opportunities that the growth of big data presents.

4.3 In addition, regulatory requirements also pose the necessity of data collection. The implementation of fuel consumption data reporting regulations has been ongoing in an effort to reduce GHG emissions and the EU-MRV (European Union - Monitoring, Reporting, Verification) regulations for ships operating in the EU area began in 2018. The upcoming IMO DCS regulations require all globally operating ships over 5,000GT to collect fuel consumption data and create an annual fuel consumption data report to submit to their flag administration or recognized organization for verification.

4.4 While more shipping companies need and are willing to share information with a view to reaping the benefits of big data or complying with the international or local regulations, the approach to data capture remains very fragmented as seen in Fig. 1. Similar data is routinely sent to several vendors and analysis is still being carried out almost entirely on a ship-by-ship basis, in processes that are both time-consuming and inefficient.

4.5 To make larger gains, an effective platform capable of centralizing and managing such diverse data was considered essential. However, creating and maintaining this kind of platform is costly, time-consuming and unrealistic for some organizations. Furthermore, special care needs to be given to the handling of data to ensure confidentiality of information; hence it is also necessary to establish a secure yet effective platform from an impartial perspective.

**Fig.1 Fragmented data capture**

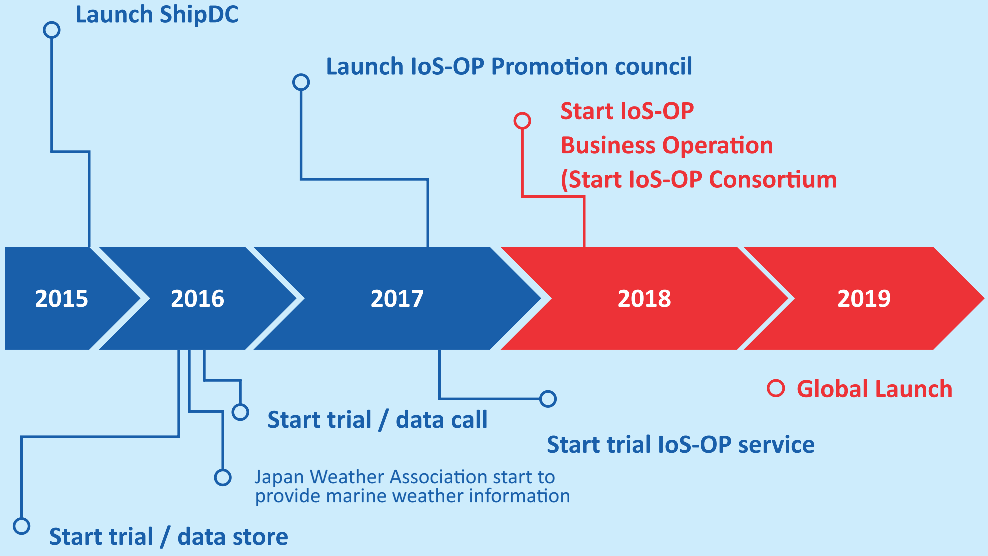



## 5. Timeline and Thoughts

5.1 ClassNK has long served the maritime industry through its technical and third-party service responding to industry needs. Its longstanding commitment to helping shipping realize the potential of big data is summarized as follows. In Dec. 2015 Ship Data Center Co., Ltd. (ShipDC) was established as a separate entity from ClassNK. It started to store shipping data in May 2016 as a trial, and simultaneously, ShipDC started to receive marine weather information from Japan Weather Association. Through Japan Weather Association's free provision of real-time marine weather information such as offshore wind (direction, speed), waves (height, frequency, direction) and ocean currents (direction, speed), the comprehensive analysis of voyage data from vessels at sea and marine weather information was made possible.

5.2 As seen in Fig. 2, in Aug. 2016, the trial for calling the data started. While ShipDC was preparing for the data center operation and technical trial to transmit the ship data to shore, it discussed with industry players how to best utilize the data related to ships. In 2017 the related conferences were held with more than 700 attendees in total, and the “Internet of Ships Open Platform Promotion Council” was established to deepen the discussion.

**Fig.2 Summary of ShipDC Activities**




5.3 Without data collection beyond the border of companies, the data cannot become real Big Data. However, a giant platformer's monopoly on data and data use for their own business, which is often seen today in other industries, is not appropriate for industry platforms containing highly confidential information. There must be clear rules for fair data use between data owners and data users, and confidentiality of the data has to be strictly guarded. With this kind of framework, players especially who own the data can be willing to pass and share it. The conclusion from the discussion confirmed the necessity of common rules for data property and distribution, and a fair, reliable, and independent scheme.

**6. IoS-OP and IoS-OP Consortium**

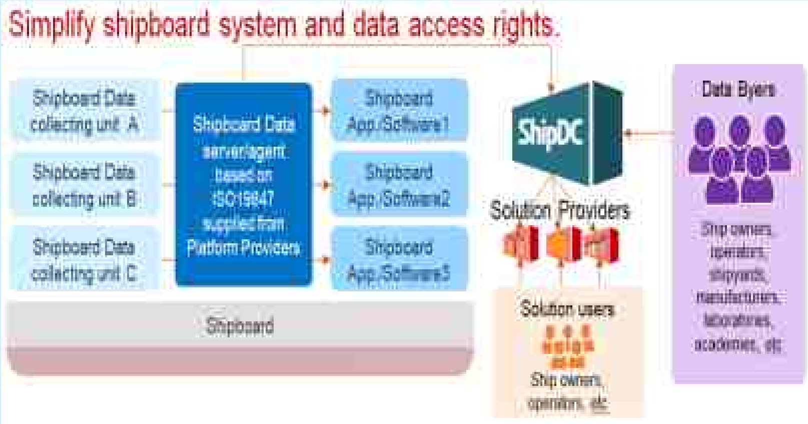
6.1 In May 2018, for satisfying the above-mentioned requirements, the “Internet of Ships Open Platform (IoS-OP)” was launched as the common platform to share and distribute the operation data of ships to enable shipbuilders, manufactures and other stakeholders to access the data without infringing on data providers' interest. IoS-OP consists of the data center service and the common rules for data distribution agreed among the industry. The initiative is aiming to co-create data-driven new values, new solutions, and foster innovation.

6.2 In order to operate IoS-OP as the neutral platform, and avoid any monopoly of the data, an association was formed by the member of ShipDC users which is called as “IoS-OP Consortium”. ClassNK is also a member of IoS-OP Consortium and any important decisions to operate IoS-OP shall be made by the prescribed procedures of IoS-OP Consortium. This ensures sound and permanent management of the IoS-OP. Initial members of the IoS-OP Consortium consist of 46 shipping companies, shipbuilders, marine manufacturers, ICT and other organizations based in Japan.

6.3 On IoS-OP, data will be collected from multiple vessels, regardless of class or company, through data collection devices onboard. Companies will be free to choose what they want to share and to specify whether they want it shared with engine makers, equipment manufacturers, shipyards or other stakeholders who might benefit.

6.4 During 2018 the IoS-OP was available to the IoS-OP Consortium members located mainly in Japan. Having confirmed the validity in the period, it was globally launched in Apr. 2019. At that time the number of members had grown to 55 organizations.

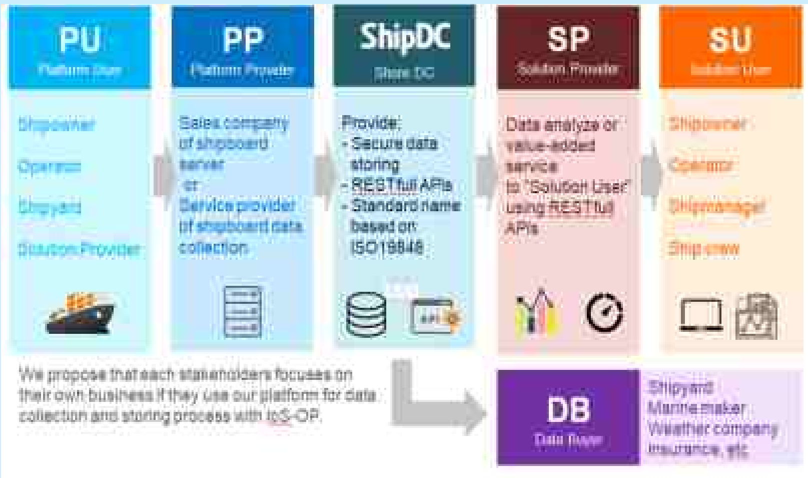
**Fig.3 Simplified and Integrated Data Capture**




### 6.5 Outline and Roles on IoS-OP

The players on IoS-OP are described as seen in Fig. 4.

**Fig.4 Outline of IoS-OP**




### 7. Platform User (PU):

7.1 The PU should mainly be a ship owner or operator. A shipyard and Solution Provider (explained later) may also take this role. The PU bears the cost of data collection (data ownership). Costs here means shipboard server cost, data communication cost and data storage cost, etc. The PU manages data access rights and data collection of the data they provide and authorize solution user and data set range.

### 8. Platform Provider (PP):

8.1 The PP is a service provider of data collection to the PU, which should be a sales company of shipboard servers or service provider of shipboard data collection.

### 9. ShipDC (DC):

9.1 Through devices and services of the PP, the data shall be transmitted to the data center operated by DC. DC is ShipDC itself storing the collected data securely and providing RESTfull API for the data distribution. Furthermore, it harmonizes the data captured from ships, as seen in Fig. 3, by converting the specific data format of a software service provider or system into a standardized ISO format: “ISO19848:2018 Ships and marine technology — Standard data for shipboard machinery and equipment”, which was originally developed by Smart Ship Application Platform (SSAP). SSAP is the project of Japan Ship Machinery and Equipment Association.

**10. Solution Provider (SP):**

10.1 The SP provides the data analysis or any value added service utilizing the transmitted data such as remote maintenance, performance report, condition monitoring, and so on. SP will use ShipDC's RESTfull API as the data access interface.

**11. Solution User (SU):**

11.1 The beneficiary from SP and their service is categorized as SU, who should be a ship owner, operator, ship manger, or crew.

**12. Data Buyer (DB)**

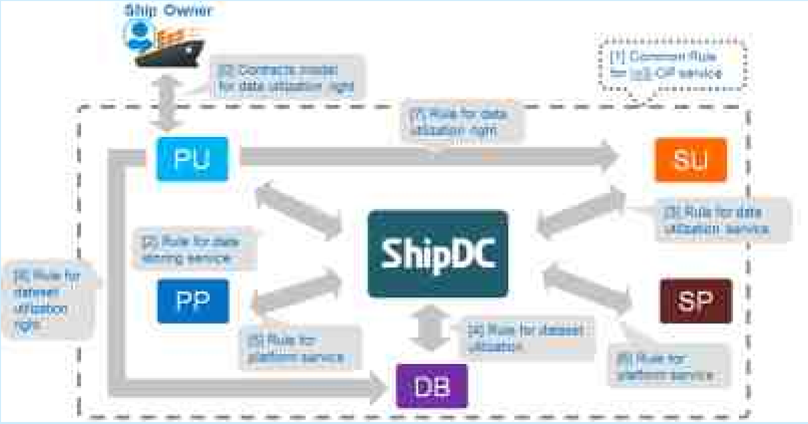
12.1 The DB uses the data for improvement of its own product/building ship, big data analysis, performance analysis, and so on under the authorization of PU. DB should be a shipyard, marine manufacturer, weather company, or insurance company.

12.2 For ensuring fair and transparent data use, membership in IoS-OP Consortium and company registration are required for the PP, SP and DB. On IoS-OP, each stakeholder can focus on their own business by using the common platform for data collection and storing process.

**13. Rules for IoS-OP**

13.1 IoS-OP provides common and individual rules corresponding to the role and relationship of each stakeholder in order to distribute IoS-OP data among stakeholders fairly. For the time being, nine sets of rules are stipulated (see Fig. 5).

**Fig.5 Rules for IoS-OP**




(a) Contracts model for data utilization right The contract model is for ship owner and PU to reduce the related negotiation of data ownership and data utilization rights.

(b) Common Rule for IoS-OP service The rule is a basic one to be applied to all IoS-OP users. It will be applied between ShipDC and each stakeholder.

(c) Rule for data storing service (for PU)

(d) Rule for data utilization service (for SU)

(e) Rule for dataset utilization service (for DB)

(f) Rule for platform service (for PP)

(g) Rule for platform service (for SP)

These rules contain requirements for participation qualification, registration condition, use condition, observance matters and prohibited items by each role.

(h) Rule for data utilization right between PU and SU

(j) Rule for dataset utilization right between PU and DB

These rules are for relative transaction between PU and SU/DB for data/dataset utilization right.

**14. Shipdc's Service on IoS-OP**

14.1 The primary role of ShipDC is data center operation of IoS-OP, centralizing the data from ships to shore. However it provides additional service for smooth distribution including data standardization.

14.2 On IoS-OP ShipDC provides the following functions to receive data from various equipment, facilities, and systems onboard:

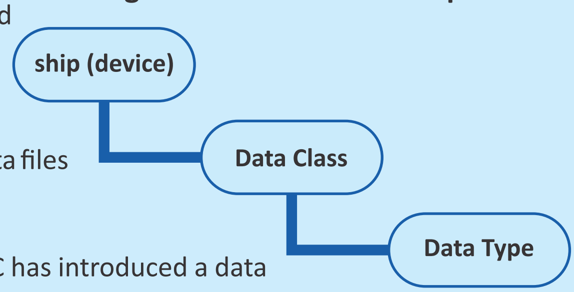
(a) Automatic data registration from attached data files based on the file naming rule

(b) Support multiple onboard devices

(c) Support data other than text-format data files

(d) Support confidential data for maker

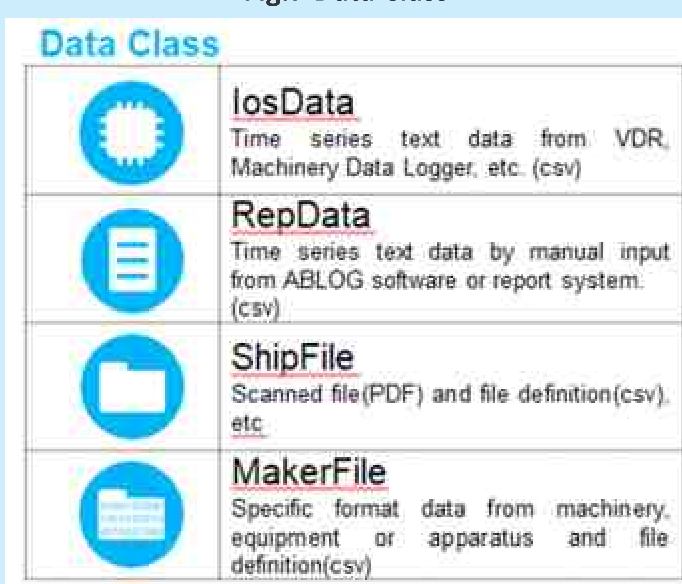
**Fig.6 Data structure concept**




In order to accept and process various data, ShipDC has introduced a data structure as seen in Fig. 6.

"Data Class" defines the attribute of the data as seen in Fig. 7.

**Fig.7 Data Class**



Data Class

| | |
|---|---|
| | **IosData** Time series text data from VDR, Machinery Data Logger, etc. (csv) |
| | **RepData** Time series text data by manual input from ABLOG software or report system. (csv) |
| | **ShipFile** Scanned file(PDF) and file definition(csv), etc |
| | **MakerFile** Specific format data from machinery, equipment or apparatus and file definition(csv) |

15. 'Data Type' is for specifying the data definition in "IoSData" and "RepData".

15.1 As the information hub for the maritime industry, security measures are taken for safe and secure distribution of data such as protection from unauthorized writing by specifying senders of data transmission mail, data key distribution by encrypted file, communication protection in data call, enhanced authentication for data access interface.

15.2 For data access control ShipDC provides sub-user setting function to grant access authority based on data ownership and schemes to detect/correct error data. ShipDC issues and distributes data keys with an access range set by ShipDC based on the request of data ownership holder. Users access data using the data key via software/application authorized by ShipDC. For data quality improvement, it also provides an error data detection/notification scheme to mechanically detect/notify errors including email non-delivery, data file damage, numerical data blanks and notification.

**16. Requirement of Shipboard Devices (PP)**

16.1 From onboard to shore, the data is stored in the database automatically by the email from a shipboard device to ShipDC with an attached data file as seen in Fig. 8. The following processes are necessary with the shipboard device.

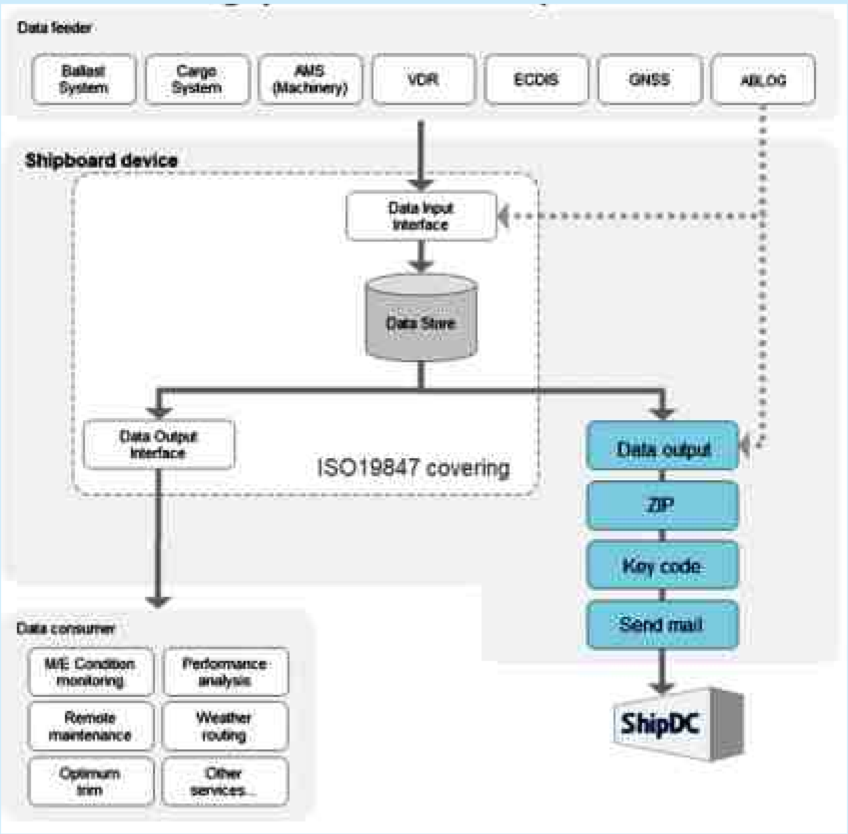
(a) *Data output:* output text and file data in designated format

(b) *ZIP:* compress data files in a ZIP file

(c) *Authentication key code:* generate authentication key code by each sending action to prevent manipulation and unauthorized update

(d) *Send mail:* send mails to ShipDC with ZIP file and authentication key code file for data storage

**Fig.8 Requirement of Shipboard Devices (PP)**



## 17. Restful API Service

17.1 For SP, utilizing the data for their service or solution, RESTful API is provided as the data access interface. These API are:

(a) *DataSet API:* GET available ships and data type list

(b) *DataClass API:* GET accessible data with data key

(c) *Weather API:* GET free marine weather information mapping to ship position/ date & time in time series data provided by Japan Weather Association

(d) *Maker API:* GET specific data sending/storing available for maker confidential data

(e) *Other API:* GET supplementary data such as data type definition (meta information)

## 18. Conclusions

18.1 IoS-OP is the adaptive scheme to best utilize the big data in the maritime industry and consists of the data center with various functions to encourage the data use and "the common rules" to store, exchange, and utilize the data. Following its establishment in 2018, ShipDC data center and other operation for IoS-OP and partners had been working on the global launch of the service in 2019.

# SOME DESIGN CONSIDERATIONS FOR FUTURE ASW PLATFORMS

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## 1. Abstract

1.1 For increased range and bearing accuracy of submarine detection, low frequency sonar transducer arrays with large aperture fitted onboard ships and submarines offer clear technical advantages in certain ocean environmental conditions. For flow noise isolation and structural protection, the transducers on ships are fitted inside water filled appendage structures called sonar domes. The location, size, and shape of the sonar domes affect the platform speed, manoeuvrability, and the operating costs. Dome size, and consequently the sonar array sizes and optimum operating frequencies, is also limited by the available ship building infrastructure such as dry dock dimensions. For submarines, the location of torpedo tubes determines the size of the maximum sonar array that can fit on them. This paper gives an overview of DRDO's successful effort in indigenizing sonar domes for ships and submarines, and elaborates on the design considerations of future ASW platforms.

## 2. Introduction

2.1 Detection of submarine is an ongoing race between the advances in stealth technology and sonar technology. Acoustic propagation characteristics of a complex environment like the ocean offers 'shadow zones' for submarines where it can hide and evade detection by sonars of surface and subsurface platforms. While different types of variable depth sonar systems and other techniques are developed to enhance the underwater target detection capability, large aperture sonar transducer arrays fixed on the bow of ships and submarines still plays an important role in Anti-Submarine Warfare. These transducers that transmit and/or receive underwater sound signals form the heart of a sonar system. The transducers are fitted in 'sonar domes' at various locations on ships and submarines depending on the platform type and sonar system functional requirements. A 'sonar dome' is a streamlined and watertight enclosure that provides structural protection for one or more sonar transducers or arrays and associated equipment, while offering minimum interference to sound transmission and reception. A sonar dome should be strong enough to withstand the structural and hydrodynamic loads. An important function of a sonar dome is to minimise flow induced acoustic noise in the sonar. The design of a sonar dome is based on its type, operating frequency range, size and the location of the sonar transducers they cover.

2.2 Early sonar domes were made of metals like steel and titanium. These were later replaced by domes made of composite materials and rubber. The non-metallic domes typically have superior acoustic performance due to better acoustic impedance matching with water. Owing to high flexural vibration damping properties, they are also better in filtering out the noise in the sonar system by attenuating the platform generated and flow induced dome vibrations. This fact was clearly established in 1970s by the US Navy through a side by side trial of two ships of the same class fitted with identical sonar systems. One ship was fitted with a metallic dome and the other with a rubber dome. The following statement from the book titled 'Probing the Oceans for Submarines' by T.G. Bell, who was the Project Director of US Navy's AN-SQS 26 sonar system development, is a testament to the importance of the sonar dome design in ASW: "*[After seeing the results of the rubber dome performance],* NUSL's Frank White, who had spent many years attempting to improve SQS-26 sonar system performance by devising modifications to the sonar transmitters and receiver processing, reacted by stating that this solid piece of mechanical engineering - the rubber dome window - was far more effective in increasing sonar performance than all the other electronic improvements taken together." [1]

### 3. Sonar Dome Projects of DRDO

3.1 Indian ships and submarines were traditionally fitted with sonar domes imported from countries like United Kingdom, Germany and Russia. The need for indigenising the sonar domes was identified in the early 2000 and a project was taken up by DRDO's Naval Physical and Oceanographic Laboratory (NPOL), Kochi, to develop hull mounted ship sonar domes in association with Indian Institute of Technology Madras (IITM) [2]. Successful completion of this project laid the foundation for the ambitious NPL-219 project under which different types of sonar domes for submarines were developed. This was followed by many more projects - bow mounted domes under RDE-414 project, sonar dome for DRDO Technology Demonstration Vessel, the hull mounted dome for the research vessel INS Sagardhwani and huge composite domes for future submarine platforms [3]. Photographs of some of the domes made by DRDO are shown in Fig. 1.

**Fig. 1: Some of the sonar domes developed by DRDO**

(a) First composite sonar dome made in India by NPOL and IIT Madras in early 2000s.

(b) HMS-X sonar dome fitted onboard a foreign platform. Inside the dome is HUMSA sonar.

(c) RDE-414 bow mounted dome undergoing acoustic testing in the tank at NPOL. This dome is fitted onboard a P-15A platform.

(d) A part of the acoustic window for DRDO's Technology Demonstration Vessel being immersed in acoustic tank for testing.

## 4. Trends in Sonar Dome Design

4.1 Indian Navy has projected a requirement of lower operating frequencies of NPOL's HUMSA sonar systems intended for future warships in order to improve the detection ranges. Since the wavelength of the acoustic waves in inversely proportional to the frequency, lowering the operating frequency would require larger transducer arrays for ensuring optimal sonar performance. Consequently, the new ships will require larger sonar domes.

4.2 A brief survey of the internet reveals that the sonar transducers and domes of the ships and the submarines operated by the advanced navies are much larger than those used by Indian ships and submarines (Fig. 2).

**Fig. 2: Large sonar domes of foreign ships and submarines**

(a) A bow mounted ship sonar transducer array [4]

(b) A large bow mounted ship sonar dome [5]

(c) A submarine sonar array [6]

(d) Bow sonar dome of a submarine [7]

4.3 To establish the reach and dominance in blue waters, the Indian Navy has to enhance its ASW capabilities. Building ships and submarines with larger sonar domes to accommodate large low frequency sonar transducers is one of the critical steps towards this mission. Attaching a large sonar dome has serious implications on the platform design. It may also be required to establish new warship building infrastructure for this purpose. These considerations are briefly described in the following section.

## 5. Design and Building Considerations for Platforms with Large Sonar Domes

## 6. Ship Design Considerations

6.1 A large bow mounted bulbous sonar dome hanging below the keel of a warship has serious implications on the ship dynamics and operating costs. Optimizing the ship design for achieving the desired sonar dome size and shape without compromising the speed, agility, manoeuvrability, stability is a challenging naval architecture problem. Building and operating costs and endurance may be affected by increased propulsion power and fuel requirements.

6.2 Large sonar domes typically carries low frequency sonar arrays. Since own ship noise is higher at lower frequencies it is a problem for such large sonar domes. Therefore, it is required to isolate the platform generated noise at these frequencies from reaching the sonar transducer through proper vibration isolation of the machinery by damping of the hull vibrations. A part of the structure borne and water borne noise can be isolated by installing acoustic baffles inside the sonar dome.

## 7. Dome Design Considerations

7.1 Sonar dome design is a problem of optimisation of acoustic, structural and hydrodynamic requirements. The structural configuration and shape of the dome should be selected in such a way that the acoustic waves do not suffer energy attenuation or signal distortion beyond acceptable limits. Damping of flow induced and platform generated flexural waves of the dome through suitable material selection is critical to reduce the noise in the sonar system.

7.2 In most ship domes, the critical design load is the stress during ship slamming in high seas during which the pressures acting on the outer surface of the dome can be several times the internal hydrostatic pressure and the dome should be able to withstand these pressures. An internal hydrostatic pressure balancing system is essential to avoid buckling of the dome when subjected to high external pressures. Maintaining a high hydrostatic pressure inside the dome also ensures that water always flows outwards though any leakage path. It also prevents transducer cavitation during high power, low frequency operation.

## 8. Ship Building Infrastructure

8.1 Some ship sonar domes hang as low as 2.5 m below the keel line of the ship. Most dry docks in the shipyards and naval dockyards in the country cannot accommodate a destroyer with such a bow sonar dome. Photographs available in internet show that large sonar domes of US warships are accommodated in a pit built on the dry-dock (Fig. 3). Such facilities are not currently available in India. Therefore, to build large ASW warships with large, low frequency sonar arrays might require an upgradation of the existing shipbuilding infrastructure.

**Fig. 3: Sonar dome of a US Navy ship is accommodated in a pit in the dry dock [8]**

## 9. Weapon Delivery Scheme in Submarines

9.1 As can be seen in Fig. 2d, the nosecone of a typical US submarine is occupied by sonar transducer arrays. A large aperture spherical passive array, a low frequency transducer array surrounding this passive array, and a hemispherical active transducer array can be seen in the figure. In the case of Indian submarines, a significant portion of the bow is taken up by the torpedo tubes and only the remaining portion is available for the sonar transducers. The entire nosecone of US submarines is available to fit the transducers because the torpedoes are launched from the flank. Moving to a flank torpedo launching scheme can be considered for future submarine platforms to enhance the sonar capability as it would provide space for larger sonar transducer arrays.

**Fig. 4: Torpedo launching schemes. Larger sonar transducers can be fitted in the nose cones of submarines with flank launched torpedoes.**

(a) Nose launching [9] (b) Flank Launching [10]

## 10. In-situ Manufacturing of Composite Sonar Domes

10.1 The largest submarine sonar dome can be as large as 10 m in diameter and a ship dome can be more than 5 m in width. Domes of such large dimensions cannot be transported by road from the factory to the shipyard as a monolith. One solution is to manufacture the dome in multiple pieces and join them in the shipyard. But the joints typically have poor acoustic transparency. This will cause discontinuities in the sonar beam patterns which would result in poor target detection performance and reduced bearing accuracy. Another solution is to manufacture the dome as a single piece in a factory near the sea and transport them to the shipyard by sea. At present such facilities are not available in India.

10.2 A third and more viable solution is to make the dome as single piece in the shipyard itself. This is not difficult because the large domes are fabricated at room temperature and use pressure curing processes. Only a humidity controlled enclosed space is to be provided by the shipyard.

## 11. Dome Acceptance Testing

11.1 At present the sonar domes and windows developed in India are qualified through testing in the acoustic tank at NPOL. However, the transportation of large sonar domes from the factory to NPOL, its deployment in the tank and transporting it back to the shipyard is a cumbersome process. As mentioned in the previous section, the transportation may not be practical in the case of large domes proposed for the future platforms. Methods for testing the acoustic transparency of the domes through NDT tests in factory and to carry out acoustic acceptance trials at sea after fitment are to be developed. These methods also will be useful to conduct the periodic health monitoring of sonar domes fitted onboard the platforms. NPOL has initiated the work in this direction.

**12. Status of Research on Large Sonar Arrays and Domes**

12.1 NPOL is planning to develop the technologies and subsystems for the future sonar systems with large sonar systems. However, the currently available platforms in India cannot accommodate these large transducer arrays due to limited dome size. To overcome this limitation, NPOL is planning to use various research ships and platforms being built by DRDO. The PGAD TDV being built in CSL can accommodate sonar transducer arrays that are larger than the existing transducers. The New Acoustic Research Ship (NARS) planned by NPOL has facilities to install and test much larger sonar transducer arrays. The submersible testing platform, SPACE, being built in Underwater Acoustic Research Facility (UARF) in Idukki Reservoir can be used to test full sized submarine sonar transducer arrays. The sensors being developed can be installed and proved on these test platforms and can be made ready to fit onboard the naval platforms with larger sonar domes when they are ready.

**13. Conclusion**

13.1 To enhance the ASW capability, it is required to equip the warships and submarines with larger sonar transducer arrays, which would require sonar domes that are much larger than the ones installed presently. Installation of large domes has serious implications on the dynamic characteristics of the platforms. Present shipbuilding infrastructure might not be able to support such ships due to increased draught. Entire submarine nose cone will be available for the sonar transducers if the torpedo delivery scheme is changed from nose launching to flank launching, but it would also require major changes in the platform design philosophy. Due to difficulties in transporting large domes by road from the factory to a testing lab or to the shipyard, the large domes may have to be manufactured and tested in the shipyard itself.

13.2 DRDO, along with the production partners, has successfully developed and installed sonar domes onboard ships and submarines of the Indian Navy. The technology for building and installing such domes is already available within the country. The challenges in the ship design and shipbuilding aspects can be addressed by a concerted effort by the Navy, the shipyards and DRDO.

**14. Acknowledgement**

14.1 The indigenous development of sonar domes in India was initiated under the visionary leadership of Dr. J. Narayan Das, Chief Controller (Research and Development), DRDO (Retired) during his tenure at NPOL. Manufacturing technology for the first indigenous composite dome was developed by Prof. N.G. Nair (Retired) of the Indian Institute of Technology Madras. The sonar dome projects in NPOL were executed under the direction and guidance of Mr. Kurian Isac, Scientist G (Retired), Dr. D.D. Ebenezer, Scientist H, and Dr. S.K. Srivastava, Scientist G (Retired). RDE-414 bow mounted sonar dome project was led by Dr. Makarand Joshi, Scientist G and the team of R&DE (Engineers), DRDO, Pune. The export dome project HMS-X was funded by M/s Bharat Electronics Ltd. Bengaluru. M/s Kineco Ltd., Goa and M/s Larsen and Toubro Ltd. were the production partners for various sonar dome projects. Ms S. Vasanthakumary, Technical Officer B of NPOL who characterised dozens of test panels and domes through acoustic measurements in the tank during the past 14 years deserves a special mention. The author also wishes to thank Director, NPOL for granting the permission to publish this paper.

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# MARITIME POLICY FRAMEWORK TO REVITALISE INDIAN SHIP BUILDING INDUSTRY

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**1. Maritime Sector**

1.1 Shipping Industry is a vital part of the global freight transportation system, and is responsible for transporting 90 per cent of the world trade. As far as the Indian subcontinent is concerned, approximately, 95 per cent of the country's trade by volume and 70 per cent in terms of value is moved by sea and thus shipping continues to dominate the transportation sector of India's economy.

1.2 Geographical factors, such as the vast coastline close to 7517 km, along with 12 major, and 187 minor ports besides about 1,197 island territories puts the Indian maritime sector at an advantageous position. This coupled with its strategic location along most of the major shipping highways; India will continue to be a potential destination for shipping and transhipment in the futures to come.

**2. Shipbuilding - A Strategic Industry**

2.1. With aspirations of becoming, a major economic power, it is essential that India possesses a potent commercial shipping fleet, which is duly supported by a large ship building and repair industry.

2.2 As on 31 Oct 18, the number of ships under Indian Flag, was 1399 (12.79 Million Tonnes). It emerges, that with a growing maritime industry, there is need of adding about 20-30 ships in the merchant fleet each year. Additionally, defence of the merchant fleet, off-shore resources and the country's vast coastline, demands that the country simultaneously expands its naval ships and submarines for superior command and control in the Indian Ocean Region (IOR).

2.3 The dynamics of India's economic growth will continue to create a demand for new ships. Therefore, shipbuilding needs to be seen in the perspective of a strategic industry, intended to upgrade its national defence capability, drive economic development and serve as a catalyst for the nation's economic growth with the development of steel, and equipment manufacturing industries.

**3. Global Ship Building Scenario**

3.1 A century ago shipbuilding was dominated by Europe, having a world market share of about 80 per cent. However, due to high labour cost and ageing population of Europe, shipbuilding construction gradually moved away and is now highly concentrated to East Asian region, with South Korea, the People's Republic of China and Japan accounting to more than 90 per cent of the global production.

3.2 In terms of the four major ship building segments, whilst China and Japan dominate the Bulkers sector with a share ranging from 40-55 per cent each, Korea continues to dominate the containers and tankers sector with a share of more than 40 per cent. However, as far as cruise ships and passenger vessels construction is concerned, the EU continues to dominate the market by a substantial share of about 60 per cent. Although all four segments are concentrated geographically, the shipbuilding still is regarded as a global industry, due to large number of players/ shipyards, who are in constant competition for global contracts.

**4. India's Commercial Shipbuilding Industry**

4.1 Despite ample availability of the two major parameters of shipbuilding within the country viz. steel and labour, India remained largely insulated from the boom in global ship building industry and has a meagre contribution as far as the world ship making sector is concerned.

4.2 At present, India contributes about 0.5 per cent in global shipbuilding market. Infrastructure wise rated capacity of the country's shipbuilding yards is marginal vis-à-vis the world's capacity. Even then, the assets of the major private ship building yards remain largely unutilized due to low domestic demands. As on date, the commercial ship-building industry has a turnover of mere Rs 3,200 crores and focuses primarily on small and medium sized offshore vessels and cargo/bulk carriers.

**5. Government Initiatives - Commercial Shipbuilding Industry**

5.1 The Indian government over the past decade, has initiated a slew of measures to encourage domestic shipbuilding such as, granting of infrastructure status to the shipyard industry to help the shipyards to get long-term financing at cheaper rates, launching of a Rs. 4000 crores Shipbuilding Financial Assistance Policy for 10 years (2016-2026), and introduction of Right of First Refusal (RoFR) policy giving preference to Indian-built ships for carrying cargo or providing other services to State-run entities. The government is also undertaking a major infrastructure development of ports and inland water transportation, under the ongoing 'Sagarmala' programme.

5.2 The Indian shipbuilding industry has around 25 commercial shipyards and more than 30 dry docks. Despite the above listed government initiatives, there has been marginal revival of domestic shipbuilding industry, which has very few orders in the commercial shipping sector.

5.3 The medium/ large private size shipyards, such as ABG, Bharathi and Pipapav (now Reliance Naval and Engineering Limited) shipyards had a promising run for the initial few years in commercial shipbuilding sector, wherein they augmented their infrastructure and bagged some significant ship building orders, including export orders for medium and small ships. But in the long run they could not maintain their order book, amidst global shipping crises, which started in 2008 and peaked in 2015 - 2016. As on date, capacity utilization in the private shipyard is just over 25 per cent.

**6 Ecosystem for Commercial Shipbuilding**

6.1 The Indian shipbuilding industry is heavily dependent on the government support for subsidy, as majority of the private players are small shipyards and therefore lack infrastructure to build large/ medium ships. Further, the present fiscal and statutory rules on shipbuilding in the country are heavily loaded in the favour of export and discourage construction of ships by Indian yards for Indian flag. For the Indian shipping industry, it may be cheaper to run foreign vessels under a foreign flag. Earlier in 1980's, about 40 per cent of the country's export-import cargo used to be carried by the Indian Ships, today it has slipped to about 6 per cent.

**7. Diverse Maritime Regulations**

7.1 The shipping industry, catering to the demand across continents, is regulated by both domestic and international regulations. Domestically, there are several acts that regulate the Indian shipping industry, such as: the Merchant Shipping Act (1958), the Inland Vessels Act (1917), the Coasting Vessels Act (1838), and the Multimodal Transportation of Goods Act (1993). Besides, there are other statutes that govern the shipping industry indirectly. These include the Indian Ports Act (1908), the Dock Workers (Regulation of Employment) Act (1948), the Seamen's Provident Fund Act (1966), and the Inland Waterways Authority of India Act (1985). The wider regulatory framework makes stricter entry barriers into the industry, and adds cost to the compliance of such regulations. The present requirement to obtain multiple clearances from various departments acts as a deterrent to attracting investment into this sector.

**8. Multiple Actors in Policy Framework**

8.1 In India, the nodal responsibility of the Nation's shipbuilding and ship repair Industry vests with the Ministry of Shipping. The department of shipping controls the shipping and ports sectors and drafts national policies for shipbuilding and ship-repair, major ports, national waterways, and inland water transport. The Ministry also has the administrative control of two public shipyards, namely the Cochin Shipyard Limited (CSL), and the Hooghly Dock & Port Engineers Limited (HDPEL), which are primarily involved in commercial shipbuilding and ship repair.

8.2 Although the Ministry of Shipping remains the nodal state actor for shipbuilding industry, it is the Ministry of Defence, which is steering the Defence shipbuilding Industry, with a massive turnover of new construction vessels for the Indian Navy and the Coast Guard. Defence shipbuilding in India has largely been dominated by the four Defence Public Sector Undertaking (DPSU) Shipyards, viz. Mazagon Dock Limited (MDL), Garden Reach Shipbuilders and Engineers Limited (GRSE), Hindustan Shipyard Limited (HSL), and Goa Shipyard Limited (GSL), and are under the administrative control of the Department of Defence Production, MoD. Unlike commercial shipping market, defence shipbuilding industry has grown from strength to strength and at present about 32 IN ships and a number of CG vessels are under construction in multiple shipyards.

8.3 In addition to these two ministries, there are, in fact, more than dozen ministries, agencies and departments within the Government of India that also oversee policies related to the seas. For example, Ministry of Animal Husbandry, Dairy and Fisheries (formed in 2019) and the offshore hydrocarbons under the purview of the Ministry of Petroleum oversee policies related to the sea but of their concern.

8.4 The maritime potential of India can be realised only if all the state actors come on a common platform for formulation of supportive policies and measures such as, subsidies, easy finance, tax benefits, preferential orders, etc., to lay a thrust on development of the sector. It is vital that both commercial shipbuilding and warship building are looked in tandem. The Ministry of Defence with its huge order book can play a pivotal role in revitalizing the private shipyards, in collaboration with its DPSUs.

**9. Nodal Organisation for Developing Maritime Ecosystem**

9.1 Along with bringing the state actors together, it is imperative that all the associated stakeholders of the shipbuilding industry also come on a nodal platform to formulate strategic policy framework and a maritime conducive ecosystem. The collaborative forums of Shipbuilders Council of America (SCA) and the China State Shipbuilding Corporation (CSSC) are some of the examples of centralised bodies, rolling out effective strategies for indigenous shipbuilding. Both these bodies comprise members from the defence shipbuilding and repair yards, the major commercial ship building companies and the associated maritime supplier base.

9.2 As a nation with aspirations of a global ship building industry, we need a nodal organisation that would formulate policy and regulatory roadmaps and monitor all the developments in the maritime field. This organisation need to be represented by all stakeholders of this domain, i.e. senior representatives from the Ministry of Shipping, Ministry of Defence and other associated Ministries, Managing Directors (MDs) of all related PSUs and major private shipyards, leading indigenous steel manufacturers and equipment OEMs, along with a suitable representation from relevant academia.

9.3 With all stakeholders onboard, we can thereafter, look at enhancing the essentials of ship building industry such as, availability of land, trained labour force and matching industrial support from other sectors such as, the iron and steel, metallurgical and machinery manufacturing industries. Suitable capital investment is to be earmarked to strengthen and upgrade technical and technological capability, to enhance its design and construction capability for the competitive construction of ships. This centralised framework will offer a platform for establishing joint ventures for enhancing domestic shipbuilding industry and to demarcate shipyards for repeat orders of similar kind of vessels.

**10. Defence Shipbuilding Industry**

10.1 Since the past many decades, IN and CG shipbuilding requirements have been met through the four DPSUs, who over the years have acquired substantial expertise in the hull design and construction of warships, in line with stringent Naval specifications. For instance, M/s GRSE, which delivered its first warship in 1961, has come a long way and as on 30 Mar 19, and has delivered its 100th warship - A Landing Craft Utility, L-56 to the Indian Navy.

**11. Private Shipyards in Warship Construction**

11.1 A few years back, as state-owned defence yards were strapped for capacity and bandwidth, the government evaluated and approved some private yards for building warships. However, despite defence shipbuilding industry migrating from the age old public shipyard nomination era to the present competitive bidding practice, the private shipyards have failed to grab major warship orders. Unlike a well-established public shipyard, a medium/ small private shipyard needs to invest heavily in building up infrastructure and therefore has to perforce consider this while quoting. Further, in the absence of a strong order book, a private shipyard faces difficulty in retention of its trained manpower and this affects its ongoing operations.

11.2 By and large, involvement of private shipyards in warship building has not yielded the desired results. Majority of the selected private shipyards are now facing financial constraints, in terms of losses in the operations, and calling back of loans by secured lenders, which has affected the timely execution and delivery of existing warship orders.

11.3 The recently concluded IN shipbuilding contracts for 04 Survey ships, 16 ASW shallow water and 02 Diving Support Vessels (DSV) with M/s GRSE, CSL, HSL respectively, implies that the public shipyards will continue bagging orders, with their cost competitive bids.

**12. Warship Orders for Future**

12.1 In line with the nation's aspiration of a 'blue water' Navy, defence shipbuilding requirements are likely to expand appreciably. As per the Maritime Capacity Perspective Plan (MCPP), the Indian Navy is likely to grow from its existing 137 ships to a 200 ship fleet by 2027. The ICG, which has more than 160 platforms presently, is expected to acquire additional 50 vessels in the next five years. Therefore both IN and CG combine would require 100 plus ships over the next 10 years, at a demanding rate of about 10 warships per year.

**13. Joint Ventures of Public - Private Shipyards**

13.1 Collaboration between the private yards and the DPSUs would bring forth a host of advantages for not only the shipyards but also to the customer, i.e. IN and CG. Wherein, the DPSUs have experience in warship building and retain a skilled design team; the private yards, for their part, can provide efficient managerial skills and faster decision and outsourcing capabilities, thereby limiting time and cost overruns. Joint ventures and partnerships between the private and public sector could result in private yards gaining the much needed experience to design and build ships indigenously and the public yards mastering modern managerial skills and reducing material procurement cycle at competitive rates. Joint ventures also open up additional geographical market options for localizing the construction materials for cost effective supply chain management. At the front end, the DPSUs being themselves part of the government machinery and with their past customer relations, can enable better communication and coordination with defence/ the Indian Navy in formulation of vessel/ equipment design specifications, and acceptance procedures, leaving the private shipyards to concentrate on core production activities.

13.2 Under the joint venturing, DPSUs with their credible financial health and reputation may present itself as the lead yard, which will absorb the risk component associated with shipbuilding industry, so that customer interests are protected and in turn insulating the private shipyard from environment pressures.

13.3 The need of the hour is for public and private shipyards to sit together and come up with an optimal shipbuilding load share plan for sustainable growth. Based on their respective strengths and available infrastructure (docks/berths) in shipyards, each DPSU may identify and tie up with a small/ medium scale private shipyard for common bidding for all future defence shipbuilding projects.

**14. Shipbuilder to Service Provider**

14.1 In the forthcoming decade, with the expansion plans of a 200 ship fleet for both IN and CG, the maintenance load on the existing Naval Repair yards is likely to exceed their capacity. The defence industry may look at the shipyards for adopting dual roles of both, shipbuilder and a service provider in maritime domain. Shipyards may conclude comprehensive CMCs with IN and CG for a class of ships to undertake major maintenance (AMPs/refits), thereby ensuring a constant source of work for the life of the ship. The ship, in turn, will tend to gain, as it will provide them a single point contact for all the onboard maintenance. The shipyards will be expected to liaise with respective OEMs for spares and OEM assistance (if any). Once the modalities of service provider are formulated and successfully tried out on a pilot defence project, the CMC cost may be henceforth, considered for inclusion in the main project cost under the capital budget. Even Base and Depot spares/ storage responsibility can then be shifted to shipyards, for catering spare support for the ships. Service provider model is being practiced by many Navies of the world, with considerable benefits for both navy and the shipyards.

**15. Conclusion**

15.1 The study of various aspects of the global and the Indian shipbuilding industry clearly shows that India needs to look at multiple areas, including regulatory framework and maritime policies and establish a centralised forum for building up an ecosystem which promotes commercial shipbuilding. Considering the financial constraints of existing private shipyards and the experience or the strong order book of Defence Public Shipyards, Joint Ventures/ partnership between PSUs and private shipyards should be the way ahead for future ship building in defence industry.

15.2 In light of the likely demands of about 100 new warships from both the Indian Navy and the Coast Guard, over the next decade and the ever expanding domestic shipping, the Indian shipbuilding industry has the potential to grow considerably.

# EVOLUTION OF MODERN TECHNOLOGIES IN INDIAN SHIPBUILDING INDUSTRY

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**1. Introduction**

1.1 The tides of change that are sweeping India and the globe have presented many challenges as well as opportunities for the future. Rather than let ourselves be swept away by the changes, we, the warship designers and builders have to proactively manage these changes with vision and adaptability. It is high time that we discuss the future possibilities and technological innovations that could revolutionize the art of shipbuilding in India. Through this paper various technology enablers have been highlighted for an efficient shipbuilding environment. The future of shipbuilding confidently lies in the hands of naval constructors in the Indian Navy.

**2. History of Naval Architecture in India**

2.1 The glorious maritime past and rich shipbuilding tradition of India dates back to as early as 2300 BC. The world's first dock at Lothal (2400 BCE) was located away from the main current to avoid deposition of silt. Modern oceanographers have observed that the Harappans must have possessed great knowledge relating to tides in order to build such a dock on the ever-shifting course of the Sabarmati, as well as exemplary hydrography and maritime engineering. This was the earliest known dock found in the world, equipped to berth and service ships. It is speculated that Lothal engineers studied tidal movements, and their effects on brick-built structures, since the walls are of kiln-burnt bricks. However, in the beginning of the 16th century our control over the seas started diminishing with the invasion by the Portuguese in the end of the 15th century and thereafter the British East India Company in the 17$^{th}$ century. In 1947, the Republic of India's navy consisted of 33 ships, and 538 officers to secure a coastline of more than 4,660 miles (7,500 km) and 1,280 islands. The Indian Navy conducted annual Joint Exercises with other Commonwealth navies throughout the 1950s. The Navy saw action during various wars of the country, including the Indian integration of Junagadh, the liberation of Goa, the 1965 war, and the 1971 war. Following difficulty in obtaining spare parts from the Soviet Union, India embarked upon a massive indigenous naval designing and production program aimed at manufacturing destroyers, frigates, corvettes, and submarines.

2.2 The East India Company had set up factories and a shipyard for repairing and building ships. In 1735 the shipyard was shifted from Surat to Bombay, which is now the Naval Dockyard (Mumbai). During the course of the next 100 years this yard built no less than 115 war vessels and 144 merchant ships, including 84 gunships for the Royal Navy. The Indian ships were superior to the British built ships, prompting the Admiralty to place orders on Bombay. This provoked the historical strike among the Thames shipbuilders. The early Indian Naval fleet consisted mainly of squadron of ships deployed from the Royal Navy. Post-independence, the first Chief of Naval Staff, Sir Mark Pizey floated the ten-year replacement plan of the Indian Naval ships in 1951, which also envisaged building of minor naval vessels.

## 3. The Evolution

3.1 Warship building in Independent India was ushered in with the license production of the Leander class frigates in the early sixties at the Mazagon Dock Ltd. Six ships of the class were built and delivered between 1972 and 1981 with the last two of the class undergoing extensive design modifications for accommodating the organic Sea King helicopter. This modification was carried out by the Indian Naval architects and these ships then became the smallest platforms in the world to carry such large helicopters. With a modest beginning of designing ocean going Tugs, LCUs and SDBs in the sixties, the Navy's design organisation embarked on the design of the Sandhayak class survey vessels and eight ships were built and delivered to the Navy. These ships serve as the workhorses of the navy for hydrographic survey operations. In the seventies, the Navy's design organisation embarked on the first warship design - the Godavari Class frigate and three ships were built and delivered to the Navy. The highlight of the design was the use of the same propulsion plant of the smaller Leanders to drive a larger hull with 1000t more displacement to give a slightly better top speed performance.

3.2 Three more ships with a modified design of Godavari, designated P16A Brahmaputra class, were built and delivered between 2000 and 2005 by GRSE. The early eighties also witnessed the design of the Khukri class (P25) corvettes. Four ships were built and delivered with four more of the modified P25A class delivered by GRSE between 1998 and 2003. The design of the Magar class LST (L) was undertaken in 1987. Two ships of the class have been built and delivered to the Navy with the last one built to a slightly modified design. Three more ships of the follow-on class have been ordered on GRSE, Kolkata. The first of the series 'Shardul' has been delivered. In the mid-eighties, the Navy embarked upon the design of the prestigious Delhi class destroyers. Three ships of the class have been built and delivered by Mazagon Dock Ltd. These majestic ships are the proud frontline combatants of the Navy, showcasing India's design and building capabilities for warships. India's four defence shipyards - Mazagon Dock Ltd, GRSE, Goa Shipyard Ltd and Hindustan Shipyard Vishakapatanam have despite several trials and tribulations, successfully given form to the designs of the Navy. Realisation of these designs would not have been possible but for the dedication and steadfast commitment of our shipyards.

3.3 In the late eighties and the early nineties there was a lull in indigenous design and construction activity due to lack of funding for new projects. However, after obtaining a sanction for design in 1995, the design of the P-17 class frigates was progressed. The P-17 design marks a watershed in the design history of the Navy. This design embodies several new design concepts, and enhanced survivability features to meet future requirements. This has benchmarked the design strategies and design procedures for future projects. In addition, the Navy's design organisation is engaged in the design of the P-15A class destroyers, which are a follow-on of the successful Delhi class but with improved features and updated weapons and sensors.

3.4 There has been a significant growth in the ancillary industry base over the last few decades to support the growing warship building in the country. We are indeed proud that the indigenous content of our warships has gone up to over 75 per cent. The last few years has seen the private sector joining the fray for indigenous development of weapon systems.

## 4. The Global Change

4.1 The world is now passing through many tides of change. The changing geo-political and geo-economic scenarios are redefining global relationships and strategic alliances. The emerging economies owing to their growing political stature are having to cope with added dimensions of their defence strategies and foreign policies. World over the theatres of action are moving from the blue waters to the littoral seas. Navies are facing conventional as well as asymmetric threats. There is also the need for cooperative joint operations with international maritime forces to serve the diplomatic initiatives of the government as well as participate in joint disaster relief operations. The rapidly changing technology has brought in its wake a host of possibilities, which if ingeniously exploited can help build cost effective warships in enviable timeframes with tremendous flexibility of roles.

4.2 Against the above backdrop no nation or organisation can survive if it is resting complacent and adapts only to incremental changes. What is required is a whole and sensible transformation to cope with the rapidly evolving environment.

**5. Vision of Transformation**

5.1 In realisation of the above facts, the Navy has voluntarily indoctrinated a "Vision for Transformation". The major aspects of the vision relevant to warship design and construction are as follows: -

(a) Focus on "deliverable effects" and associated capabilities rather than merely on numbers of platforms.

(b) Progressive achievement of complete maritime domain awareness through a commitment to network centric capability.

(c) Flexibility and agility in terms of platform and equipment so as to enable transnational capabilities for use in operational, disaster relief or humanitarian situations.

(d) Build capacity to work in close partnership with the private sector and/ or Defence Public Sector undertakings, in order to deliver cutting edge capabilities to our maritime forces, through indigenisation.

(e) Promote cost consciousness and accountability by a continuous and dynamic review of processes and procedures.

(f) Change in extant processes to enhance efficiency and achieve shorter and assured lead times within which to deliver the desired capabilities.

(g) Adopt technology related to "best practices" from industry and/ or the Navies of other countries.

(h) Articulation of training philosophies that caters to future challenges and manpower implementation.

5.2 In a nutshell, the Navy's vision enjoins us to recognise the full spectrum of operations of our future warship and focus on exploiting the best available technology through partnership with industries to produce cost effective warships with considerable flexibility in attractive timeframes.

**6. Resource Management**

6.1 The changing technology has afforded several efficient processes, equipment and systems for warship design, construction and maintenance. It has also revolutionised the manner in which we can manage the processes of design and construction. But it has also brought in its wake the risk of obsolescence. With traditional ship design and building methods having a gestation period of up to 10 years from concept to commissioning, the systems become obsolescent by the time the ship enters service. There are also considerable difficulties of product support during the service life of the ships due to obsolescence of technology. It, therefore, calls for ingenious strategies to exploit technology for designing, building and supporting warships so that they remain modern and supportable throughout their service life. These technology management strategies may broadly be categorised under the following: -

(a) Design philosophy to support evolutionary acquisition or technology insertion at any point during design, build or service life of the warship.

(b) Increased participation of the OEM in design, fabrication, integration and life cycle support of the system.

(c) Exploit IT enabled technologies for collaborative design and construction in order to drastically cut down timeframes for realising a warship.

(d) Navy-Shipyard-Industry partnerships going well beyond the current relationships for conceiving, designing, executing and life cycle supporting of warships.

6.2 Although the spirit of "concurrent design and build" strategy adopted for indigenous warship projects was aimed at achieving reduced build times, the process is now beset with several stifling points when the designer and builder do not get detailed interface definition of the numerous "handshake points" of the OEM's system /equipment with the ship. The whole picture gets a little murky with the customer wanting continuous improvements, the supplier continuously developing the system and both arguing with the shipbuilder that design and production in the current state can do without the data for much more time. We, therefore, need to adopt a strategy of modularity that will allow minimal interfaces of the OEM equipment/ system with the ship and even these minimal interfaces can be standard agreed interfaces at very early stages of the project.

6.3 With evolving technologies, sophistication and complexity of equipment and systems, warship projects are becoming capital intensive and high-risk ventures in terms of realising intended capabilities within the timeframe and cost budgets of the projects. There is, therefore, a need to forge a much stronger partnership between the Navy, shipyard and the industry in order to realise a new warship. This partnership will be based on early and continuous involvement, deep sense of purpose, assured ordering, transparency of cost and timeframes, judicious balancing of cost, time and capabilities and sharing of risks of the project. The focus of the Navy must be on defining capabilities of equipment and systems while the detailed specifications are evolved by the industry. This will help clearly demarcate responsibilities for development within strict timelines.

6.4 With a comfortable economy, while funding warship projects has now not been much constrained, there is nevertheless the pressure to complete projects within projected cost and timeframes. The present system of obtaining sanctions and revised sanctions seeks to place considerable accountability for cost and time overruns. Future acquisition projects have to, therefore, carefully work out strategies for completing projects within projected cost and timeframes. This now underlines the need to complete the design and freeze ship definition in adequate detail before sanctions for build are obtained.

**7. Technology Enablers in Shipbuilding**

7.1 **3-D Printing Technology**. The 3D printing technology makes it possible to construct real objects from virtual 3-D objects. This process is carried out by cutting virtual object in 2-D slices and printing the real one, slice by slice. There have been several 3-D printing processes invented till date but very few are commercially affordable and sustainable. Currently, this technology is being used in industries to produce scientific equipment, small structures and models for various applications. Further developments in this process can lead the industry to use this technique to build complex geometries of ship like bulbous bow easily. The prospect of using 3-D printers to seek quick replacement of ship's part for repairing purpose is also being investigated. The Economist claims use this technology to be the *"Third Industrial Revolution"*.

7.2 **Buckypaper**. Buckypaper is a thin sheet made up of carbon nanotubes (CNT). Each CNT is 50,000 thinner than human hair. Comparing with the conventional shipbuilding material (i.e. steel),

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buckypaper is 1/10th the weight of steel but potentially 500 times stronger in strength and two times harder than diamond when its sheets are compiled to form a composite. The vessel built from this lighter material would require less fuel, hence increasing energy efficiency. It is corrosion resistant and flame retardant which could prevent fire on ships. A research has already been initiated for the use of buckypaper as a construction material of a future aeroplane. So, a similar trend can't be ruled out in case of shipbuilding.

7.3 **Shipbuilding Robotics**. Recent trends suggest that the shipbuilding industry is recognizing robotics as a driver of efficiency along with a method to prevent workers from doing dangerous tasks such as welding. The shortage of skilled labour is also one of the reasons to look at robotics. Robots can carry out welding, blasting, painting, heavy lifting and other tasks in shipyards. Geoje shipyard in South Korea which boasts of launching around 30 ships a year, 68 per cent of its production processes is carried out by robotic systems which contribute to achieve such high production rates. Robot was first designed for welding process in shipyards but now inspection and pipe cleaning robots are also available. The most interesting one is a spider robot which autonomously crawls over the surface of vessel and prepares surface for painting by blasting off rust and other contaminants. The 'Iron Man' wearable robot is also in fray which can enhance worker's strength and stamina. Hyundai Heavy Industries (HHI), which has developed mini welding robots, is set to use robotics in shipbuilding. These trends clearly suggest that the future of shipyards will be smart and digital.

7.4 **Big Data Analytics**.Big data analytics is a term used to describe the process of analysing this big data to uncover hidden patterns, unknown correlations, ambiguities, market trends and other useful information. The huge amount of data produced today is difficult to be processed through traditional data techniques and applications. The scale of the challenge is well illustrated by the current estimate of a 4,300 per cent increase in annual data generation by 2020 and the figure is projected to increase even further by 2030. The management and analysis of big data will become increasingly important and it is predicted to create a major impact on the marine world in the future, driven forward by the demand for information and the need to handle the variety of new data sources that are likely to appear.

However, big data may also face other factors that can threaten its adoption, such as the lack of the necessary data analysis skills required to exploit big data. Most definitions of big data include the 'three Vs' (data of high volume, velocity, and variety) for enhanced insight and decision making. Some organisations have also added a fourth V that represents veracity, which concerns the accuracy and reliability of data. With these definitions, greater volumes of data will not necessary mean a better output. The more important thing is analysing poor quality data that can lead to ambiguous and misleading information, potentially resulting in poor decisions. In the future, new technologies may emerge that can improve big data analytics. Among these will be some of the so-called 'smart machine' technologies and computing systems that process data in a manner similar to the human brain.

7.5 **Artificial Intelligence (AI)**. Sea-going ships are autonomous complex objects that are intensively automatized due to safety and economic factors. The issue is complicated enough to entail a need for powerful methods such as Artificial Intelligence techniques. There are several problems in shipbuilding industry where Artificial Intelligence seems to be particularly suitable. They include: inventing diagnostic models on the basis of experimental data, power systems protective relying, unmanned power plant control system and merchant fleet management. The concept of the sea-going robot-ship is widely discussed, and some general remarks on the Artificial Intelligence approach to problem solving and conclusions containing agenda for research are today's hot topics of discussions in technical forums.

The South Korean Government hopes to increase productivity by 20 per cent and lower production costs by 10 per cent with the project. South Korea accounted for 43 per cent of global shipbuilding orders this year, ahead of China, but smaller and mid-size yards still tend to lose out. They only got orders for four tankers in the first quarter of 2018, and their share of the global market dropped from 10 per cent in 2014 to four per cent in 2016. The government has begun a preliminary feasibility study of the Korean Smart Shipyard (K-Yard) project in 2018. The total budget of the project is estimated at 400 billion won (US$ 360.04 million). From this, 250 billion Won (US$ 225.02 million) will source from the central government and 150 billion Won (US$ 135.01 million) from the local government and the private sector.

7.6 **Connected Sensors**. The term 'sensor' covers the wide range of devices used to measure the physical environment in which a vessel may be operating in, the characteristics and state of the vessel, as well as the physiological and mental condition of the ship's crew. Sensor technologies are developing rapidly to meet the ever-growing consumer demand for data and information. As an example, The Internet of Things (IoT) allows real-time monitoring, control of systems and also addresses the need of ever-increasing capabilities to measure the ocean environment, including biological, acoustic and electromagnetic characteristics. Sensor adoption is driven by advances in miniaturisation coupled with low-power generation technology. Moving the intelligence into sensors with closer integration of sensors, actuators and processing power, lower production costs to meet the demands of wearable technologies; standardisation, in particular at the junction between device and chip architecture; low-power transmission of data and energy harvesting; and the management and integration of sensor types such as semiconductors and Micro- Electrical-Mechanical-Systems (MEMS) sensors act as the enabler for technology developments in improving the interaction between people and machines. Cognitive systems will not necessarily be programmed to anticipate every possible answer or action needed to perform a function or set of task; instead it will be designed to feed the learning loop in an exponential manner through artificial intelligence (AI) and machine-learning algorithms. The widespread use of sensors is already being introduced in areas such as automotive and scientific applications and soon will expand into the marine/ maritime domain, enabling better situational awareness and vessel management.

7.7 **Advanced Material**. Advanced material refers to all material engineered to deliver specific physical and/ or functional properties in their application. The trend with all metallic, ceramic, polymeric and composite materials is to achieve improved capabilities such as strength, toughness, durability and other useful functionalities by designing it at the nanoscale and harnessing those properties in large structures. The structure and properties of advanced materials at the nano scale- i.e. one millionth of a millimetre - is now well understood, and this is leading to the challenge of manufacturing advanced materials to realise capabilities in bulk structures. Termed as nano-engineering and the materials are referred to as nano-materials, the research and commercialisation of nanomaterials will continue to accelerate large-scale structures with increasingly refined and reliable properties. Desirable functionality, such as environmental sensing, self-cleaning, self-healing, enhanced electrical conductance and shape modification, is anticipated through the development of nano-materials, and, in turn, will deliver performance benefits in the commercial shipping, naval and ocean space industries.

7.8 **Virtual Reality (VR)**. The shipbuilding industry faces challenges such as high costs of production, while designing large and complex ships which have to comply with safety requirements. VR gives a realistic understanding of a ship model's data. Virtual Reality enables path planning of ergonomics inside the ship, visibility and maintenance operations. VR solution for Virtual prototyping is used during the design and development stages of shipbuilding. Besides, when a VR system is installed next to a production site, it can also be used by the team preparing and assembling the ship: they are immersed in a realistic environment and can foresee what needs to be changed. Virtual Reality based environment can also be created which allows the virtual execution of critical operations such as ship docking, ship positioning verification and transfer of equipment and components on the ship. This Virtual Docking environment enables the user to verify design aspects of ship repair operations from the ergonomics point of view, to place the ship on the dock as well as to evaluate alternative positioning ways, control the cranes and get critical quantitative information about the executed processes.

7.9 **Human Augmentation**. Human augmentation has made considerable advances in terms of enhancing both physical and cognitive human capabilities which include power assisted suits and exoskeletons that enable paraplegics to stand and walk; ocular sensory substitution devices to enable improved vision; and cochlear implants to enhance hearing. The field of human augmentation extends beyond the use of prosthetics and exoskeletons to include bionic implants (referred to as 'bions') and the development of drugs and administrations that can enhance human biological functions. Alongside these developments, work is also focusing on 'neuro-enhancements' to enable superior memory recall or speed of thought. Human augmentation promises improved human performance and the need for future navies to operate more effectively with fewer crew members that will drive the technology adoption. Exoskeleton technology is expected to be at the forefront of this adoption, but intrusive bions and neuroenhancements will appear much later as they generally augment human strength only rather than replacing it and tend to enhance one part of the body. Without external power, exoskeleton technology can deliver a 10-20 per cent boost to the user's lifting power by transferring weight to the ground.

7.10. **Vision for Future - The Digital Shipyards**

*Greater user visibility in design*: It is essential to increase the use of virtual reality in the future to help the user to more clearly perceive the ship's arrangements in order to introduce required changes at an early design stage itself. The present practice of tendering drawings and documents are not adequate for the user to get a feel of the design. The thrust would be to have increased simulation studies to optimise ship arrangements and systems design and enable product evaluation before selection.

As labour pools continue to dry up and shipyards struggle for efficiency gains in an intensely competitive global market, shipbuilders are increasingly relying on greater levels of automation to keep up with their order books. It is the same story in almost every corner of the heavy industry - regardless of labour shortages or economic austerity. Employers are recognising the value of robotics as a driver of efficiency and a method of sparing human workers from monotonous or dangerous tasks. While robots continue to help plug the labour gap in all manner of heavy industry sectors, the rise in their use is becoming a significant job creator elsewhere. As the use of robotics in shipbuilding expands and technology such as sensor systems and artificial intelligence becomes more complex, the industry is gradually (in an industry like shipbuilding, all change is gradual) customising automation tech to optimise its use for shipyard operations.

The existing Wide Area Network Connectivity (WANDS) with the shipyards needs to be extended to major equipment/ system suppliers. Web-based utilities need to be acquired and added to existing ship design and production software in order to facilitate design in a multi-user environment.

*Develop Advanced Hull forms.* To meet the Navy's requirement of speed, agility and flexibility we need to develop advanced hybrid hull forms combining the advantages of powering, sea keeping and stability. At the same time the hull form has to afford considerable usable space in convenient dimensions for housing mission modules to give the platform considerable flexibility of roles and potential for future technology insertion. There is thus a need to work closely with the R&D establishments through the hydrodynamic subcommittee to evolve new unconventional hull forms.

## 8. Conclusion

The Indian Navy is passing through an intense phase of modernisation and transformation. The future induction programme of ships, submarines and weapon systems will have an increasing thrust on indigenous acquisition. Evolving technology and need for flexibility of roles of future warships call for adopting bold new strategies in design and construction. Automated technology and robotic systems are as big a part of modern shipbuilding as many other manufacturing industries. Robots, carrying out welding, blasting, heavy lifting and other tasks, are helping to plug the labour gap at shipyards, while sparing their human colleagues the most dangerous and thankless tasks. Stronger partnerships between the navy and the industry including transnational cooperation as well as judicious exploitation of available modern technologies for collaborative design and building will help meet the Navy's vision for transformation.

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### Disclaimer

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# DIGITAL TRANSFORMATION IN INDIAN SHIPBUILDING AND INDUSTRY 4.0 PERSPECTIVE

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**1. Introduction - Digital Transformation**

1.1 Digital technologies are accelerators of innovation. It can improve efficiency in design and development of new product, in manufacturing, make new products and services smarter and enable new business models. Industry segments like Transportation, Discrete Industrial manufacturing and Shipbuilding are gearing up to get into next level of maturity with digital transformation and Industry 4.0 initiatives.

1.2 With increased adoption of IoT/IIoT for connected products, connected manufacturing, inclination of MBD/MBE/MBSE for developing product where model (fully developed models and not just 3D Geometry) is the basis for collaboration, *these soft models along with IoT sensor data are later being used for building Digital Twin* of the product, manufacturing system in production. For aftermarket services these CAD models are used to create highly intuitive AR/VR/MR applications for either services, maintenance or for e-Learning.

1.3 Digital transformation is not just about adopting new technologies its significance in the business parlance extends to how technology can be used to create and sustain a competitive advantage.

1.4 It is taking shape of Industry 4.0 solutions in manufacturing by leveraging these emerging technologies along with Artificial Intelligence (AI), Cloud, Big data, Analytics and Blockchain as strategic business choices around technology. Digital Twin based on the field data via sensors and other means is a transformative thinking to efficiently monitor the construction of large capital sensitive assets like Ships and later run them efficiently during operation.

1.5 Growing product complexity, increasingly distributed processes and systems, and fast time to market are key drivers pushing manufacturers to urgently modernize through digital transformation. *PLM once solely an engineering product development tool, has now become central to any digital transformation initiatives.*

1.6 PLM was called "*Single Source of Truth*" has now become "*Single Source of Digital Thread*" enables the collaboration across enterprise functions and processes across the value chain of Digital Thread to make the processes lean and efficient, results into faster time to market during development of product /construction of an asset like Ship and later in operation enables Digital twin, Data Analytics etc for intelligent decision making and smart lifecycle support as market services.

**2. Shipbuilding Exploring Digital Transformation**

2.1 All developed countries are concerned with maintaining industrial and innovation capabilities as engines of their economies. Understanding that there is no sustained economic growth without a strong and innovative industry, there is a global approach to improve industry performances by leveraging new technologies, known as the Fourth Industrial Revolution. [1]

2.2 Digital Transformation in Shipbuilding is in exploration via adoption of PLM to transform Ship design and development and i4.0 for manufacturing by way of leveraging the new digital technologies as IoT/IIoT for smart connected machines, M2M communication, ML & AI with cloud hosted data analytics solutions.

2.3 It can transform the design, manufacturing, operation, shipping, services, production systems, maintenance and value chains in all the aspects of shipbuilding industry. In a traditional approach, shipbuilding industry continuously improved with new machines, technology and new implemented organizational restructuring. Whereas, today there are five main problems that are considered; production efficiency, ship safety, cost efficiency, energy conservation and environmental protection. Therefore, to create new value, the ship must become a Smart Ship capable of "thinking" and to be produced through Smart Shipbuilding Process. [2]

2.4 Navantia, Spain has finished the analysis of the concept i4.0 in 2016 and its application to the naval shipbuilding industry, referred as 'Shipyard 4.0'. The implementation process has begun with several projects that involved various technologies. To incorporate them in the new project, for naval vessels and systems, special focus has been put in the future F-110 Frigate. [1]

2.5 *This white paper attempts to highlight the challenges faced by Indian shipyards in digitalizing their information flows and processes and brings out possible solutions for a sustainable digitalization offensive.*

### 3. Indian Shipbuilding and its Readiness for Digital Transformation

3.1 Indian Shipbuilders particularly in the Public Sector, also like European Shipbuilders, are currently swimming on a wave of success that is carrying them across some shallows. The shallows of an incomplete digitalization, which although allowing a comparably high degree of industrialization of ship production with the participation of a multitude of sub-contractors and vendors, is still by far not as consistent as it could be. Therefore, it is imminent for the Indian Shipbuilders to drive forward the digitalization of their business processes across the stakeholders namely Customer, Designer, Internal shipyard departments, Operator/ User and further extending it with partners and suppliers. Bringing the information together in a digital product model that accompanies the entire ship (product) life cycle, including the operating phase, as a digital master and later as digital twins, not only promises enormous rationalization potential in the processes, but also opens the opportunity for companies to offer new value-added services. Ships are increasingly becoming cyber-physical systems in which things such as propulsion control, dynamic positioning or ship management are functionally determined by software and can be changed during operating life by updates. [5]

3.2 While new ship construction has been declining worldwide for more than ten years and two thirds of all shipyards have disappeared from the scene since 2009 alone, most Indian Pubic Sector shipyards are doing well. They are currently receiving more orders, both by nominations as well as competitive bidding, than they can process and are thus expanding their order backlog. The success of Indian shipbuilding is not least the result of the concentration on the construction of complex products such as warships and submarines, whose demand continues to exist in consonance with strategic requirements of the Indian Navy, it is also supported by the Government of India who have unleashed a slew of initiatives to promote shipbuilding in India. Shipbuilding industry in India is envisioned to grow as 'Strategic Infrastructure Industry', which also is being promoted and publicised in this International seminar on 'Nation Building through Shipbuilding'.

3.3 *The use of digital technologies plays a key role – with respect to both*, the efficiency of internal processes between design, development, planning, procurement, production, etc., and an efficient integration of the supply chain, which contributes more than 80 percent to value creation in warship and other ship construction. The ability to manage the entire process logistically as prime contractor and thus ensure on-time delivery of the ships is a key success factor and competitive advantage for Indian shipbuilders.

3.4 Indian shipyards like Mazagon Dock Shipbuilders Ltd and Garden Reach Shipbuilders Ltd under the aegis of Integrated Headquarters of MoD (Navy)/ DND(SSG) have already started digitalizing their business processes earlier than their competitors in the country by implementing PDM/ PLM for Project 17A, however, they are yet to be in a safe harbour. Their lead must continue and that is why they need to think about where and how they are moving forward with their digitalization. As a cutting-edge PLM consulting and solution provider, duly backed by shipbuilding domain expertise, L&T Technology Services, a prominent jewel in the crown of Larsen & Toubro Group of Companies; endeavours to support shipbuilding industry in the digital transformation and implementation of i4.0 initiatives as well. Over the last 10 years, the company has developed into a recognized partner for not only the maritime industry along with Siemens but also, today counts renowned companies such as Vestas, Scania, Wartsila, IHC, Thales, UTC Carrier, OTIS & Collins Aerospace, Exxon, Shell, Gardener Denver, Calsonic Kansei, Mercury Marine, etc among its global clients to name a few apart from internally transforming new product development at L&T Heavy Engineering, L&T Hydrocarbon via PLM.

## 4. Business Challenges in Digitalization

4.1 The major challenges being faced in Global Shipbuilding industry are: -

(a) Need for **Significant design maturity and creation of digital assets /** *optimal solutions* as the first major milestone rather than all milestones based on physical progress like PKLD.

(b) Need for **Collaboration in Design, Procurement & Manufacturing** by getting rid of information 'silos' out of people, teams, stakeholders, departments & systems. And while undergoing it, getting out of *'illusion'* that it has taken place.

(c) **Leverage the in-depth expertise from Legacy Data / Systems.**

(d) **Organization Change Management to adapt to New Ways of Working** – Willingness to embrace change and work as a team for the best interest of the company.

4.2 In ship design and construction, huge amount of digital information is generated with different IT systems. The great challenge navy and shipyards are facing is the efficient management and exploitation of this information during the complete life cycle, right from Preliminary/ Functional Design to Detailed Design development, Procurement and through Production processes to Operations. To achieve this, the integration of the heterogeneous system landscapes in the Shipyard and their supply chains must be improved. Especially the exchange between mechanical CAD systems (such as NX, CATIA) and shipbuilding specific applications like AVEVA Marine, CADMATIC or NAPA is a highly complex topic due to the different system approaches.

4.3 The different philosophies not only complicate the horizontal data exchange between mechanical and intent-driven CAD systems and the provision of data into applications for production preparation and production control, but also the vertical integration with the enterprise PDM/PLM and ERP applications. These applications are the basis for consistent management of data and change management throughout the entire ship life cycle. In practice, these are often located in different file-based or database 'silos' that are hardly integrated with each other. As a result, the digital flow of information within Shipyards and with its stakeholders is often difficult due to format and even media breaks. Under such circumstances, digital *traceability* is virtually a challenge. [5]

4.4 In the absence of a continuous and consistent digital ship model concept, the exchange of digital information between the departments is usually drawing-based and often paper-based. Coordination during development, production and assembly therefore involves a great deal of organizational effort. With the delivery of the ship, the Navy/ Customer receives a huge stack of paper documentation, which they need to process manually and import into their IT systems to support operations or maintenance. Trace back of changes to ships during their operational life to the digital model implies lots of effort or is not possible at all.

**5. Key Digital Initiatives for Shipbuilding**

(a) Digital Thread - from Concept to Lifecycle support in Shipbuilding.

(b) Industry 4.0 - for Smart manufacturing.

(c) Multi-dimensional (5D+) Integrated Project Management.

(d) Digital Twin - Digital Ship Model efficient construction and operation management.

(e) Data Driven approach to Document Management - Mining hidden data intelligence and putting it to use.

(f) Data Aggregation & Analytics.

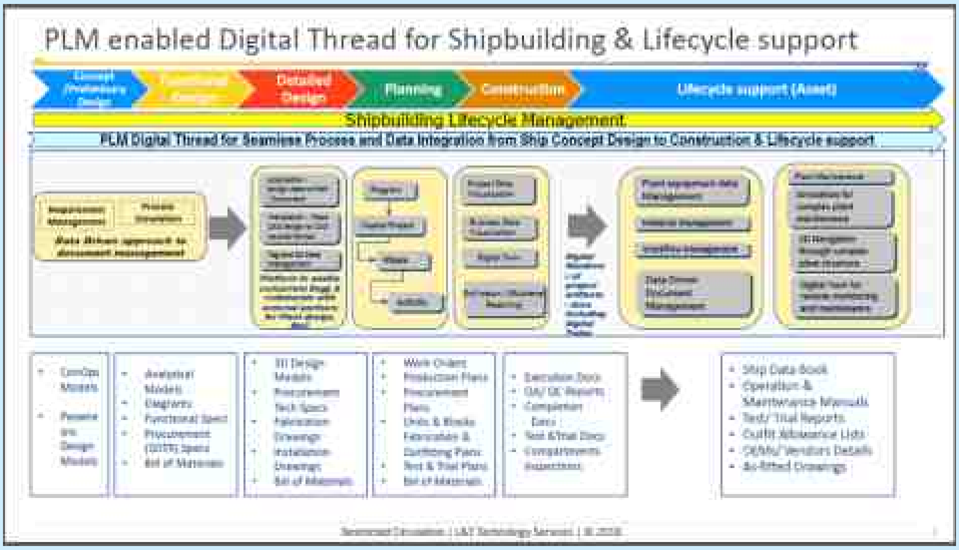
5.1 Following diagram depicts Digital thread for Shipbuilding from Its Concept/Preliminary design to Construction and later it is extended to Lifecycle support during operation.

5.2 It shows major digital transformation areas like PLM enabled Multi-Dimensional Integrated Project management enabling digital handover of asset to customer/operator, Industry 4.0 for smart manufacturing with virtual commissioning, simulation, Tool & Fixture design, Automation, Digital twin during construction and operation, Data Driven approach to Documents management and Data aggregation for dashboard and analytics during operation to further compliment Digital Twin.

5.3 At the bottom, it captures the major Shipbuilding process areas during the lifecycle and how digital thread can make a seamless integration to various otherwise dispersed and siloed systems & processes.

5.4 Though Indian shipbuilders are aware of the importance of digitalization to secure their competitiveness but are often facing the question where to start with their digitalization initiative to achieve due benefits.

5.5 L&T Technology Services (LTTS), based on the know-how from the ongoing and numerous other projects in a wide variety of discrete manufacturing industries identifies three key aspects for a sustainable digitalization journey to enable Digital Thread: -



(a) Availability of a digital platform.

(b) Ensuring of digital infrastructure/ continuity.

(c) Digitalization of business and/or engineering processes.

5.6 **Availability of a Digital Platform**. The vertical and horizontal integration of the various IT systems is the basis for an efficient flow of information and its consistency. LTTS has developed a solution to integrate the available Design CAD i.e AVEVA Marine and PDM/PLM i.e Teamcenter systems. The solution forms the heart of a digital platform that supports Configuration Lifecycle Management (CLM) across system boundaries and enables collaboration across shipyard. Open CLM makes the changes of digital master and digital twin traceable along the time axis without being a giant sink for redundant data.

5.7 **Ensuring Digital Continuity**. LTTS uses a standardized approach to evaluate information flows in shipyards to uncover redundancies, bottlenecks and interruptions in the information flow more efficiently without having to carry out a complex process analysis. The aim is to improve the consistency of digital information along the entire value creation chain.

5.8 **Digitalization of Business Processes**. Using various modules available with Siemens PLM/ Teamcenter such as Engineering Change Management, Multi-Site Configuration, TC Reporting & Analytics, Document Management, Requirement Management, Substance compliance, Schedule Manager, BOM Management, Maintenance Repair & Overhaul, Active Workspace, Quality & Acceptance procedure, LTTS has developed solutions for various business/ engineering processes categories, such as Design, Planning & Project management, Production, Quality Assurance, Change management, etc.

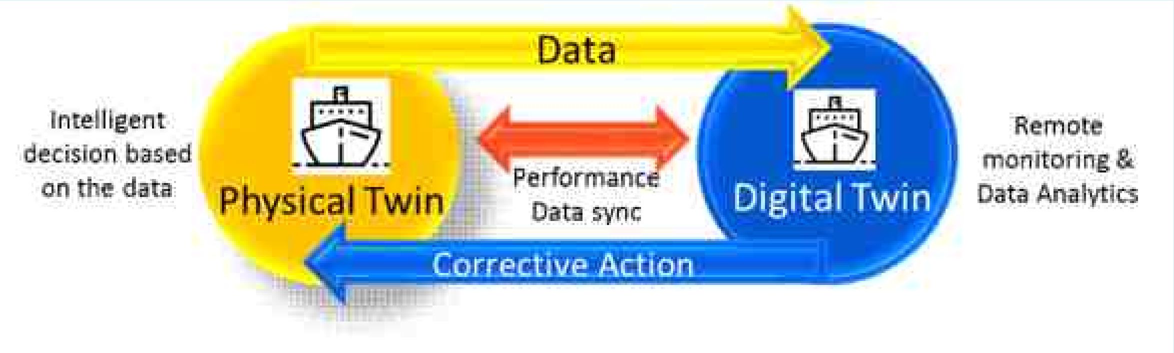
**6. Digital Ship Model to Digital Twin**

6.1 *Digital Twin is one of the major digital transformation area for shipbuilding. It enables* to develop a digital product model that reflects the exact construction status of the ship throughout its entire life. *This digital master, from which* **digital twins** of the *delivered product are derived later, is to a certain extent the driver for digital transformation*. It not only supports the optimization of existing business processes, but also enables the development of new value-added services and service-oriented business models in combination with the information collected during operations. [5]

6.2 Following diagram explains the concept of a digital twin, which compares the Physical and Digital replica of Ship for improved operation, maintenance as decision are taken based on the actual field data and data analytics. It can also be used for improving the design with improved simulation with better quality field data.

6.3 A lot of information relevant to operation and maintenance is passed on as documents, often on paper, which require manual post-processing at the user's/operator's side. It not only includes geometry models but also to non-geometric information like structures, relationships, and attribute values such as PMI (Product Manufacturing Information).

6.4 Data driven approach to Document Management as a part of digital transformation can bring in intelligence and can help in building rich Digital Twin models.




6.5 Among users/ operators there is a growing demand for a provision of digital ship information. Shipyards however fear that too much of their intellectual property will be disclosed and could be misused. They therefore need a solution that, following the need-to-know principle, only transfers the information in a quality and detail that the user/operator really needs and that also allows to protect this information with appropriate mechanisms against tampering and misuse. *LTTS has the know-how about processes and technology required to build such solutions allowing to provide tailored information appropriately protected, thus ensuring safeguarded intellectual property.*

6.6 Fully developed Digital twin with intelligent and modular documentation offers advantages to all stakeholders involved in design, development, procurement, production, operation, maintenance and user/ operator of ships: -

(a) To enable customer to map the current condition of their ships in digital twins and to feed these twins with operational information for efficient operation.

(b) Smart inspection for naval inspection agencies that regularly inspect the ships can offer users/operators and naval ship repair yards new value-added services such as system simulations or predictive maintenance based on digital twins.

(c) For shipyards, the digital provision of ship documentation can be a unique selling point and opens the possibility to use the operational information from the Digital Twins for the optimization of the next ship generation. Assuming if the naval agencies are prepared to make the information available to them.

(d) Shipbuilders, ship operators and classification societies should therefore agree on how they can jointly meet the challenges of digitalization to the benefit of all. The technical solutions are now available and pilot projects have provided the technical proof of concept. [5]

**7. Conclusion**

7.1 Digital Technologies such as IoT/IIoT, MBD/MBE, Digital Twin, AR/VR/MR, Big Data, Cloud, Analytics, AI, ML along with PLM as Digital platform have vast potential to transform the design and development of product, enable Industry 4.0 for connected manufacturing and smart efficient operations.

7.2 Shipbuilding is seriously contemplating to take up the journey of Digital Transformation with adoption of PLM platform and other i4.0 initiatives. *There is a high interest for building digital twin during construction and operation.*

7.3 PLM platforms are critical to build digital thread for Shipbuilding lifecycle from concept phase to construction and extending till operation. It can enable Multi-dimensional (5D+) Integrated Project Management, set foundation for Digital Twin for either improving design as closed loop PLM or for operation management, implement Data driven approach to Document management to mine hidden data intelligence and putting it to use and Engineering Data Aggregation & Analytics during operation.

7.4 Indian Navy and Indian Shipyards must continue with their digitalization efforts to maintain their leading position in global competition. Similarly, Indian Shipyards must consistently use their digital information assets by integrating their IT infrastructure to avoid breaks in the information flows across system boundaries.

7.5 Further, the creation of digital assets, ensuring consistency of digital information and the digitalization of processes are the most important aspects for a sustainable digitalization offensive. This shall further enable the transition of digital ship models to digital twins, which also support operation and maintenance of ships.

7.6 With its Smart Manufacturing & Operations Group and vast knowledge of Shipbuilding, L&T Technology Services can support Indian Shipyards in defining and implementing their digitalization strategy. However, to make the digital transformation in shipbuilding a true success, all stakeholders must understand digitalization as a coordinated approach that benefits all of them.

## List of Abbreviations

| Ser | Abbreviation | Description |
|---|---|---|
| 1 | IoT | Internet of Things |
| 2 | IIoT | Industrial Internet of Things |
| 3 | MBD | Model-Based Definitions |
| 4 | MBE | Model-Based Enterprise |
| 5 | MBSE | Model-Based System Engineering |
| 6 | AR | Augmented Reality |
| 7 | VR | Virtual Reality |
| 8 | MR | Mixed Reality |
| 9 | i4.0 | Industry 4.0 |
| 10 | GDP | Gross Domestic Product |
| 11 | MoD | Ministry of Defence |
| 12 | DND(SSG) | Directorate of Naval Design (Surface Ship Group) |
| 13 | PDM | Product Data Management |
| 14 | PLM | Product Lifecycle Management |
| 15 | CAD | Computer Aided Design |
| 16 | IT | Information Technology |
| 17 | LTTS | L&T Technology Services |
| 18 | ERP | Enterprise Resource Planning |

| Ser | Abbreviation | Description |
|---|---|---|
| 19 | CLM | Configuration Lifecycle Management |
| 20 | CATIA | Computer Aided Three Dimensional Interface Application |
| 21 | AVEVA marine | Detailed Design Software |
| 22 | CADMATIC | Detailed Design software |
| 23 | NAPA | Initial Ship Design Software |
| 24 | 3D PDF | 3-Dimensional Portable Data Format |
| 25 | PMI | Product Manufacturing Information |
| 26 | PKLD | Production, Keel laying, Launching, Delivery |
| 27 | M2M | Machine to Machine |
| 28 | AI | Artificial Intelligence |
| 29 | ML | Machine Learning |

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# INVESTIGATION OF SHIP PROPELLER PERFORMANCE USING CFD TOOL


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**1. Abstract**

1.1 In the ship design process, the propeller is a complex geometry used to perform in a non - uniform flow with maximum efficiency. The forces developed by operating the propeller are used to run the ship against the various resistance forces of the environment. It has been noted that the pressure fluctuations at the propeller plane leads to the generation of the thrust force, which propels the ship. In the present paper, an existing model propeller is considered for predicting the propeller open water characteristics using CFD methods. The propeller is a five bladed, 150 mm diameter having a mean pitch of 150 mm, manganese bronze material. The CFD results obtained are comp ared with the experimental data available. A computational solution using CFD tools provides a good platform to get the estimation of the open water characteristics. The complexity and time consumption for the ship scale propeller experiments is avoided by carrying out the model experiments. It can be concluded that the present approach provides easy, fast and reliable solutions for the performance characteristics of the propeller.



**2. Keywords**

2.1 Propeller, CFD, Open water characteristics.


**3. Introduction**

3.1 Improvement of technology over the years and adoption of more advanced numerical methods in Computational Fluid Dynamics (CFD) such as Reynolds Averaged Navier Stokes (RANS) equation, finite element method have helped obtain good precision even in complex models. The prediction method used for propellers was the lifting line theory till the 1960s and the initial numerical methods were based on the same, and later the lifting surface models was developed. Kutty – Rajendran [1] used the numerical prediction method to determine the small scale performances of a propeller using a standard k-ω turbulence model.

3.2 Bosschers [2] used RANS method for analysing the viscous flow around the ship hull and determined the velocity at the propeller plane. Boundary element method (BEM) was used to solve the acoustic wave equation which was computed to get the pressure fluctuations of the propeller. It may be noted that while these advanced methods produce good results in comparison to experimental data, there are a lot of practical issues which have to be taken into consideration during the analysis. Colley [3] analysed a propeller based on the model KCD 32 (Emerson and Sinclair, 1967). The analysis was computed using OpenFOAM, and the pressure distribution and effects of cavitation were compared to experimental results.

3.3 Zhang [4] employed RANS equation – finite volume method for numerically investigating the propeller/hull interaction and predicted the hydrodynamic performance. The SST (Shear Stress Transport) k-ω turbulence model was used for turbulence closure in the study. Sridhar et al. [5] predicted the frictional resistance using CFD Fluent 6.0 for ship in motion and validated the results with the experimental data. Stajuda et al. [6] used Multiple Reference Frame model in ANSYS CFX to simulate a steady state condition and the results obtained were validated by experimental data. Zhi – feng [7] studied the cavitation characteristics of a propeller using the viscous multiphase flow theories. A hybrid based grid of Navier – Stokes (NS) and bubble dynamics equations were used to predict the hydrodynamic performance under various operating conditions.

3.4 Byung-Young et al. [8] studied the flow analysis of pressure distribution, discharge flow rate and consequent thrust force for various rotational speeds of a three-dimensional screw propeller, using Fluent V13.0. Salvatore et al. [9] conducted a computational analysis using the INSEAN-PFC propeller flow code developed by CNR-INSEAN. Experiments were carried to obtain the open water characteristics, evaluation of velocity field in the propeller wake and prediction of cavitation performance in uniform flow conditions.

3.5 Nakisa et al. [10] numerically investigated refinement methods of mesh to obtain an independent mesh solution for a marine propeller. The open water characteristics were calculated using RANS equations and compared with the existing experimental results. Subhas et al. [11] performed flow analys is and studied cavitation performance of the INSEAN E77a model propeller using Fluent 6.3 software. The computational results obtained were validated by the existing experimental data.

3.6 The computational or numerical analysis provides accurate results which helps in closely monitoring the important parameters of a propeller such as efficiency, performance characteristics, cavitation inception etc. The simulated patterns are in good agreement with the experimental data in most of the cases. However, the turbulence caused in the real time experiments may not be properly simulated in the CFD tools and hence aspects such as wake formation is not properly captured in the computational methods. More detailed study of mesh patterns and turbulence models have to be studied and implemented accordingly to get accurate results.

3.7 In the present paper, the CFD solver – ANSYS CFX software is used to obtain the open water characteristics of the propeller. The investigation is carried out for a standard k-ϵ model. The open water characteristics of the propeller i.e advance coefficient (J), thrust coefficient ($K_T$), torque coefficient ($K_Q$) and efficiency (η) are calculated from the post-processing CFX solver and compared with the experimental data as available from the literature.

## 4. Geometric Modeling

4.1 The geometric model of the propeller is carried out in CATIA V5.0. The available non dimensional data of the KCS SVA 1193 model geometry was converted to coordinate data to get the aerofoil sections. Coordinates were lifted from the expanded, developed views of the existing data. The sections were stacked as per the radial distances from the centre of the hub as shown in Fig 1. The sections were rotated as per the pitch angle. Finally, these are lofted and wrapped around the respective diameters to get the final sections. Table 1 shows the dimensions of the subject propeller. Table 2 provides the blade section characteristics of the propeller.

## Table 1. Dimensions of the KCS SVA 1193 model propeller

| | |
|---|---|
| Propeller Diameter | $D_p$ = 150 mm |
| Number of blades | Z = 5 |
| Pitch ratio(nominal) | $P_{0.7}/D_p$ =1 |
| Skew | $\theta_s = 12.658^0$ |
| Rake angle | $\theta_i = 7.96^0$(forward) |
| Expanded area ratio | EAR = 0.7 |
| Hub diameteratio | 0.16667 |
| Direction of rotation | Right handed |

## Table 2. Blade section characteristics of the propeller

| $r/R_p$ | r (mm) | c (mm) | $T_{max}$ (mm) | rake (mm) | $\theta_p$ (deg) |
|---|---|---|---|---|---|
| 0.2 | 15 | 34.9 | 4.89 | 2.108 | 58.081 |
| 0.3 | 22.5 | 39.52 | 4.335 | 3.162 | 47.936 |
| 0.4 | 30 | 43.05 | 3.78 | 4.216 | 39.848 |
| 0.5 | 37.5 | 45.19 | 3.225 | 5.27 | 33.487 |
| 0.6 | 45 | 45.93 | 2.67 | 6.324 | 28.463 |
| 0.7 | 52.5 | 45.02 | 2.115 | 7.378 | 24.463 |
| 0.8 | 60 | 41.37 | 1.56 | 8.432 | 21.223 |
| 0.9 | 67.5 | 33.22 | 1.005 | 9.487 | 18.563 |
| 0.95 | 71.25 | 25 | 0.728 | 10.014 | 17.409 |
| 1.0 | 75 | 2.1 | 0.45 | 10.541 | 16.351 |

### 5. Domain and Mesh Generation

5.1 **Flow Domain**. The computational predictions made in this project is done using ANSYS CFX V18.2 CFD solver. The Multiple Reference Frame model (MRF) approach was put into use to get the results for the open water characteristics. The solid modelling of the propeller was done using CATIA V5 before generating the grid. The complete domain is divided into two categories i.e stationary and rotating domain. The outer global boundary simulating the far end boundary is considered as the stationary domain (Fig 3) is represented by a box type enclosure.

**Fig 1: Stacking of sections**

The rotating domain is present inside the stationary domain which covers the entire proximity of the propeller and is used to simulate the rotation condition during analysis. A cylindrical enclosure is selected for the rotating domain.

The inlet and outlet boundaries for the stationary domain are at a distance of 4D from the propeller origin. The far field boundary conditions are hence chosen so that the upstream and downstream flows do not affect the computational results during the analysis. For the rotating domain, the enclosure is set at 0.4D and 1.1D.

**Fig. 2 : 3D model developed in CATIA**

**Fig. 3: Stationary domain showing velocity inlet and outlets**

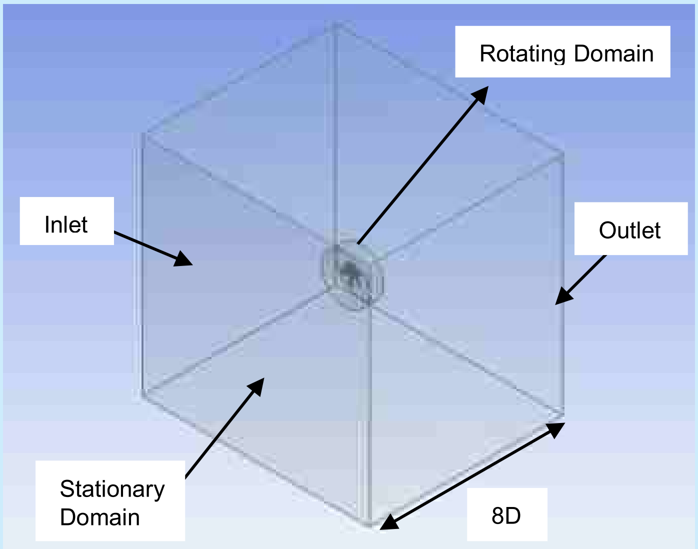
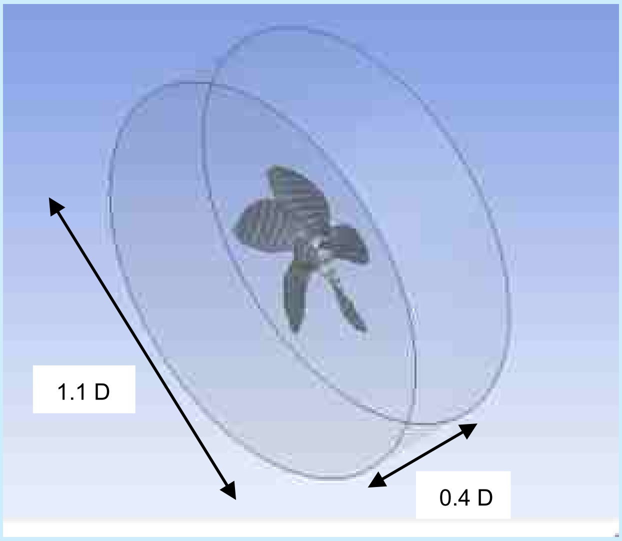


Fig. 4: Rotating domain consisting the propeller




5.2 **Mesh generation**. The standard mesh tool of ANSYS CFX 18.2 is used to generate the grid over the entire domain. The generation of the grid is a necessity as it helps discretizing the elements which provide the individual representation of the complex geometry. For the current project, the cell sizes are varied a from smaller range at the blade sections to larger ones nearing the periphery of the far field boundary. This ensures that the refinement of the grid across the domain interfaces improves the accuracy in the results. Fig 5 shows the grid over the propeller and the entire domain used for simulations.

The grid generated is a fully unstructured tetrahedral mesh in both the stationary and rotating domains. The unstructured tetrahedral mesh is preferred in this project over hexahedral mesh because of the ability to discretize the complex geometries and faster resolution with lesser human intervention and errors. Also the adaptation of the grid – grid coarsening or refinement is easier in unstructured mesh than structured grid. The total number of cells generated after convergence for

Fig. 5: Grid over the propeller

the entire grid was 0.39 million. The quality of the computational meshing grid gets directly influenced by the computation time of analysis and rate of convergence of the cells. Fig 6 shows the grid over the rotating domain. The interfaces have been defined with respect to the stationary domain to get the appropriate results. Fig 7 shows the complete grid over the entire domain for the propeller simulations.

**6. Solver Parameters Settings**

6.1 **Boundary Conditions**. The simulations were conducted in the flow conditions with a rotational speed of 1800 rpm for the propeller. The region outside the rotating domain was kept stationary and the Moving Reference Frame (MRF) was assigned to the fluid inside the rotating domain. The

**Fig. 6: Grid over the rotating domain**

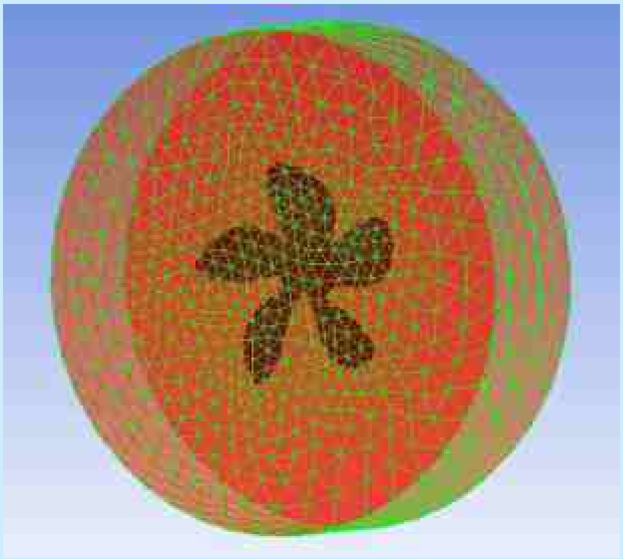


**Fig. 7: Grid over the entire domain for the propeller simulation**

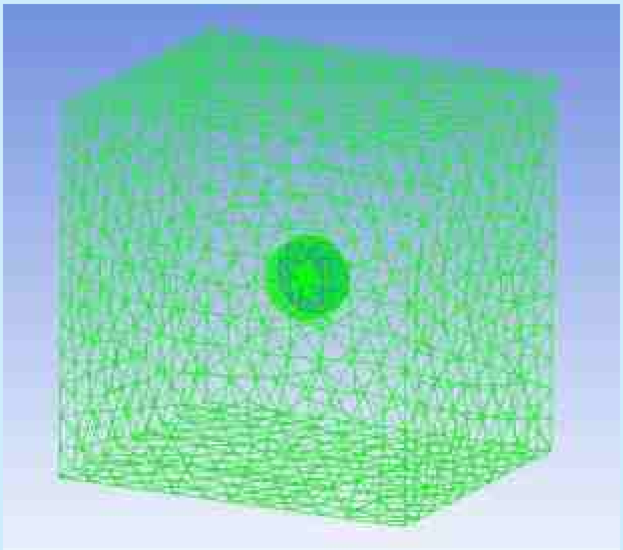


**Table 3. Meshing grid details**

| Sizing | Proximity & Curvature |
|---|---|
| Growthrate | 1.20 |
| Curvature Minimum Size | 0.001 m |
| Proximity Minimum Size | $1.2564*10^{3}$ m |
| Element Size | 0.12564 m |
| Curvature normal angle | $18^{0}$ |
| Relevance Centre | Coarse |
| Minimum Edge length | $9.053 * 10^{5}$ m |
| Smoothing | Medium |

velocities were varied at the inlet as per the advance coefficients. The outflow was maintained at a pressure of 1 atm. A no-slip condition was assigned to the wall. The domain interfaces were properly assigned for the simulations. The interface will help in the transformation of the local frames which enables the usage of flow variables by the adjacent cell zones.

The model approach is highly suitable for this analysis as it requires the interaction amongst the two domains. The wall forming the propeller blades were also assigned as rotational, with a velocity of zero with respect to the adjacent cell zone.

**7. Results and Discussions**

7.1 The propeller performance characteristics are represented in terms of non dimensional coefficients i.e thrust coefficient (KT), torque coefficient (KQ) and efficiency (η0) varying with the advance coefficients (J). ANSYS CFX V18.2 was used to get the computational solution for the flow analysis of the propeller. The software estimated the torque and thrust values for the varied speed of

**Table 4. Propeller Domain details**

| | |
|---|---|
| Principal Dimension (Propeller) | Diameter (D) = 150 mm |
| Stationary Domain | Shape = Box<br>Length = 8 D |
| Rotating Domain | Shape = Cylinder<br>Diameter = 1.1 D<br>Length – 0.4 D |
| Mesh count | 0.39 million Tetrahedral cells |

**Table 5. Solver Parameters**

| | |
|---|---|
| Pressure – velocity coupling | SIMPLE |
| Turbulence equation | k-epsilon |
| Turbulent wall functions | Scalable |
| Turbulence Numerics | First Order |
| Turbulent Dissipation Rate | First Order Upwind |
| Momentum and Pressure | Second Order Upwind |
| Buoyancy model | Non buoyant |
| Near wall treatment | Standard wall functions |

advances as per the advance coefficient. Table 6 shows the thrust and torque estimated at 1800 rpm by the CFX solver.

**8. Results and Discussions**

8.1 The propeller performance characteristics are represented in terms of non dimensional coefficients i.e thrust coefficient ($K_T$), torque coefficient ($K_Q$) and efficiency ($\eta_0$) varying with the advance coefficients (J). ANSYS CFX V18.2 was used to get the computational solution for the flow analysis of the propeller. The software estimated the torque and thrust values for the varied speed of advances as per the advance coefficient. Table 6 shows the thrust and torque estimated at 1800 rpm by the CFX solver.

8.2 The axial force and momentum around the propeller axis gives the thrust and torque values. Comparison of the predicted and experimental values for the thrust and torque coefficients is shown in Table 7 and Fig 8.

**Table 6. Computational estimation of Thrust and Torque**

| Advance Coefficient (J) | Velocity of Advance ($V_A$) | Thrust(T) N | Torque (Q) N - m |
|---|---|---|---|
| 0.3 | 1.4572 | 233 | 5.2 |
| 0.4 | 1.943 | 214 | 4.75 |
| 0.5 | 2.428 | 185 | 4.16 |
| 0.6 | 2.9145 | 155.2 | 3.6 |
| 0.7 | 3.4 | 124.5 | 3.01 |
| 0.8 | 3.886 | 85 | 2.3 |
| 0.9 | 4.3717 | 51.5 | 1.55 |
| 1 | 4.8575 | 10 | 0.75 |

**Table 7. Comparison of CFD and experimental results of the non dimensional coefficients**

| Advance Coefficient (J) | Thrust Coefficient | | Torque Coefficient | | Efficiency CFD ($\eta_0$) |
|---|---|---|---|---|---|
| | $K_T$ (CFD) | $K_T$ (Exp) | $K_Q$ (CFD) | $K_Q$ (Exp) | |
| 0.3 | 0.4396 | 0.389 | 0.654 | 0.584 | 0.321 |
| 0.4 | 0.4 | 0.345 | 0.597 | 0.529 | 0.43 |
| 0.5 | 0.349 | 0.298 | 0.523 | 0.471 | 0.53 |
| 0.6 | 0.29 | 0.249 | 0.45 | 0.408 | 0.61 |
| 0.7 | 0.23 | 0.198 | 0.38 | 0.341 | 0.69 |
| 0.8 | 0.16 | 0.145 | 0.29 | 0.27 | 0.74 |
| 0.9 | 0.09 | 0.088 | 0.19 | 0.1924 | 0.71 |
| 1 | 0.01 | 0.028 | 0.09 | 0.1081 | 0.31 |

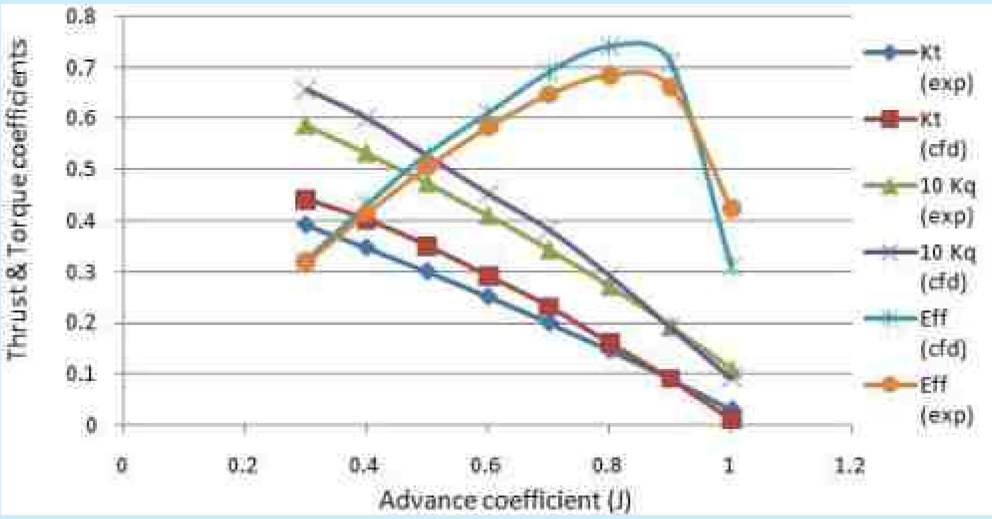
8.3 The result shows that the thrust and torque coefficients are decreasing with the increasing advance coefficients.

## 9. Conclusion

9.1 Based on the work done and analysed throughout this project, we can conclude that:

(a) The CFD results obtained were in good agreement with the experimental findings. The computational accuracy opens opportunities to analyse more complex problem, advanced phenomenon such as cavitation in the propellers and propeller radiated noise field.

**Fig. 8: Comparison of estimated KT & KQ with the experimental data**




(b) The computational methods proves to be very effective and can become a good replacement for experimental analysis, which is time consuming and incurs huge expenses.

(c) The usage of multiple reference frames provides clear explanation to the flow analysis around the propeller. The various turbulence models can be further examined and analysed to get more accurate results.

(d) The CFX solver can determine the open water characteristics for the simulated conditions with reasonable accuracy and provides a good user interface. CFX can be chosen over other solvers to get a better numerically stability and can effectively work out complex models.

## 10. Acknowledgements


10.1 Authors express sincere thanks to all the members involved directly and indirectly in this project. We also thank the anonymous references for their useful insights and suggestions.

10.2 Conflicts of Interest: The authors declare no conflict of interest.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# ENHANCING EFFICIENCY BY REALTIME QUALITY & VENDOR MANAGEMENT SYSTEM


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**1. Abstract**

1.1 Warship construction is a complex project activity, involving multiple stakeholders. In the last decade Indian Shipbuilding Industry has experienced a paradigm shift in the manner it functions. The market has become fiercely competitive. Industry processes are undergoing a transformation with many new concepts and process improvements. This paper presents a review of ongoing development of an online Quality Module (QM) in warship construction at Garden Reach Shipbuilders & Engineers (GRSE) for Indian Navy and Coast Guard ships.

1.2 This paper aims to demonstrate the advantages of an ERP based Quality Module, its challenges and its future developmental opportunities. QM aims to provide a framework for tracking of project progress and completion of goal based domain activities. The concept has extended the Quality Module to create a Vendor Assessment framework in a rule based environment.

1.3 GRSE has successfully implemented the inspection part of the QM in GRSE and are progressively working towards the realization of project progress linked with weightage and comprehensive vendor performance tracking. While there are challenges in front of us for complete implementation of QM, the advantages of such tool by far outweigh the disadvantages. Such rule based tools with multi-purpose use is definitely a way-ahead for improvement in process efficiency in shipbuilding industry.


**2. Introduction**

2.1 Indian Shipbuilding is a complex project based industry of which Indian Navy is by far the biggest client. Indian Navy's operational footprint has increased in the past decade and is now targeting to achieve 200 ships fleet from current of about 137 by 2027 as a part of the nation's modernisation and expansion of its maritime forces. [6] This explosion of requirement of the Indian Navy Fleet and increased competition in the market calls for an immediate transformation of the shipbuilding concepts and processes.

2.2 Over the years, several developments have been carried out across various divisions of shipbuilding at Garden Reach Shipbuilders & Engineers Ltd. (GRSE), with a target to enhance the contribution to quality and timely delivery of ships. Accordingly, the foundation for the implementation of Quality Module & Vendor Management System on an ERP platform was framed.

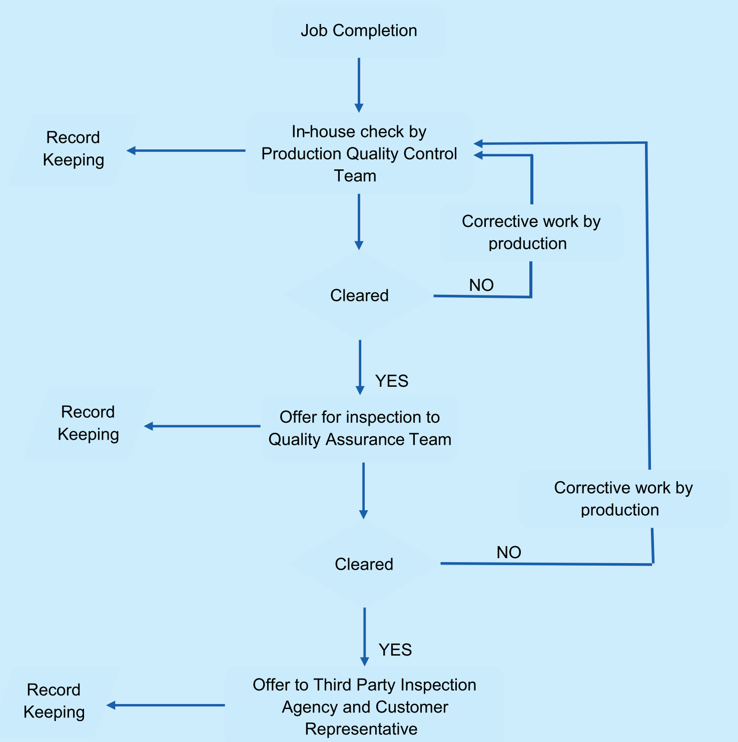
2.3 With increasing competition among the stakeholders in the industry, the number of suppliers for goods and services has increased manifolds. There is a need to put in place a robust, rule based framework of operation. The system should enable the shipyard to assess and reward high performers, improve deficiencies of average performers and weed out the non-performers. This paper aims to demonstrate the concept of an online system for Quality Module and vendor management in shipbuilding industry.

### 3. Process Definition

3.1 The Quality Module (QM) of GRSE has been created in a manner that it can be mapped at a granular level of activity for all ship building processes, namely, Hull construction, Hull outfit, plumbing, electrical Outfit and Engineering outfitting. An overview of the steps involved in the construction/inspection is presented in the succeeding paragraph to provide an understanding of the working principle of the quality module.

3.2 To further illustrate the point, in case of hull fabrication and assembly, on completion of a job, a quality control team is deployed by the production team to check 100% of the work. When that step is completed successfully, it is then passed to the quality assurance department for inspection, who checks the performance of Manufacturing's quality control efforts. This step is intended to be an audit operation. After successful completion of this step, the inspection agency and customer representatives are called out for a formal inspection. When the formal inspection is completed, the assembly can progress to the next phase of construction. In most yards, these inspection points are at predetermined milestones, such as panel fabrication, module construction, and final erection in the hull for structure. Likewise, piping systems, machinery installations, and electrical distribution systems are also inspected at predetermined stages of completion. Stage inspections ensure defects are caught early and corrected immediately. During this whole process, record keeping is critical for the quality assurance function. The records must be compiled and maintained as the ship is built, so documentation exists to prove required testing and inspections were successfully accomplished. The "proof of the pudding" is during the sea trial where the ship is put through planned tests while underway to confirm operation and safety of the crew under actual conditions, including hard turns and emergency stop demonstrations. A flowchart depicting above process is shown overleaf.

**Fig. 1: Flow Chart of General Inspection Process in Shipbuilding Industry**



3.3 The activities in figure 1 have been mapped in the Quality module (QM) with the aim of enhancing efficiency of shipbuilding operations by:

(a) Online confirmation of Internal & External project activities

(b) One point recording of QA inspections and observation reports

(c) Consolidated progress recording of shipbuilding project

(d) Strengthening Vendor Base from the parameters retrieved from QM

3.4 In GRSE, Vendor management is a multi-stage process consisting of obtaining feedback in the form of points for various parameters of performance of vendor, viz. quality, and timely delivery etc from process/product owner or Project Leader. This will in return aid in assessing the performance of vendor. Though the number thus obtained does not truly reflect the vendors' performance and thus the aim of actual assessment of performance of vendors is not being served. This brings out the requirement for an online system for vendor management where, the credibility of marking system is maintained.

**4. System Framework**

4.1 The framework of QM have been divided into basic master lists which when combined with the WBS level 2 elements of the detailed Project Structure, will substantiate to the desired results. Master lists designed for QM are as follows:

| Ship Types (as per Coding Mask created in the system) | |
|---|---|
| A | Small/ Very Small Ships |
| B | Medium Ships |
| C | Big Ships |

Table - 1

(a) **Ship Type Master**. This master list is meant to identify all the types of ships for which the Production Process steps along with Quality steps may differ. Ships are primarily categorized in 3 major categories namely Small/ Very Small Ships, Medium Ships & Big Ships.

**Discipline Master**

| Discipline ID | Discipline Text |
|---|---|
| 1 | Hull |
| 2 | Hull Outfit |
| 3 | COFS |
| 4 | Machinery |
| 5 | ACVR |
| 6 | PLUMBING |
| 7 | ELECTRICAL |
| 8 | WEAPON & SENSOR |

Table - 2

(b) **Discipline Master**. Shipbuilding & traditional practice to monitor the shipbuilding project can be divided into the following disciplines namely: Hull, Hull Outfits, COFS, Machinery, ACVR, Plumbing, Electrical and Weapon & Sensor. In certain cases, as per the Client's monitoring requirement, a few disciplines may get merged with other disciplines resulting in lesser disciplines being created at the project level. Hence this discipline master is to maintain all the disciplines applicable for shipbuilding process (not specific to any project).

(c) **System Master**. Shipbuilding can be divided into multiple systems based on discipline, which constitutes the entire ship. These list of system might be different for different ships as each customer requirement for each project might not be same. This master list is the crucial aspect of the QM framework as a number of master list gets linked to system master.

Change View "System Master": Overview

| System ID | System Description |
|---|---|
| BFAL | BLOCK FABRICATION (AL) |
| BFMS | BLOCK FABRICATION (MS) |
| CF | CHEQUERED FLOORING |
| DS | DRY SURVEY OF BLOCK |
| ERAL | ALIGNMENT OF BLOCK / ERECTION |
| ERFP | FIT-UP OF BLOCK / ERECTION |
| ID | FITMENT OF INLET DUCT |
| MA | MISCELLANEOUS ACTIVITIES |
| OHDS | OUTER HULL DRY SURVEY |
| PB | PLATE BENDING |

Linked to WBS level 2 element, where weightage of each activity is maintained, for project progress tracking

Table - 3

(d) **Discipline-wise Attribute Master**. Every discipline (like Electrical, Plumbing, and Machinery etc.) will have relevant set of attributes to be referred to. For example, Plumbing will have attributes like OD of pipe, thickness of pipe, location etc., whereas Electrical will have attributes like location of cable, cable diameter etc.

Attribute Master with reference to Disciplines

| Discipline ID | Attribute ID | Attribute Text | |
|---|---|---|---|
| 1 | H1 | Cutting Length | For Plate Cutting |
| 1 | H2 | Marking Length | |
| 1 | H3 | Plate Dimension | |
| 1 | H4 | Material | |

Table - 4

These attributes are to be maintained against each discipline so that they are captured right from component list maintenance phase. These attributes will be automatically available for reference (based on discipline) when Production department is confirming any task and when Quality department is acting on any Inspection offer. They will also be reflected in the Inspection note.

(e) **Process Master**. Every ship system (like Fresh water system or Salvage system etc.) will have sequence of activities to be carried out. For example, piping of Fresh water system will have Primary Erection (PE), Preliminary Inspection (PI), Final Erection (FE), Final Inspection (FI) etc. Out of these activities some will be production activities and some quality activities. All these process masters (relevant for all possible discipline and systems) shall be maintained in the QM. Process masters are the back bone for this customized QM solution.

Change View "Production/Quality Assurance Flow Chart":

Production/Quality Assurance Flow Chart

| Qua... | Sequence | Activity | Assigned To |
|---|---|---|---|
| [illegible] | 1 | Hot Work | P Production |
| [illegible] | 2 | Installation | P Production |
| [illegible] | 3 | Preliminary Inspection | Q Quality |
| [illegible] | 4 | Final Installation | P Production |

Table - 5

(f) **Process Master Tagging**. Each ship system (like Lub Oil System, Salvage System etc.) shall be linked to its corresponding process master and maintained in this master list. In simple terms, it is the applicability of QAP based on ship type, discipline and system.

DISCIPLINE ID

Master for maintaining ship type/dscipline/system/mat/QAP

| Ship Type | No | System ID | ma... | Quality assurance plan |
|---|---|---|---|---|
| B2 | 1 | BFAL | NA | H5 |
| B2 | 1 | BFMS | NA | H3 |
| B2 | 1 | CF | NA | H14 |
| B2 | 1 | DS | NA | H9 |

Table - 6

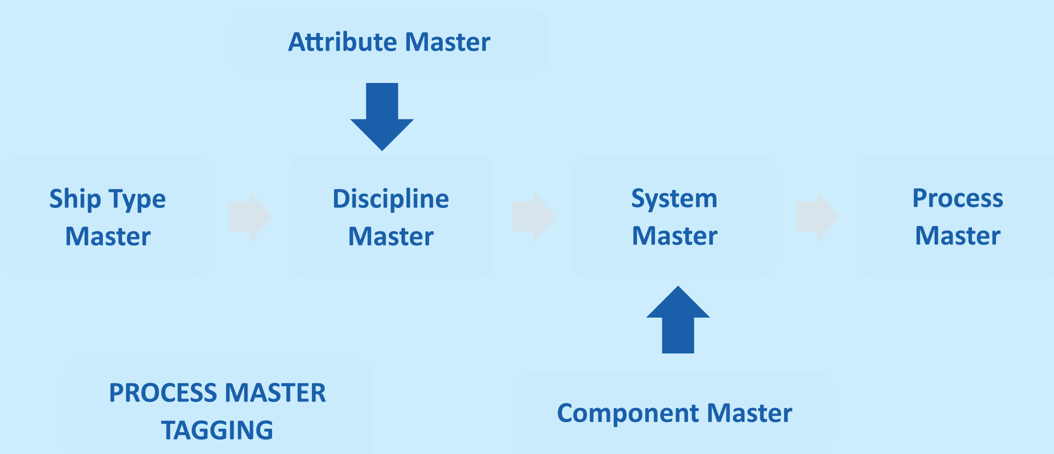
Fig.  2: Flow of Process Master Tagging


(g) **Component Master**. Each ship system in a particular project shall comprise of inspect able components which will be maintained in this component master list. These will be the smallest actionable element of the QM framework.

**Table – 7 - Sample Data for Component Master**

| Item No | Component No | Component Qty | Material | UoM | Description | Cutting Length | Marking Length | Plate Dimension |
|---|---|---|---|---|---|---|---|---|
| 1 | U2-A1 | 1 | NA | EA | MAIN DECK PANEL ASSEMBLY (A10, A108, A109) | | | |
| 2 | U2-A11 | 1 | NA | EA | WT BHDs ABOVE L DK (A11, A12, A13) | | | |
| 3 | U2-A14 | 1 | NA | EA | MINOR BHDs (A14, A15, A16, A17, A18, A19, A101, A102, A103, A104, A105, A106, A107) | | | |
| 4 | U2-A7 | 1 | NA | EA | WT BHDs BELOW L DK (A22, A32, A7) | | | |
| 5 | U2-A20 | 1 | NA | EA | LOWER DECK PANEL ASSEMBLY (A20, A201, A202, A203, A204, A205, A206, A207, A208, A209, A30, A37, A38, A39, A301, A302, A303) | | | |
| 6 | U2-A4 | 1 | NA | EA | BOTTOM SHELL PANEL ASSEMBLY (A40, A21, A23, A24, A25, A26, A27, A28, A29, A31, A33, A34, A35, A36, A41, A42, A43, A44, A45, A46, A47, A48, A401, A8, A9) | | | |
| 7 | U2-A5 | 1 | NA | EA | SIDE SHELL ASSEMBLY (A50, A51) | | | |
| 8 | U2-A6 | 1 | NA | EA | SPRAY RAIL ASSEMBLY (A60, A61) | | | |

Fig. 3: Flow Chart Depicting Relation between 7 Master Lists of QM




**5. Working Methodology**

5.1 QUALITY MODULE

(a) The QM framework is a customized solution based on the 7 master list defined in the above section. Though there are some pre-requisites for the framework to perform with desired results,

(i) The system and stakeholder (final approving authority for each system) tagging at WBS level 2 element, where weightage of each activity being performed in the ship has been uploaded.

(ii) Effective one-to-one relation establishment with WBS level 2 element, System ID and Process ID.

**Fig. 4: System Tagging at WBS Level**

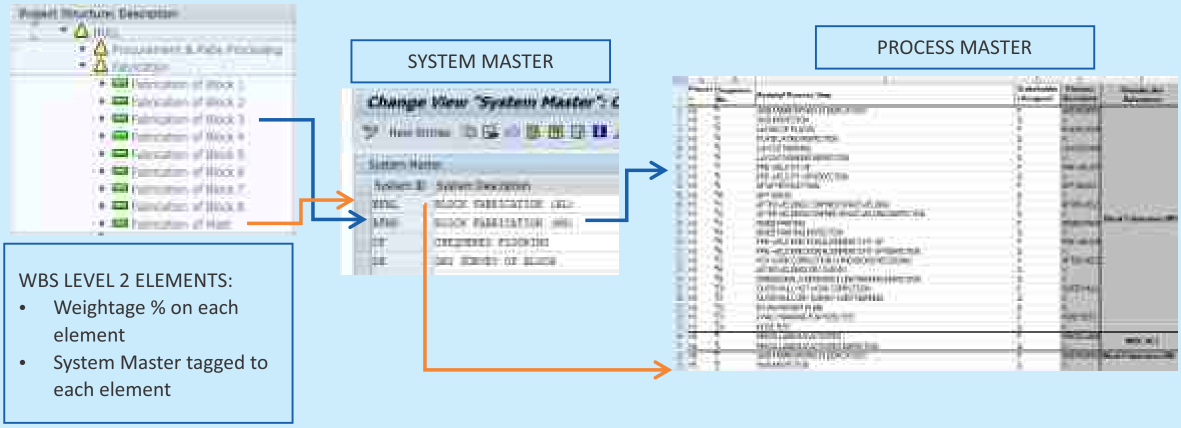
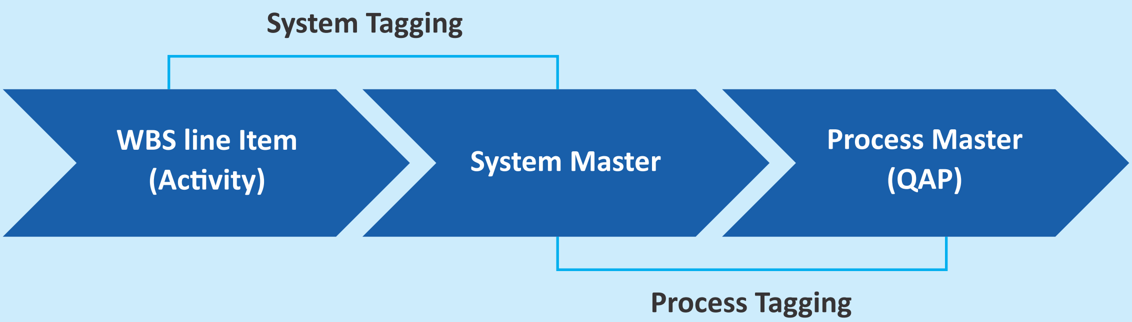



**Fig. 5: One-to-One Relation between WBS activity, System Master and Process Master**




(b) Once all the master data is fed in the QM system, production user can initiate call for inspection to Quality user. This will generate a unique RFI (Request for Inspection) Id for the inspection call. On receipt of the RFI ID, quality team shall be deployed to physically perform the inspection, after completion of which, respective inspection observations shall be uploaded in the system. As per the final status of the inspection call (cleared or rejected), the inspection will be carried out by third party inspection agency/customer representative or the inspection call shall be sent back to the production user for re-work.

## 6. Leveraging Quality Module

6.1 QM aims to provide a framework for tracking the project progress and completion of goal based domain activities. QM is integrated with activities sub-ordinated to level 2 Work Breakdown Structure (WBS) element of Project Structure (PS) in ERP, where weightage of various activities is defined prior start of any project. The PS in ERP is enhanced along with the customized solution for QM functionalities is developed to solve the followings:

(a) Detailed Activity Planning considering the granular components

(b) Integration of production steps & quality steps according to Quality Plan/Process Master

(c) Automatic generation of Request for Inspection (RFI)

(d) Relevant Document & Drawing availability to the granular components as well as at the system level

(e) Confirmation of granular component by Production & Quality team which will automatically report to project activity and subsequently derive the project progress.

(f) Keeping a track of component's progress and inspection using the QM system. Documentation of entire inspection process by capturing the inspection comments of Internal Quality Team & Third-Party Inspection Agency.

(g) Capturing the number of rejection/re-offers for a particular job or vendor.

**7. Vendor Management System**

7.1 The performance of vendors is assessed based on the numbers given by various departments for their respective related assessment criteria from a consolidated list of 10 parameters. This list of parameters shall be a mandatory comprehensive 4-tiered assessment of each vendor in ERP based solution. The four tiers shall be Production department, Planning department, Quality Assurance department and Human Resource Department as depicted in the table in succeeding page.

7.2 The comprehensive list shall include crucial aspects of vendor assessment such as Quality of product/service, Number of rejections/re-offers, timely delivery of product/service etc. The parameters related to quality of the product/service shall be auto-snatched from the Online Quality Module. Rating for parameter 'The number of rejections / re-offers, affected to the product / service shall be:

(a) For 0 & 1 Rejection - Vendor Rating = 5

(b) For 2 Rejections - Vendor Rating = 4

(c) For 3 Rejections - Vendor Rating = 3

(d) For 4 Rejections - Vendor Rating = 2

(e) For 5 & more Rejections - Vendor Rating = 1

7.3 Weightage (in %) shall be assigned to each of the 10 parameters. Average of all ratings (gathered from respective users/auto snatched from Quality Module) against the 10 parameters will be calculated in the Vendor Management system and thus final rating will be calculated. Final Rating for each parameter shall be calculated as follows:

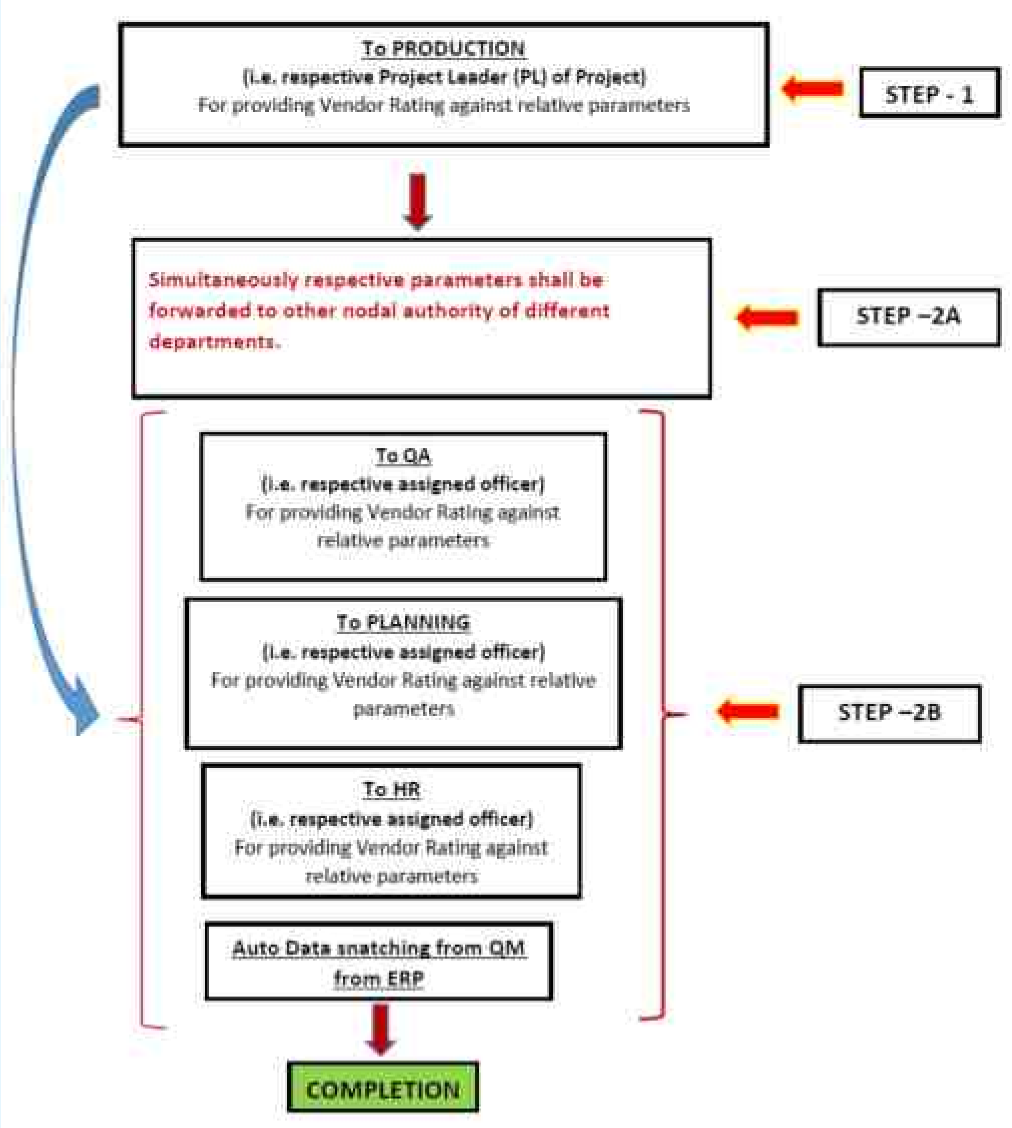
$$\frac{\text{Average of all Ratings X Weightage (already assigned)}}{100}$$

# Table 8: Vendor Performance Rating Matrix

| Purchase Order No. with Date | Sl. No. | Parameters to assess Performance of any Vendor against execution of their Service related Purchase Order | Performance Rating | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Respective Parameters for GRSE Internal Dept.'s' vetting with Shop No. / Yard No. | | | | Weightage (%) | Final Rating |
| | | | Gradation of Vendor Rating : Very Good-5, Good-4, Average-3, Below Average-2, Poor-1 | | | | | |
| | | | **Production** | **Q.A.** | **Planning** | **H.R.** | | |
| | i | Quality of Material / Service | Yes | Yes | Yes | Not Reqd. | 15 | (Average of all X Weightage) / 100 |
| | ii | Number of Rejections | **System Generated (Ratings are given below):** For 0 & 1 Rejection - Vendor Rating 5<br>For 2 Rejections - Vendor Rating 4<br>For 3 Rejections - Vendor Rating 3<br>For 4 Rejections - Vendor Rating 2<br>For 5 & more Rejections - Vendor Rating 1 | | | | 10 | (System Generated Rating X Weightage) / 100 |
| | iii | Quality Systems | Yes | Yes | Yes | Not Reqd. | 5 | (Average of all X Weightage) / 100 |
| | iv | Overall Effectiveness/Independency | Yes | Yes | Not Reqd. | Not Reqd. | 5 | (Average of all X Weightage) / 100 |
| | v | Delivery | Completion Time initially mentioned in P.O. X 5 / Actual Time of Completion | | | | 20 | (System Generated Rating X Weightage) / 100 |
| | vi | Compliance to Stage Commitments | Yes | Not Reqd. | Yes | Not Reqd. | 5 | (Average of all X Weightage) / 100 |
| | vii | Equipment / Infrastructure | Yes | Yes | Yes | Not Reqd. | 10 | (Average of all X Weightage) / 100 |
| | viii | Capable person employed | Yes | Yes | Yes | Not Reqd. | 10 | (Average of all X Weightage) / 100 |
| | ix | Planning Capability And Execution | Yes | Not Reqd. | Yes | Not Reqd. | 10 | (HR Rating X Weightage) / 100 |
| | x | Statutory Compliances | Not Reqd. | Not Reqd. | Not Reqd. | Yes | 10 | (Average of all X Weightage) / 100 |
| | | | | | | | **Total Rating** | **Average of all Final Ratings** |

Before generation of Service Entry Sheet in ERP, flow of the comprehensive Format for vendor assessment to the respective departments will be in following manner:

**Figure – 6**




**8. Leveraging Vendor Management**

8.1 The final rating thus computed can be leveraged to manage our vendors as has been brought out in the introductory paragraph. The ratings are carried out dynamically and used to encourage star performers, mentor and coach potential and future performers and at the same time identify the non-performers in a transparent and rule based framework.

**9. Conclusion**

9.1 Quality starts with the man on the job. Quality Module in a shipyard starts with effectively organizing of the conditions to apply the processes involved in ship construction with desired quality. Having an ERP based solution for Quality Module and Vendor Management System would create an objective and rule based platform where there is clarity of data, in terms of inspection observations & vendor assessment. System generated data related to quality aspects of vendors from QM would further strengthen the inviolability of data being fed in Vendor management system. QM would also offer the feature of live progress tracking of project.

9.2 Quality Module and Vendor Management systems are crucial tool for future inspections and vendor assessment. With correct data feeding in QM, it can serve as an inspection tool for all involved processes of ship construction. The system is scalable and capable of absorbing further improvements.

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# EFFICIENCY ENABLERS IN SHIP DESIGN & CONSTRUCTION


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**1. Synopsis**

1.1 Warship building historically is reflective of a nation's industrial prowess. The growth of a truly effective Navy is, thus one, that is anchored in it is indigenous capabilities, both in design and in manufacture. This is echoed in the adage "Navy is not Built in a Day". The various paradigms of warship building that contribute to nation building for other countries are analysed & assessed in the global perspective. The spin offs that warship building affords to the national economy are elaborated.

1.2 The paper recommends / concludes that the indigenous warship building is an essential contributor of nation building and industrial development. These factors flow from strategic imperatives and are fundamental and form the core around which a national identity is established. These germane factors underline the essentiality of adoption and furtherance of the measures suggested for Efficiency Enablers.

1.3 The paper highlights that in Warship Building there is now an imperative for Efficiency Enablers. The efficiency enablers are multi-pronged & encompass both External & Internal Factors. The paper highlights the aspects in which improvements have been initiated and need to be sustained & furthered. Other aspects that need to be addressed and actioned are also enumerated. The proposed approaches towards required policy adoption and implementation are discussed in the paper.

**2. Background - Significance of Ship Building to National Economy**

2.1 The ability of Ship building (and specifically warship building) to contribute to diverse industries and sectors in the modern scenario is the key economic rationale that merits attention. Ship building has a significant ability towards driving national economic growth. The salient considerations and their significance are bulleted below:-

(a) Need for Growth; Manufacturing & Services – Led by Internal Drivers

(b) Ship building; A mother Industry – Internationally Accepted Growth Driver ; Japan, S Korea & China Experience

(c) Warship Building – Non-cyclical and Strategic & Geo-political Imperative

### 3. The highlights of the opportunity of comprehensive growth that is afforded by the ship building industry are enumerated below.

3.1 Shipbuilding is one ***mother industry*** that has spin offs to other industries (both in manufacturing and services sector); these include steel, engineering equipment, port infrastructure, financial, IT, trade and shipping services. The indirect potential of shipbuilding industry in employment generation and contribution to GDP is therefore tremendous. India has about 8,000 kilometres long coastline, around 32 shipyards, 12 major ports and 200 ports under states' jurisdiction. This presents huge scope for development of shipbuilding sector considering that country's opportunities in the sector have not been utilized fully.

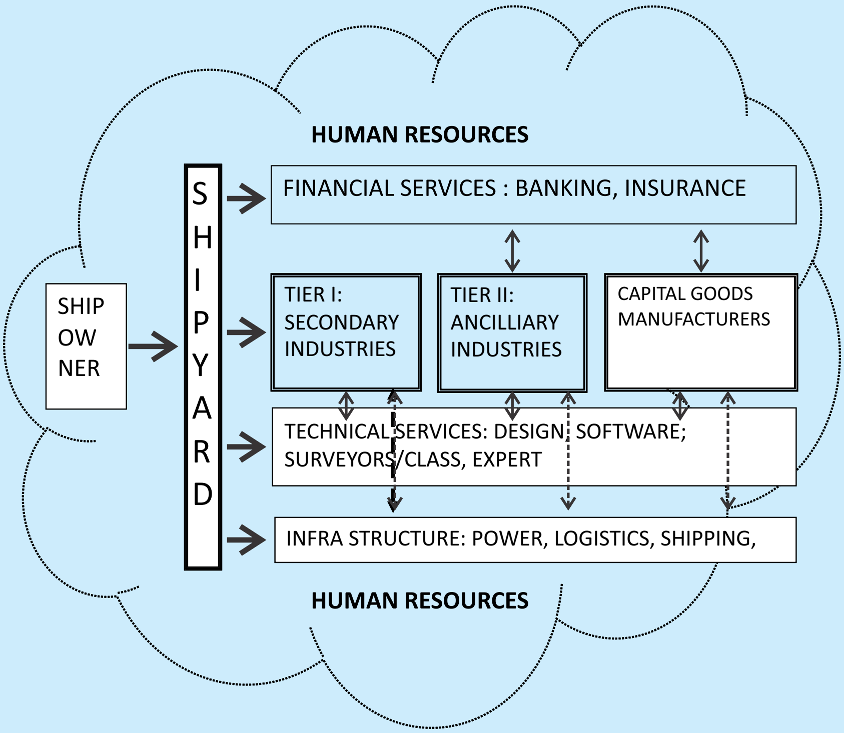
3.2 A modern well designed and built ship has all the facilities that a city has. Consequently, building of ships requires a plethora of raw material and equipment and diverse services. A commercial ship requires over 300 different types of raw material and equipment. In financial terms, costs of these inputs are about 60 % of the total cost of the ship. In the case of a warship this can be significantly higher for complex platforms going upto about 70 to 75% of the total cost. For a Low Complex Ship or lesser weapon intensive platform it has been established that the financial flow from a shipyard is mainly into 13 Tier-I industries. Tier I industries are the industries that receive direct orders from the shipyards. They comprise of Steel, Major machineries, Electrical Equipment, Air Conditioning Equipment, Paints & Chemicals etc. These industries in turn place further orders, for their production requirements onto ancillary industries such as Iron & Steel, Basic Metals, Foundries, Chemicals, Fuel & Oils, Electrical, Mining etc.. The financial flow is thus thereon into other Tier II industries. The financial flow or distribution of cost is depicted graphically in Fig No.1 .

**Fig 1: Financial Flow of a Low Complex Ship Across Various Industries [4]**

| | INDUSTRY | PERCENTAGE SHARE OF TOTAL COST OF THE SHIP |
|---|---|---|
| 1 | STEEL | 5.49% |
| 2 | BASIC METALS | 3.31 % |
| 3 | FABRICATED METALS | 2.20% |
| 4 | CHEMICALS | 2.88% |
| 5 | OILS & FUELS | 1.09% |
| 6 | PAINTS | 0.16% |
| 7 | PACKAGING INDUSTRIES | 0.15% |
| 8 | PIPES & TUBES | 0.58% |
| 9 | CASTINGS & FORGINGS | 3.89% |
| 10 | ENGG. COMPONENTS | 5.54% |
| 11 | ELECTRICAL & ELECTRONICS | 0.30% |
| 12 | PUMPS & MOTORS | 0.22% |
| 13 | MINING | 4.2% |

3.3 ROLE OF HUMANRESOURCES While Fig. No. 1 above tabulates the statistical flow of money, the contribution to associated Financial, Maritime Services and all-pervading contribution to Human Resource Development are also significant aspects that merit attention. The same is depicted graphically in Fig No. 2.

**Fig. 2: IMPACT ON SHIP BUILDING ON ECONOMY [ 4 ]**




3.4 LEVERAGED FOR GROWTH BY OTHER COUNTRIES The significance and almost direct correlation of the maritime dominance of trade and sea control to the emergence of nations that is evident from Fig 1 and it's galvanizing effect on the entire economy has been recognized by many nations in recent times. Japan, South Korea and China have in past four decades used this sector as a spring board. Their economies have leap frogged many including India and achieved spectacular growth using ship building as a cornerstone. The only adverse aspect of the ship building particularly the commercial ship building industry is it's close linkage to the international shipping and trade. This is in cyclical in nature and hence the commercial ship building tends to be also cyclical in nature.

**4. Warship Building : Non - Cyclical Industry With Strategic & Geo-political Imperatives**

4.1 **Need For Warship Building**. Warship building flows from the strategic imperatives and economic wherewithal of a nation. Sea power is not a synonym for naval might, nor can it be strictly associated with matters military. The enlarged understanding of sea power is the capability of a state to accelerate its technical and industrial progress backed by research and development in the field of seabed resources, fishing and merchant seafaring with a navy to safeguard these interests.

4.2 **Geo - Political Scenario**. To realise the extent of maritime wealth across India's coastline, there is a need to further nurture and sustain all aspects of maritime capability in a cohesive and coordinated manner. A strong shipbuilding (both warship and commercial ships) and shipping infrastructure is imperative for enhancing the maritime capability of any country. In the changing global environment, where economic activity is paramount, the maritime sector has gained substantial importance. Trade, the most essential aspect of a nation's economy, is largely sea–based. India's trade figures resemble those of other littorals—70 per cent in value and 90 per cent in volume of the country's trade is by sea. The need to secure the merchant fleet and to safeguard the sea lines of communication (SLOC) underscores the requirement to strengthen of both the capability and capacity of the Navy. Another imperative to enhance the capability of the Indian Navy is that the Indian Ocean region is India's strategic backyard where many traditional and non-traditional security challenges are being played out.

4.3 GROWTH PLANS. As a logical consequence of the aforementioned rationale the Maritime Capability Perspective Plan (MCPP) has envisaged certain force levels of marine combatants that necessitated a sustained warship building plan. Further taking cognisance of the geo-political environment, export of warships to friendly and strategically important nations are also being furthered. These dual factors are leading to sustained warship building orders. This needs furtherance so that it can be used as a growth engine for the entire national economy.

4.4 Duly considering the aforementioned factors it is imperative that the Warship building Industry be made efficient and highly productive. The succeeding section highlights the issues that need to be overcome to achieve higher efficiency. The Way Ahead to achieve these Efficiency Enablers discussed.

**5. Efficiency Enablers - Way Ahead**

5.1 **External to Industry - Industrial Environment / Govt Policy /Global Considerations**

(a) Industrial environment. The nation is taking the first steps in ensuring professionalism is ingrained in the corporate character. Towards the same recent steps in ensuring financial probity and stringent audit compliances are noteworthy. It is now required to put in place measures (and where frame work is existing for backing the same with exemplary actions) for technical correctness of industrial products. This will ensure that firms will not make partially correct claims towards technical compliance at the tender stage and then seek waivers at delivery and trials. (The incident of Volkswagen's fuel mileage claims & BMW Diesel Cars' exhaust norms and the resultant backlash are case in point internationally). This will ensure that the products emerging from the industry are top of the line quality. This is turn will make the Defence Sector excessive quality inspection checks redundant. It will also lay the foundation towards enabling the export of Indian warships.

(b) The recent promulgation of the Govt initiative of Self Certification for Defence products has been promulgated. Towards the same PSU and private players with established Quality Management Systems can be awarded Self Certification. There is a need for tangible action on these. It is proposed as test cases; Steel , Large engine aggregates; specialized electronics related to sensors , etc may be taken up for award of Self Certification.

(c) Export Considerations The export of warships to friendly countries is the first step towards building long term relationship. The export of warship leads to :-

(i) People to people Contacts with the crew and the builders interacting over an extended duration.

(ii) Crew training. Crew training at Indian Naval Training Establishments contribute towards greater military inter-operability & bi-lateral cooperation.

(iii) Extended business opportunity. The warship needs periodic repairs and refits. These entails subsequent follow up interactions; both technical and commercial with shipyard and the equipment makers. This leads to further development of business.

**6. Way Ahead**

6.1 Export Push Considering the above, and also duly considering that making the ship may take an extended duration, that be at times, may not be available for diplomatic push due to a myriad of constraints, it is proposed that the shipyards be given grants (With a Foreign Exchange component) to make ready ships in which they have a proven design. The vessel can be sailed to coincide with important Diplomatic visits to that country. The weapon and sensor fit can be customized for the target country's requirements. GRSE can make Light Frigate/ Corvette, Landing Ships, Fast Attack Crafts to further this dual diplomatic/ export push.

**7. External to Shipyards – Customer Dependent, Fixed & Firm Customer Requirements & Delayed Design Inputs**

7.1 A constantly changing design and the consequential impacts in production of modifications and re-work are one of the biggest contributors of delay in warship building projects.

7.2 There is a need to shift from open ended and continually changing requirements (hangover from Cost Plus Projects) to fixed and firm contracts with no back-door clauses for creeping changes.

7.3 Whilst this is a wish list, there are accepted challenges in these that have prevented it's adoption thus far. Thus there is a requirement to understand the various aspects of the need for changes to design during construction.

(a) **Long Gestation Projects & High Obsolescence The warship design is a culmination of a complex multi-disciplinary approach**. This is a long drawn out process and extensive national investment goes into the same. Consequentially, Warship construction projects are long duration and high value projects. The weapon and sensors in these need to be state of art and the high turnover/ obsolescence of the same leads the customer changing them after the initial identification & nomination at the early stage of the project. This issue has been partially addressed by making some of the developmental items Buyer Furnished Items. However, the Design Data availability and system Integration modifications for these are still significant.

(b) **Maintainability Concerns**. The customer (in this case the IN and ICG) are also the maintainers of the warships for the ship's entire life cycle. Hence the customer is interested and concerned about the equipment supportability and the long term logistics management of the equipment fit in the warships. This leads to extended delays/ changes at the time of equipment selection and trials thereof.

(c) I**ntroduction of new developmental products / equipment** The introduction of new products in new construction ship projects are a significant cause of delay in the finalization of design inputs. This stems from the requirements of long timelines for type tests, binding data approvals and then the Quality Assurance Plans (QAP)s approvals. All these are sequential activities and they result in delayed design maturity.

**8. Suggested Way Ahead.**

(a) **Series Production**. In order to leverage the national investment it is recommended that a series of ships of the same class need to be built. There have been success stories notably the Godavari- Brahmaputra Frigates, Project-15 Destroyers, Project -17 Shivalik & 17A and Waterjet/ Fast Attack Classes. However certain series like the Project-28 class also need adoption for series production for the leveraging of the all the advantages. The subsequent ships of the class, can have upgraded weapons and sensor suite. This enables the shipyard to have the advantages of series production and the customer of latest versions of weaponry.

(b) **Deferred Production Start**. A detailed study undertaken and adoption of Integrated Construction was identified as key enablers of faster design and production. However, the principal pre-requisites of the same is Design Maturity. One of the key areas contributing to long project timelines was the lack of maturity of design and timely availability of main equipment. Towards the same the adoption of deferred construction start was adopted as a test case. This needs to be furthered and implemented & adopted in all new projects. It may be built into new projects that production to commence only when all equipment are ordered (with Binding Drawings and QAPs approved) and there is no further changes /adaptations/ modifications from customer and design maturity reaches more than 75%. This in the larger perspective will enable the faster project implementation and capital will not be blocked for the long term.

(c) **Comprehensive Platform Maintenance**. There is a need to explore the modalities of comprehensive Platform Maintenance component as part of the Ship Building Contract. The suggested modalities are:-

(i) Builder to maintain the platform for the first 5 years with an option of renewal on the right of first refusal.

(ii) Operational availability of a stipulated number of days

(iii) Maintenance period indicated.

(iv) Onboard maintenance by customer as per manuals

(v) Multi Port support

d) Projected Direct Advantages

(i) This will lead the shipyard to have greater flexibility in independent selection of the equipment with provisions of back to back long term supportability.

(ii) The Indian Navy will not have to block a significant amount of it's budget towards building and sustaining repair & logistics infrastructure.

(iii) The shipyards will have alternate revenue stream that is assured and de-linked from new buildings

**9. External to Shipyard – Customer Dependent, Equipment in new construction ships to be frozen and proven equipment**

9.1 One of the contributors leading to delayed design maturity and delayed delivery of equipment is the inclusion of developmental and non-proven equipment in the customers' contracts. The onus and impact of the equipment development is thus transferred and borne heavily by the shipyards. The delays encompass the following :-

(a) Time for development of firm technical Specifications

(b) It has been observed that extended timelines are required for completion of ordering process as the specifications are nebulous and non-tenderable and vendor seek extensions.

(c) Time required for finalization of Binding Drawings

(d) Approval of Quality Assurance Plans

(e) Extended time for developmental trials,

9.2 As new construction projects are long gestation, the efficacy of the new developed products/ equipment are not readily observed in terms of the efficacy of the overall platform and while performing with the entire fleet. It is stated that in event the performance is not upto the mark then the operational efficiency of the entire series of ships' performance is compromised.

**10. Way Ahead**

10.1 It is proposed that New Products/equipment (or manufacturers with new products) be proven on MR-MLU ships as retrofits, if successful post comprehensive user trials, then the Binding Drawings and QAPs to be approved and firm to be given Self Certification. After this only product / vendor is to be adopted for new construction ships.

10.2 This will also obviate the issues related to delayed design maturity for new construction ships.

**11. Internal to Shipyard - Steps Towards Efficiency**

11.1 **Fast Procurement**. Shipyards need to focus on fast tracking of procurement and contracting actions. The procurement procedures need to be enabled for faster tendering, scrutiny and order placement. There is a need to critically review the overall timelines for procurement process and wherever required the policy correctives are to be taken.

11.2 **Ease of Doing Business**. An internal audit of Ease of Doing Business and implementation of these measures should be a mandatory norm for all organizations. These should cover areas for external and internal customers. Not only there should ease of doing business but the PCCM Model needs a vigorous implementation. This is an essential to creative a dynamic and responsive organization

11.3 **Inventory Standardization/ Repeat Ordering One of the means suggested that will enable both faster design and procurement is placement of repeat orders.** This will also enable inventory standardization and design ease. To enable this across the entire spectrum it is suggested that the shipyards and related PSUs have a common intra-PSUs portal (like the Samanvay initiative) wherein all the Purchase Orders placed and their attendant technical specifications are available. This will enable selection of the similar & suitable items into design. Thus, design will be faster and it will obviate

(a) Repeat Type Testing, Drawing Approvals and QAP concurrences.

(b) Stakeholders will benefit from economies of scale.

(c) End customer (ie. Navy) will benefit by

(i) lesser inventory

(ii) reduction on training costs for maintainers.

**12. Internal to Shipyard – Building Up Vendor Base**

12.1 **Prime contractor/integrator Tiers in Warship Building Industry**. The facilities and shipyards that construct, convert and repair, comprise a mix of public and private yards. For example in United States there are four active public naval shipyards, which perform repairs of warships and the Coast Guard. The private shipyards of the commercial shipbuilding industry are a multi-tier business. They consist of 18 different first-tier shipyards having construction facilities for large vessels. These large shipyards are like very large subcontractors; they combine the products of hundreds of specialists into a single ship on behalf of a system integrator. The second-tier yards, producing ships of less than 122 meters in length, number several dozen. The shipyards in the second tier; generally integrate fewer complex systems in order to construct smaller warships, as well as a wide range of auxiliary crafts.

12.2 India is yet to develop its own second and third tiers firms within the shipbuilding industry that are of world-class excellence. This is only possible by marrying the experience of the Public-Sector shipyards and the new management / production philosophies of the budding private yards. This exercise will lead to widening the base, for a productive and quality conscious warship construction industry. The nation needs these tier two and tier three firms, which can be called in for subcontracting for warship construction. An endeavour of this nature will create a strategic depth for the country's navy beyond the Defence Public Sector Undertakings (DPSU).

12.3 If India is to build larger number of warships, which are better in quality and built on time, then the shipbuilding industry's real strength has to be enhanced, at the base of the production pyramid. This pyramid has at its base numerous subcontractors and inspectors that do actual outfitting and assembly and QC checks onboard ships. These tier three contractors who execute the subcontract for the installation of propulsion, power generation, and habitability and control systems for military vessels, are required to understand the nuances and demanding regimes of a warship construction. The promulgation of the most stringent Defence Standards or Military Specifications are an effort in vain, if the vendor development has not resulted in sufficient benchmark standard to be achieved.

**13. Way Ahead.**

13.1 Initiatives taken by shipyards in western coast, in harnessing the capability of local private shipyards by outsourcing entire hull fabrication are a step towards building up pyramidal capabilities and eco-systems of warship building hubs and associated industries. Similar exercises have been done in GRSE with the development of a vendor base along the

River Hooghly for block fabrication. These models are now being further developed to encompass other areas of Turnkey Outsourcing contracts.

**14. Internal to Shipyard – Upskilling & Sustaining of Subcontract Work Force.**

14.1 The ship building industry world over depends on a large sub-contract workforce. The subcontract workforce consist of a large number of temporary labourers / casual workers. A subcontractor's business at times is unpredictable and they are not always able to employ an exclusive set of workers. Thus, a temporary worker may work for piping contactor A one quarter and for B contractor next quarter and for C subcontractor the quarter after that. Though all contractors are working on similar jobs in the same project, this has the effect of inflating the pool of available subcontract labour. So when the shipyard during peak load, essentially requires to crash the project delivery time they are not able to mobilise all the registered vendors working with them.

14.2 The shipyards as per their internal commercial mandates make different subcontractors compete for the work among themselves. The restricted pool of skilled manpower means, the workers who actually do the work rotate between companies, depending on which firm has the current contract. The effect: there are only enough workers to fully staff one or two subcontractors rather than all the companies. A growing trend with budding clusters of private shipyards beyond the defence shipyard is that, many subcontractors that have learnt their trade and gained skill are slowly being weaned away to perform work in private shipyards. This means, that warship yards in certain parts of the country may be competing with one another for skills available. This model works well when neither yard is forced to operate beyond capacity. However, should the level of work increase greatly across multiple shipyards at the same time, there is no guarantee that the desired workforce with the requisite skill set will be available.

**14.3 Way Ahead**. A multi-pronged approach is underway and needs to be furthered to address the above issue:

(a) **Vendor Development & Retention**. Certain shipyards have moved away from tendering piece-meal works repeatedly that leads to both tendering / commercial delays and builds up a sense of false competition amongst the sub-contract vendor base. The same has been done by two separate approaches: -

(i) Published Rates of standard Works. In this instance the annual rates are published by the shipyard for standard works ( Steel Fabrication, Piping, Cabling, outfitting) and any registered vendor can be awarded the work as per their capacity and ongoing load.

(ii) Long Term Turnkey Contracts / Biennial Rate Contracts. Shipyard awards long term turnkey contract for comprehensive work packages that are for an extended duration 4 to 5 years. For works that are repetitive in nature Biennial rate and parallel rate contracts are entered into with established contractors.

Both these approaches give the contractor an assured business for medium term and enables them to hold on to their respective skilled workforce. The rider to these is that parent yard should have a continuous work visibility over a long term.

(b) **Skill Development Need for Skilling - Skill India**

(i) The shipyards are mandated by the Apprentice Act and also by the recent Skill India initiatives of the Govt to impart work skill training. In different regions these have developed in different forms. In Goa the development & strengthening of Institute of Ship Building Technology is one dimension. In Kolkata apart from Apprentice training and training of graduate engineers, the MoUs between Indian Institute of Engg Science & Technology and GRSE are the new models that need furtherance.

(ii) Another initiative by GRSE is to impart welder training and certification in specialized steels like DMR 249A to all interested contractors. This has gone a long way in overcoming the shortage of skilled welders.

(iii) Considering the approach of the shipyards to not engage direct workforce, another suggested way forward may be to formally get the apprentices and skill trainees to work as interns with the shipyards' engaged contractors for their practical phase.

**15. Internal To Shipyard –Third Party Inspection (TPI) and Quality Control- Need for re-look: Progress so far & Next Steps**

15.1 In the last decade as there was a push towards curtailment of inordinately long equipment delivery timelines and inspection processes of the Customer ; namely Director General Quality Assurance, one of the approaches adopted was the engagement of Third Party Inspection. In this approach the competencies in the Commercial Shipbuilding of Classification Societies were harnessed towards conduct of equipment inspections and certain ship building inspections of non-frontline ships by Classification Societies of International Association of Classification Societies (IACS). This approach has led to certain amount of reduction of inspection timelines but certain other issues have also emerged.

15.2 The IACS members have at certain times devolved the conduct of inspections to their subsidiaries / associates. The quality of inspections have suffered and thereby impacting the end product quality. This has led to certain naval & Coast Guard agencies now undertaking inspections in addition. This has resulted in dual inspections and thereby defeating the very purpose of the first approach.

15.3 There is a need of a deeper analysis of the issue. The same subsequent paragraphs dwell on it.

(a) The very word 'third party' itself signifies detachment. Third party means, that they are neither the first party (the customer) nor the second party (supplier). It is the Third Party who has no stake at hold but is authorised to inspect. If both, first party and second party, who have the largest stakes, are not ready to invest human and financial resources in controlling the quality of the building processes in shipbuilding yards.

(b) Can we expect the **third party** to be more interested in ensuring quality for our product by investing in infrastructure and manpower skill development?

(c) Third party inspection is governed purely by the contract between third party and first/second party. But experience indicates that war shipbuilding contracts, can be either too specific or general leaving scope for the subcontractor / third party to be responsible for their work, can disengage him from accountability in case of delay/ rework. Swift decisions on litigation or arbitration arising out of observed deviations from QAP by third party inspector is still a pipe dream.

(d) Third party is only ensuring that QAP as approved by the Navy is strictly followed. The third party is not able to declare equipment as 'Fitness for Use'.

(e) Some important areas which also need further attention are:

(i) Rationalisation of non-critical equipment or systems that require only performance based inspection for acceptance and preserving the more stringent hold point inspection for acceptance of critical equipment only.

(ii) Role of third party inspectors and their access to sensitive information on 'material state of readiness for warship" finally delivered.

(iii) The personnel in navy's trial team like MTU, ETMU, WOT have understanding of the pitfalls and short comings of the Indian shipyards. This knowledge base of, what to look for beyond the written document before commissioning equipment or trials onboard ship/at sea is presently irreplaceable. The experience of working on warships projects in Indian domain has not developed or ripened to a mature state with any other agency including the Classification Societies.

(iv) The drive for indigenisation causes subcontracts and third party inspection to be awarded to players with proven industrial experience but sparse exposure to marine environment. This creates interface problem in onboard integration of equipment with system especially related to man machine interface.

**16. Way Ahead**

16.1 The warship building program of the nation has achieved this level of self-reliance today because of the yeomen service played by DQA(WP), DQA(WE), Directorate of Indigenisation and Directorate of Standardisation in nurturing the warship construction industry. The procedural checks and balances created by these organisation need to be replicated in outsourcing the TPI Contracts. The developed Standard QAPs need to be shared across the spectrum and used as a template for TPI agencies.

16.2 Dual Inspections are to be avoided at all costs across the spectrum. The modalities of harnessing of the expertise of naval trials teams with TPIs acting as the onsite inspector are the areas that need further detailed deliberation towards a development of a robust model of Quality Assurance that is time and cost competitive whilst ensuring & delivering the requisite quality

**17. Conclusion**

17.1 The paper gives the underlying rationale on how the warship building is a key contributor to spurring national growth. The areas and the issues that need to be addressed are outlined with an overview of the progress so far. The road map for the immediate to medium term future is outlined for focussed attention of the Policy Makers.

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# REVISITING THE MARITIME AGENDA 2020: HOW MAY INDIAN SHIPYARDS BECOME SUSTAINABLE & SIGNIFICANT TO OUR ECONOMY


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**1. Executive Summary**


1.1 Indian shipyards which were looking for a revival this decade, started to falter when the global economy stalled post 2008. The Maritime Agenda 2020, released in 2011 had set a target for India to take 5% of shipbuilding orders by 2020. However, by 2013 post the financial meltdown, it was evident that the domestic shipbuilding Industry had nearly collapsed. This paper examines the steps to be taken by the government immediately. It calls for a review to the earlier export led revival and states that a Short-term inward looking growth will be a stepping-stone to a Long-term re-entry into the export market. It looks at how the financial crisis created havoc in the big three shipbuilding nations, China, South Korea and Japan. Their governments looked at the social cost of allowing international markets to decide the fate of the shipbuilding industry and with a long-term view have sustained it over the difficult years at the cost of market distortion. Indian government need to act similarly and forcefully.

1.2 Our inefficient Road Transport sector may give Indian Shipbuilding the much needed boost in the short term. There is a mandate by the Government to improve our Inland waterways and Coastal shipping. The paper suggests that a mature financial shipping capital market be put in place, to assist ship purchase and operators. This must be supplemented by a thrust to build efficient ships with modern processes by our shipyards. A body that analyses international shipping trade and market for the Indian cluster must be available. Information is paramount today, and this institutional void should be filled. The paper looks what we can learn from the Chinese model to improve our yard efficiencies, overhead costs and their dedicated shipping financial institutes. How the Chinese deftly combine responsible shipbuilding in defence with efficient shipbuilding in commercial ships and improve price and delivery efficiency.

1.3 Finally, it suggests a few changes to the four identified enablers, bridging the manufacturing and resource gap, improving labour skill and rationalizing governmental intervention. No major economy has succeeded historically without a mature Maritime industry. India cannot afford to ignore it.


**2. Introduction**

2.1 India has since the last more than seven decades tried to rise as a major maritime nation. The results however have been quite disappointing. Though our general economy has been continuously growing from 11th largest in 2008 to the 6th largest economy today, the Maritime Sector has been a perpetual laggard.

2.2 The advantages of tapping this huge maritime sector for its multiplier effect is well understood and documented. This prompted the Government to release a Perspective Plan Document titled Maritime Agenda 2020 in Jan 2011.

2.3 The Maritime Agenda 2020 is unique in its contents, in that it has given clear directions. It is prescriptive and laid out clear targets for both the Government and the Maritime cluster. This paper attempts look at what we have achieved so far in the Shipbuilding Sector. We had a mandate to capture a 5% share of the global order book by 2020. Where are we now?

**Table 1: Did The Indian Shipping and Shipbuilding Tonnage keep abreast with their targets?**

| | 2010 | 2014 | 2018 | 2020 | Year on Year Growth | Target as per Maritime Agenda | YOY Growth as planned In Agenda |
|---|---|---|---|---|---|---|---|
| GPD Growth (trillion USD) | 1.729 | 2.0 | 2.68 | 2.9 | About 6 % | Not Applicable | 7% |
| Indian Tonnage million Gross Tons | 10.1 | 10.3 | 14.9 | 15.2 | About 4.5% | 30.0 | 12% |
| Percentage share of global orders. | 1.0 % | 0.6% | <0.5% | - | No Growth | 5% | 17% |
| Source: Govt of India and Japanese Ship Owners Association. | | | | | | | |

### 3. Japan, Korea and the Chinese Shipbuilding Industry - 2000 to 2010

3.1 Since the last 60 years, Japan, Korea and China have promoted shipbuilding as an industry strategic to social capital. One that is also major source of employment for the labour. Starting in the 1950's Japan became the market leader in the 70's, through a combination of low labour costs, investment in modern shipyards, and development of new shipbuilding techniques. In a similar push the South Korean Government decided to promote shipbuilding as a major source of employment for its emerging economy since 1960 and by the mid -1990's South Korea became the global leader in Shipbuilding.

**Fig. 1: When will it be India's turn?**

3.2 In mid-1995, The Chinese had a deliberate aim to become the number one shipbuilding nation and made it a national policy. China in 2006 had a world market share of 18% of the world's shipbuilding market and by August 2008, China with a 30% market share overtook Japan (17.5%). Korea was still the market leader with 41% of the world's market share.

**Fig. 2: Chinese Plans to develop shipbuilding since 2003.**

**Box 3. Chinese development plans involving the shipbuilding industry**

- 2003 National Marine Economic Development Plan
- 2006 The 11th Five-Year Plan for National Economic and Social Development
- 2006 The Medium and Long Term Development Plan of Shipbuilding Industry
- 2007 The 11th Five-Year Plan for the Development of Shipbuilding Industry
- 2007 The 11th Five-Year Plan for the Development of Shipbuilding Technology
- 2007 The 11th Five-Year Plan for the Development of Ship Equipment Industry
- 2007 Guideline for Comprehensive Establishment of Modern Shipbuilding (2006-10)
- 2007 Shipbuilding Operation Standards
- 2009 Plan on the Adjusting and Revitalizing the Shipbuilding Industry
- 2010 The 12th Five-Year Plan for National Economic and Social Development
- 2012 The 12th Five-Year Plan for the Development of the Shipbuilding Industry
- 2013 Plan on Accelerating Structural Adjustment and Promoting Transformation and Upgrading of the Shipbuilding Industry
- 2013 Shipbuilding Industry Standard and Conditions
- 2015 Made in China 2025

*Source: Kalopupsidi and Barwick 2018./ Based on Clarkson's data 2018/ Market Distorting Factors in Shipbuilding- Role of Governments. OECD April 2019*

**4. India's Gain in Shipbuilding during the Boom Years from 2000 to 2008.**

4.1 In 2007, India with 1.17% of the global shipping order book, was the 4th country in terms of Market share. The shipping industry riding on a strong boom allowed India to catch an order book position that grew from Rs. 816 Crores in 2002 to Rs. 21,800 Crores in 31st December 2007.

**Fig. 3: Indian Shipbuilding Order book in 2007**

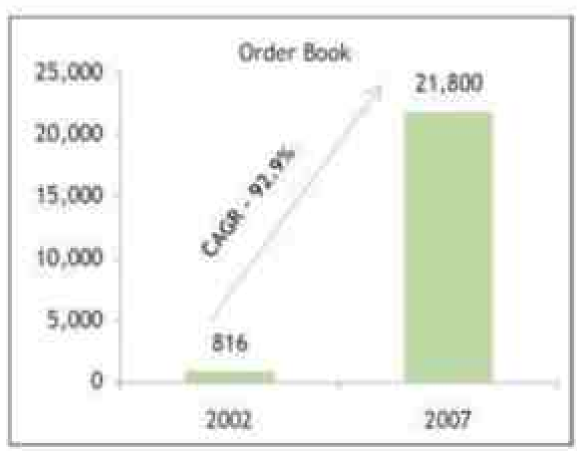


Figure 10: Order Book of India

4.2 A report prepared by I-Maritime Consultancy Private Ltd-Mumbai, provided enough evidence stating that on this highly labour intensive industry, India would have a market share of 15% with an order book of 22 billion USD by 2020. It advantages would be cost competitiveness, and an abundant labour force. A productivity comparison then, showed India's productivity was just a little behind China.

**Table 2: Global Order Book Position in 2007**

| Country | Order Book (CGT) | Market Share |
|---|---|---|
| South Korea | 62,068,956 | 41.00% |
| China | 45,573,036 | 30.10% |
| Japan | 26,372,177 | 17.42% |
| India | 1,766,695 | 1.17% |
| Vietnam | 1,735,513 | 1.15% |
| Germany | 1,709,433 | 1.13% |
| Turkey | 1,705,271 | 1.13% |
| Philippines | 1,620,778 | 1.07% |
| Taiwan | 1,620,140 | 1.07% |
| Romania | 1,036,221 | 0.68% |
| Rest of the World | 6,178,478 | 4.08% |
| Total | 151,387,698 | 100.00% |

*Source: MER(I) October 2019.*

4.3 In 2007, it seemed logical that the shipbuilding Industry would move towards low cost countries such as Bangladesh, Sri Lanka, Vietnam, Indonesia, Brazil and India. It was against this backdrop that the Maritime Agenda 2020 was released.

**5. The Maritime Agenda 2020**

5.1 The Maritime Agenda 2020 spans the 11th, 12th and the 13th 5-year plans in parts and in full.

5.2 It acknowledges that shipping is a derived industry and speaks about developing the maritime cluster. The service providers are the Ship's themselves and the support system comprises of the ports, roads, waterways, warehouses, shipyards, IT Communications, Ancillary engineering firms, Design Houses, Universities, R&D facilities, Fishing Industries, Repair Yards and a huge industry supporting the defence sector.

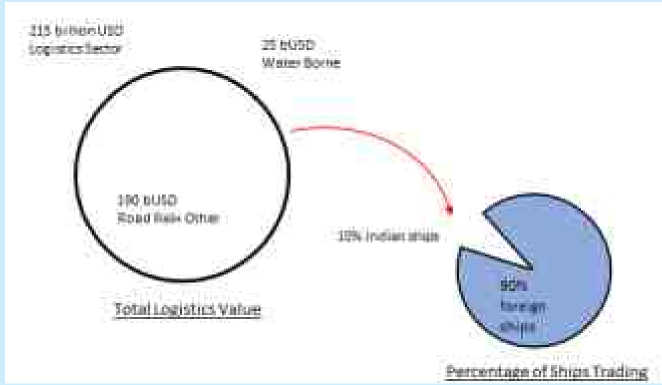
5.3 The reasons to promote both Defence and Commercial shipping arose of the need to protect the economic interests and political sovereignty of the nation. It was also felt that with the growth of Indian trade volumes the maritime sector must grow not only proportionally but also to catch up with the existing shortfall. A major concern was the cost of Logistics, primarily based on surface transport was very high in India and making transportation greener. Water transport was the solution.

5.4 The Indian Logistic turnover in 2010 was estimated at 125 billion USD (GATI Annual Report of 2011) with the share of water borne transport was around 10%. In 2019, the logistics turnover was estimated to be 215 billion USD (The Economic Times 2019). The long Indian coastline was considered underutilized and an ambitious plan was drawn for a 12% year on year growth of our existing waterborne fleet.

5.5 The plan was that the Indian owned and operated Gross Tonnage of 10 million GT in 2010, would be increased to 30 million GT by 2020 and Indian companies would in addition charter vessels of 43 million GT. The growth of Indian Fleet was also expected to be driven to a Port led Development Plan called Sagarmala, that called for a Public-Private partnerships.

5.6 Today in 2019, the Indian owned fleet stands at 15 million GT. A half of our target.

**Fig. 4: Water Borne Trade in Percentage 2019. (Data: The Economic Times)**




**7. The Maritime Agenda Identifies the Gaps to Improve Shipbuilding in India.**

7.1 The Maritime Agenda 2020 has a special section for Shipyards and Ship Repair. The box below states the proposed target for 2020.

**Target Set for the Shipbuilding/Repair Industry for 2020**

- To improve the shipbuilding global market share to 5% in 2020, from the current 1% in 2010.
- To achieve a 10% share of the Global Ship repair industry
- To develop a strong Ancillary base by 2020.
- To develop and provide 2.5 jobs both direct and indirect in the shipbuilding and repair sector.
- To develop strong R&D facilities and design capabilities for the commercial shipbuilding.
- To become self-sufficient in ship repair and replace Colombo, Dubai
- To achieve a 10% share of the Global Ship repair industry

7.2 In order to boost the shipbuilding and repair industry, four broad gaps were identified. A Summary of the areas of concern and how they are to be addressed is given in the Table No 8.

7.3 The gaps identified in manufacturing, technology, resource and training are discussed briefly.

**8. The Manufacturing Gap**

8.1 **Shipbuilding Subsidy Scheme**. A shipbuilding subsidy scheme was approved by the Union Cabinet and in force from 2016 until 2026. The 20% subsidy given in 2016 progressively reduces to 17%, 14% and finally to 11% in 2026. It requires that a standard ship, be built within 3 years of signing the contact with favourable clauses for specialized ships.

8.2 Ship Repair Units and Maintenance Hubs: There is not much progress in the earlier intension to have a ship repair yard at every major port in India.

8.3 Infrastructure Status: The status is now granted. Shipyards will be able to avail flexible structuring of long-term project loans, long-term funding from infra funds at lower interest rates and longer tenure equivalent to the economic life of their assets, relaxed ECB norms, issuance of infrastructure bonds for meeting working capital requirements as well as benefits under Income Tax Act, 1961.

8.4 Strategic Sector: Both the Maritime Agenda 2020 and the National Manufacturing Competitiveness Council have recommended that Shipyards be declared a Strategic Sector. Its role in energy security, national security and improving heavy engineering in the country is paramount. However, no progress so far.

8.5 Incentivizing Domestic Shipyards: The GOI has allowed the participation of any Indian yard having the requisite infrastructure to take part in PSU tenders even if the yard has no experience in delivering that particular ship **type. It was an incentive for shipyards to improve their infrastructure.**

### Table 3. Summary of the Gaps Identified to Incentivise Shipbuilding and Repair

Summary of the Gaps and their Improvements

| | | Manufacturing Gap | Technology Gap | Resource Gap | Skill Development Gap |
|---|---|---|---|---|---|
| Policy | Infrastructure Status | Shipbuilding industry to be given infrastructure status. | | | Government will set up new courses to Train Engineers and Naval Architects. |
| Policy | Strategic Status | Shipbuilding to be declared a strategic sector. | Policy to encourage foreign firms to set ancillary units. | Tax on domestic shipbuilding steel be reduced, and create level playing field with cheaper imports. | |
| Financial | Subsidy | Ship-building subsidy scheme for ships built in India. | Capital Subsidy will be given where technology transfer is to be bought from elsewhere. | | |
| Financial | Funding | | | Shipyards will get funding to improve infrastructure and working capital. | |
| Infrastructure | Port and Connectivity | Set up shipyards and repair yards at every major port. | | | |
| Infrastructure | Shipyard Infrastructure | Foreign Design companies will be encouraged to set shop in India for concept designs. | Shipyards will be encouraged to increase capacity by installing better facilities. | | Shipyards will start ITI training as per government guidelines. Government will provide tools as incentive. |
| Demand | Domestic Orders | Yards with suitable infrastructure are eligible to compete for Govt Tenders, building experience not a pre-requisite. Indian yards get purchase preference for global tenders. | An Offset Policy to increase ship acquisition by Domestic Shipping companies. | | |
| Demand | Export Orders | | | | |

## 9. The Technology gap

9.1 The Table 9, below shows the fates of the shipyards in the last 10 years since 2010. In the Large ships yards in the Private sector domain only the L&T Shipyard Ltd remains significantly active. Other than that, the only large yards remaining are Public Sector Yards remaining significantly active.

FICCI

**Table 4: Survival of the Fittest!**

| Shipyard | Category | Status in 2010 | Status in 2019 |
|---|---|---|---|
| Cochin Shipyard Ltd | Large/PSU (MOS) | Active | Active |
| Mazagoan Docks Ltd | Large/PSU (MOD) | Active | Active |
| Garden Reach Shipbuilders Ltd | Large/PSU (MOD) | Active | Active |
| Goa Shipyard Ltd | | Active | Active |
| Hindustan Shipyard Ltd | Large/PSU (MOD) | Active | Active |
| Hooghly Docks & Port Engg Ltd | Small/ PSU (MOS) | Signs of Strain | Strained |
| Shalimar Works Ltd. | Small/ State PSU | Signs of Strain | Inactive |
| Alcock Ashdown Ltd | Small (State PSU) | Signs of Strain | Inactive |
| Bharati Shipyard Ltd | Medium/ | Signs of Strain | Inactive |
| ABG Shipyard Ltd | Large/ Private | Signs of Strain | Inactive |
| Tebma Shipyard | Medium/Private | Signs of Strain | Inactive |
| Modest Shipyard | Small/ Private | Active | Inactive |
| Chowgule & Co Ltd | Small/Private | Active | Active |
| Shorft Shipyard Pvt Ltd | Small/Private | Active | Active |
| Dempo Shipbuilding Co. | Small/Private | Active | Active |
| Timblo Shipbuilding Ltd | Small/Private | Active | Strained |
| Waterways Shipyard Co. | Small/Private | Active | Strained |
| Siddharth Marine | Small/Private | Active | Strained |
| Vijai Marine Services | Small/Private | Active | Strained |
| A.C.Roy | Small/Private | Active | Strained |
| Titagharh Marine Ltd | Small/Private | Active | Strained |
| Reliance Naval Engg Ltd | Large/Private | Active | Significantly Inactive |
| L&T Shipbuilding Ltd | Large/Private | Active | Active |

9.2 The remaining active yards have withstood the most difficult part of the recession and thereby improved their processes and performance. Cochin Shipyard Ltd, GRSE, Mazagaon Docks and L&T Shipyard Ltd have significantly improved their competitiveness. Several of the Efficiency enablers identified in the Gap analysis table have been put into practice.

9.3 Transfer of Technology: Most yards even smaller ones have individually attempted to improve the building technology. L&T Shipyard Ltd have had a three-year collaboration with Mitsubishi Heavy Industries (MHI Shipyard, Japan). Their Block making and Erection improvements have reduced cycle times. Cochin Shipyard, which has had a collaboration with IHI of Japan, has put in place advance block outfitting and able to make a very high level of outfitting. L&T Shipyard Ltd are using data collected though ERP and Digital tools to monitor and improve man-hours used by 8% on each of their ships when produced in a series. RIL Naval Engineering yard had hired Japanese engineers for almost 5 years to improve their block making shops. Modest shipyard had approached Korean consultants and improved their production methods. Yet we have to catch up.

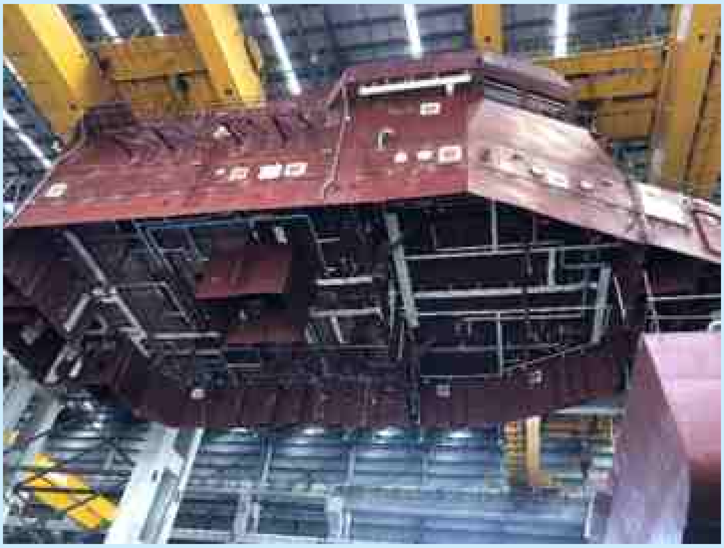
**Table 5: Comparison of Productivity using the CGT yardstick.**

| A concept of Compensated Gross Tonnage to measure yard effort is in the International Norm to compare yard effort. This measures a total completed ton of a ship, adjusting for its complexity. | |
|---|---|
| Indian yards (sample L&T Shipyard) | Korean yards |
| 50 Man-hours/ Ton | 10 Man-hours/Ton |

*Source: L&T Kattupalli Ltd.*

9.4 Modernization of Shipyards: Both Cochin and the L&T ship yards have studied work processes at yard and added cranes, mobile lifting devices, changed over to using semi-automatic welding devices to increase productivity. The L&T Shipyard has benchmarked itself to British safety standards 5 Star rating and major yardstick. Safety culture is an indication of higher productivity.

**Fig. 5: Improved Techniques in Indian Shipyards have led to significant efficiencies since 2010.**



9.5 Promotion of Design Capabilities: All PSU yards who have been building ships for some time have reliable design expertise. While concept design for modern commercial ship types are a point of some concern, the solution is to train the personnel on the job. Getting a good design from a reputed designer is not possible for smaller yards. In China, a special cell creates first quality designs and sells to the Chinese yards at a very reasonable price. This model is to be adopted. Earlier attempts by Govt. to create NSRDC and Nirdesh as design hubs have failed.

9.6 Ancillarisation: Most of the equipment and machinery have to be imported for Commercial ships while it is not so for Defence ships due to intense indigenization steered by Indian Navy. A few international companies have started manufacturing in India and the most significant being MAN who have started an assembly and testing facility at Aurangabad. However, most equipment suppliers who have a representation in India will invest only if they see signs of growth.

**10. The Resource Gap**

10.1 Special Quality Steel: Indian steel manufacturers can make shipbuilding steel provided the volume is continuous. The price between Chinese steel and Local steel is about 80 USD higher per ton, but it can be managed if the locally volumes are improved. For SEZ and export orders, duties are exempt.

10.2 Funding: Ship Financing remains a single point of concern. This is especially true for private customers both in India and abroad. They require deferred payments and a line of credit. Indian yards do not receive state support, which is prevalent in countries such as China and Korea.

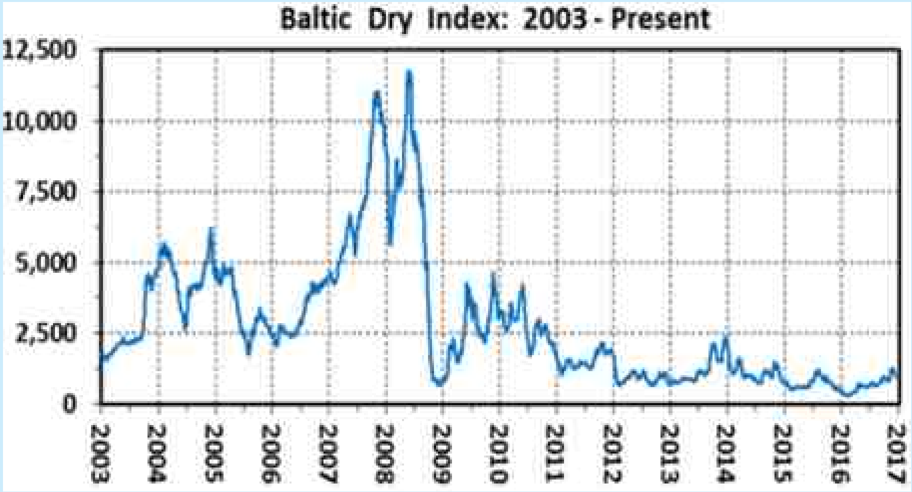
**11. The Training Gap**

11.1 The shortage of Naval Architects and Training of Skilled work force have been addressed by the government by the setting up of the IMU.

**12. Global meltdown and the collapse of the Indian Shipbuilding Industry between 2010-2019:**

12.1 In August 2008, the Lehman Brothers collapse plunged the Baltic Index, which stood close to 13000 in June 2008 to 700 in 2009. Markets recovered but charter rates were driven down to unrealistic levels. Then came the second shocker the oil markets plunged from 114 USD a barrel in 2011 to 38 USD in 2015.

**Fig. 6: The BDI Index from 2003 to 2019.**



12.2 Certainly, a Maritime forecast Report prepared in 2010 based on the events of 2007 cannot be relevant in 2016. More so from the view of disbursing shipbuilding subsidies. How can a report issued in 2011 not understand the grave realities?

12.3 By 2011 Shipyards world over were in deep trouble. Many went bankrupt and should have closed, logically market forces should take over and allowed the yards with cancelled order books to collapse, but this did not happen.

12.4 The reason is that that shipbuilding was, and still is, considered by the Chinese, Korean and Japanese governments to be social capital. Can any government allow its labour to become jobless and homeless overnight? Their governments subsidized the industry, distorting market prices and creating excess supply in the market. In 2018, China officially became the world's largest shipbuilder with a 43% market share. Ships continued to be built at prices offered that were too attractive to refuse. Shipping pundits complained about a glut in ships worldwide.

**Fig. 7: Can Trade Grow in a shrinking global world?**

*The Shipbuilding Industry between 2010-2019.*

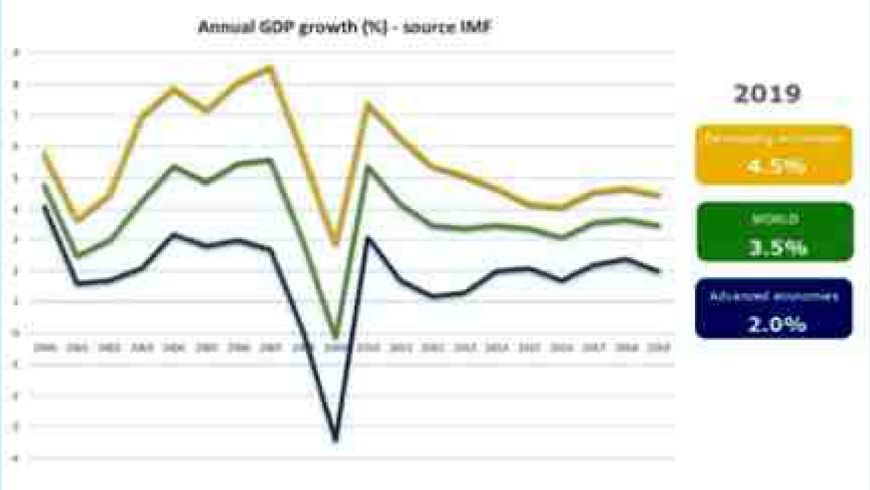
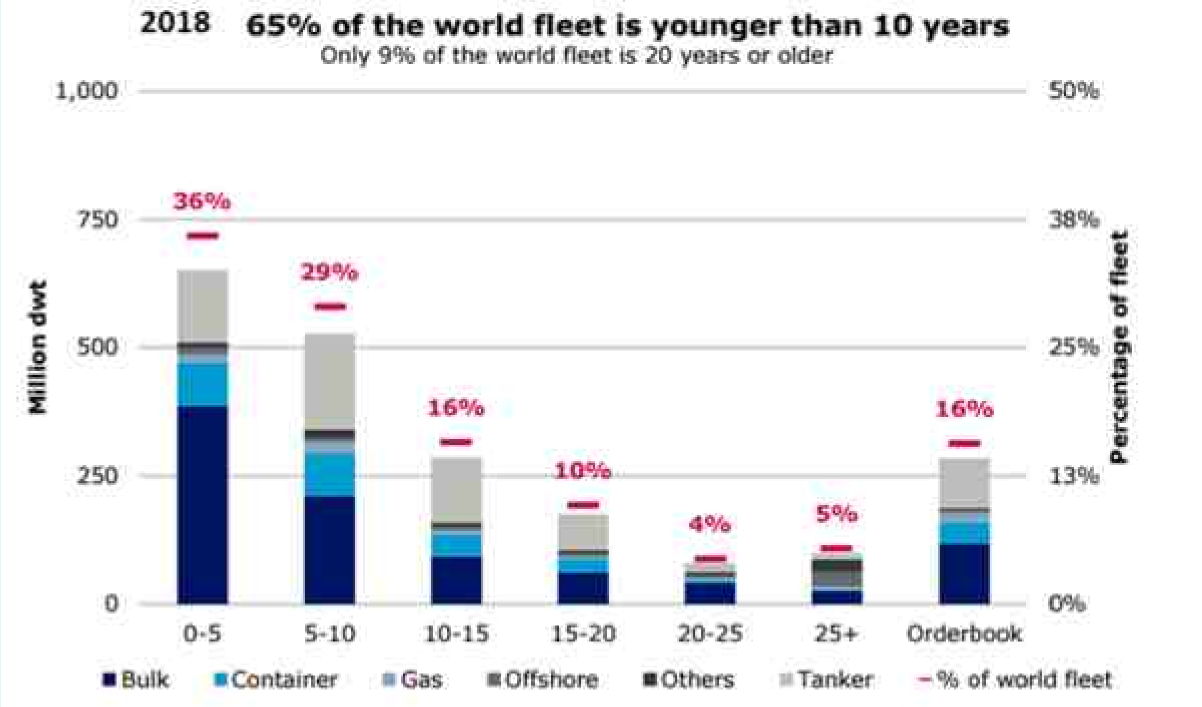



**Table 6: China becomes the world's largest Shipbuilding Nation in 2018**

| Orderbook | | 2017 | 2018 |
|---|---|---|---|
| China | Market share | 43.7% | 43.1% |
| | Ships | 1,234 | 1,283 |
| | m dwt | 93.9 | 99.8 |
| Korea | Market share | 24.4% | 27.5% |
| | Ships | 396 | 465 |
| | m dwt | 52.4 | 63.8 |
| Japan | Market share | 25.1% | 24.0% |
| | Ships | 750 | 730 |
| | m dwt | 54 | 55.5 |
| Europe | Market share | 1.6% | 1.6% |
| | Ships | 237 | 288 |
| | m dwt | 3.4 | 3.6 |
| ROW | Market share | 5.2% | 3.8% |
| | Ships | 267 | 229 |
| | m dwt | 11.1 | 8.9 |

*Source: World Order Book 2018.*

**Fig. 8: The three major shipbuilding nations Continue to Build Ships creating an oversupply. The world fleet is the youngest in decades.**




*Source: Clarksons, Danish Ship Finance*

**13. Governmental Support keeps foreign yards afloat.**

13.1 The Publication Fairplay in July 2018 reported that both Korean and Chinese shipyards are given unfair state subsidies. The European Commission is also investigating "massive" state subsidies that South Korean and Chinese enjoy. Kenji Asada of the Nikkei Asian Review wrote in its 17th July 2018 edition that the three countries China, Japan and Korea are locked in a bitter rivalry to keep their yards running. Certainly all three governments were aiding their yards. Korean yards and Japanese yards continued to consolidate and were given state subsidies, as they were too big to fail.

**14. Indian yards were Conspicuous by having no governmental support.**

14.1 Indian Private Shipyards meanwhile collapsed. See Table 9. Indian yards are conspicuous by the absence of any governmental support. In this very decade (2010-2020) almost all private yards lost their orders. The reasons were that as the freight earnings shrunk, genuine buyers wanted quality ships from reputed yards. Global realities required yards to match Chinese prices and demanded deferred payments. Most shipping technocrats being ignorant of the huge subsidies given by Chinese, Korean and Japanese yards usually blame Indian yards for their historic inefficiency.

## 15. The Complexity of Buying Ships and Building them.

15.1 Shipbuilding is part of a complex Cluster. It requires time to establish itself. One must look at Shipbuilding as a strategic sector and not get too worried by the cycles of boom and bust. This does not mean that operational profits are to be ignored. It calls for a long and short-term strategy. Therefore, price volatility is something that is inherent to commercial shipping. There is no right time to enter the shipbuilding cycle. For the ship owner the ship is a capital asset. His 'Buying Price' is always weighed against the financial wisdom of his “portfolio theory”. How much is the value and what is the earning? New Building prices in the last two decades show that the Cost price at the yard is different from the Market price. Ship Owners too are under pressure. They cannot determine the correct price level for their entry and get attracted by yards that allow deferred payments. Indian yards on the other hand demand cash up front and our accounting system do not recognize this price volatility.

**Fig. 9: Are Shipyards too big to fail!**


BUSINESS TRENDS

Beijing, Tokyo and Seoul aid shipbuilders as rivalry deepens

Governments unable to iron out differences on relieving overcapacity

**Fig. 10: Shipbuilding price volatility. What is a good time to enter? Source:**

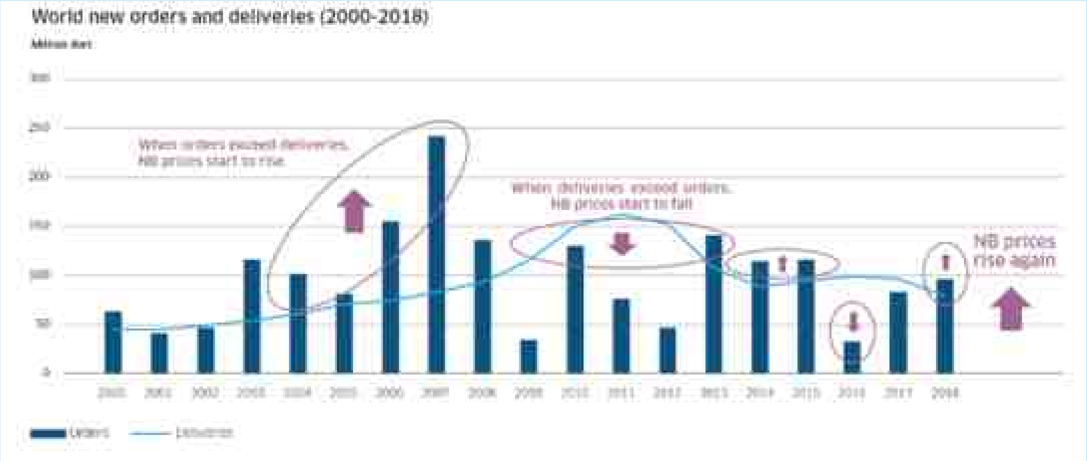
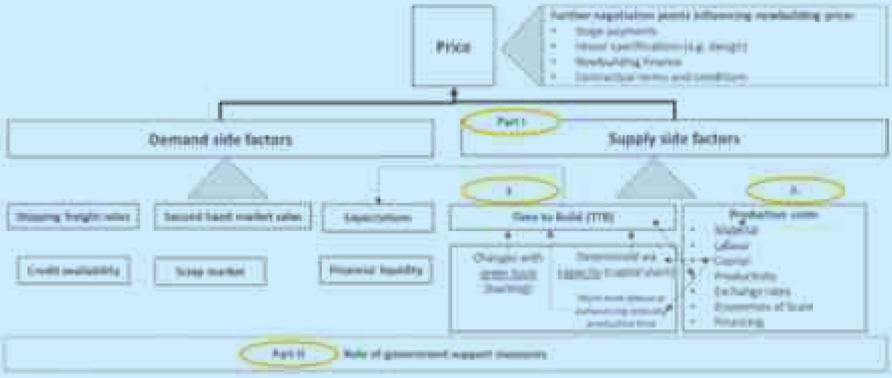



**Fig. 11: Factors That Determine New Building prices. Source:**




*Source: Stopford 2003/ An Analysis of Market Distorting Factors in Shipbuilding*

**Fig. 12: Freight rates do not justify new building prices today**


*Source: Clarksons, Danish Ship Finance.*

**16. The state of the Economy and shipbuilding entry space.**

16.1 Indian shipbuilding have missed the shipbuilding boom pre 2008 to improve the market share of the domestic shipbuilding industry. However, as mentioned earlier it is not possible to enter shipbuilding with a trader mentality that one may enter and leave at right time. The entry and exit cost are very high. Shipbuilding is a very mature market and cyclical. It is also often distorted and skewed by Governmental invention. Nevertheless, also an industrial eco-system on its own cannot be ignored. Therefore the Indian Governments approach must be strategic, long term and consistent.

16.2 We must therefore make a short and a long-term plan to re-enter the space with a strategy and governmental help.

**17. The Enabling factors: The Short and Long term Plan.**

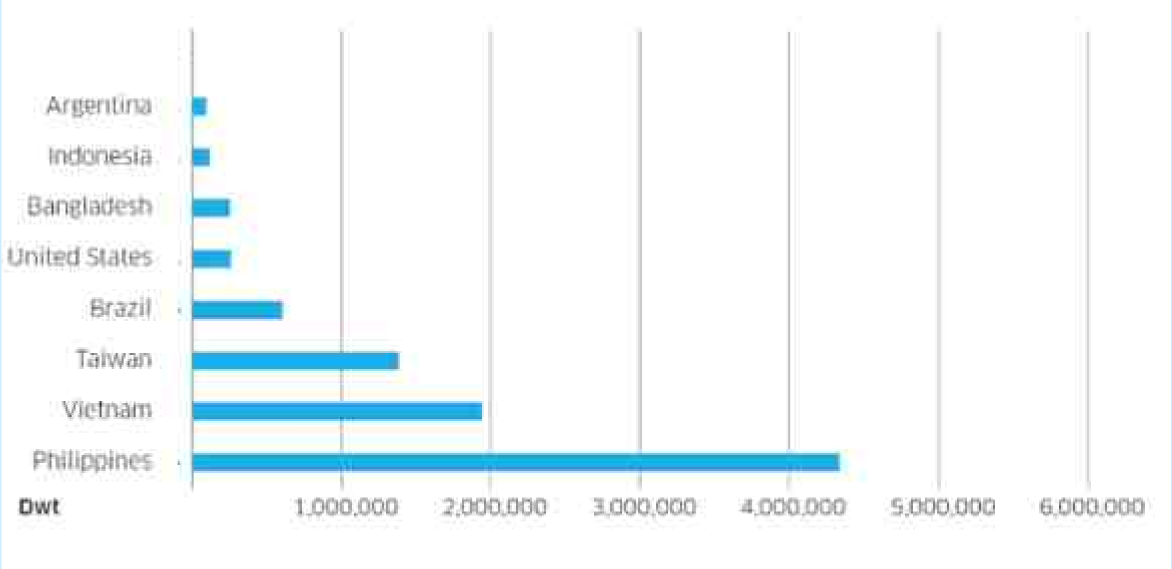
17.1 In the Short Term: It is estimated that today 100 waterways carry about 55 MMTPA (million Metric tons per annum) of cargo. Out of these, nineteen such waterways have been announced for immediate development and the NW1 currently from Haldia to Allahabad is the most significant. A major thrust area for the Indian government is utilizing of the Inland Waterways for Transport. In-fact it is almost a mandate. A plan to carry 200 MMTPA by 2025 has been envisaged by developing the last mile connectivity. This and the other waterways are expected to require about 1250 small crafts of 1500 Dwt in until 2025. The crafts are for carriage of bulk cargo, container, dredgers, tankers and ferry crafts. The study shows that only 40% of the yards will be able to produce these crafts within the time and a significant number will have to be exported. This means that yards have significant work in the short term.

17.2 Let's not discount the smaller ships of 20,000 DWt and below. Europe has an order book of 1.6% and the Rest of the World has a market share of 3.8%. Just 4 yards in Philippines, Vietnam, Brazil and

Taiwan picked up all the orders in the Rest of the World. This is not a small start if planned carefully. They will help us sustain in the short term and build up competencies. Countries are surviving on them. See table 20.

17.3 In the Long Term: The Inland waterways development along with the 'Sagarmala Project' to enhance coastal shipping will give our shipyards significant work for the next 5-10 years. Coastal shipping will allow us to explore short sea shipping between ports of Bangladesh, Malaysia, Burma, Singapore and the Gulf. This gives an immediate segment that is the 120 meters shops of all commercial types to focus on. The Long Term Plan (5-15 years) will be to re-enter the global export market with ships in the 25-15000 Dwt tonnage. They will be required globally and we can become a source for such ships.

**Fig. 13: Order book for Rest of the World by DWT**




*Source: BRS Review of Ship building 2018*

**18. Making the shipbuilding sector competitive and Financially Viable- Lessons from Chinese Shipyards.**

18.1 Finance/ Creation of Efficient Capital Markets: While shipyards are eventually export driven, in the beginning, it must be supported by the local downstream industry. A good 70% of Chinese ship owners buy Chinese ships, 90% of Korean Ship Owner and 80% of Japanese Owners place orders in their country. A majority of Chinese shipyards are all directly or indirectly owned by the state. The two main conglomerates China State Ship Building Corp (CSSC) and China Shipbuilding Industrial Corporation (CSIC) are two entities that control most yards. Chinese government also take out a white list of shipyards that get are eligible for financial assistance.

18.2 The Chinese Leasing Companies specialize in leasing. They bridge the gap left by European Commercial Lenders. They are usually subsidiaries of Chinese banks and were about 5 in number some ten years ago. Now there are about 30 such specialized leasing companies. Last year Chinese Leasing companies gave away 13b USD (2018) and 11b USD (2107) in financial assistance to ship buyers.

18.3 Most leasing companies take loans from traditional banks including BNP Paribas, DVB, Society General and Standard Chartered.

**Table 7: Leading Chinese Financial Leasing Companies and their lending in 2018.**

| Company | Total value of vessel and offshore assets (Million$) |
|---|---|
| ICBC Leasing | 12,000 |
| Bank Of Communication Leasing | 9,200 |
| Minsheng Financial Leasing | 6,000 |
| CMB Financial Leasing | 5,300 |
| Cosco Shipping Leasing Co Ltd | 5,200 |
| CSSC Leasing | 3,200 |
| CDB Financial Leasing | 3,200 |
| AVIC Leasing | 2,100 |
| CCB Leasing | 1,700 |
| Others | 3,400 |

*Source: BRS Review of Ship building 2018*

18.4 Korea and Japan also subsidize their yards though the methods are more subtle. Last year Japan has complained to the WTO about the unfair trade practices and subsidies that Korean yards are receiving from banks such as Korean Development Bank (KDB), Export-Import Bank of Korea and Korea Trade Insurance Association (K-SURE).

18.5 Indian banks have very little experience with Shipping Leasing. A one-time subsidy does not substitute the setting up of a Mature Capital and Financial Market to address the financial funding for shipyards and ship owners. Such state targeted one time financial assistance which is inconsistence with market condition is no use. What is the use of a 20% shipbuilding subsidy in 2016 when no ship-owner is placing an order?

18.6 Continuous Order Book and Concurrent Civil (commercial) and Military ship: Chinese yards follow concurrent construction of both commercial and military ships at the same yard. This allows it to flatten the loading and the production curve. Chinese yards builds repeat ships and has stupendous order chains of the same type. This allows very large reduction in time of steel cutting to delivery. Military ships and commercial ships complement each other at significant parts of the ship building 'value chain'. Welding technology in some civil ships are far superior than military ships and in other cases a transfer of technology between the two verticals complement each other. Segmentation of the type of ships allows a stable vendor base, creates clusters and lowers costs. It allows yards to acquire the capability to accelerate and build military or civil ships in times of need. Finally, indigenization and creating of ancillary units follow where 'order books' are significant. (Understanding China's Naval Ship Building Industry- lessons for India (Monty Khanna; 2019)

18.7 There is a pattern in Indian shipyards too. Shipyards that took both commercial and defence orders like Cochin Shipyard and L&T Shipyard gained much more in efficiency, than those who took only one of the two, civil or military ships. Cochin shipyard significantly improved their design capability, speed of execution and quality. Their used sub-contractors to their advantage to reduce costs and managed to have a flexible labour force.

18.8 The Government must set a target for Public Sector yards to also take and execute some percentage of civil ships. This will force them to inject efficiency and cost control.

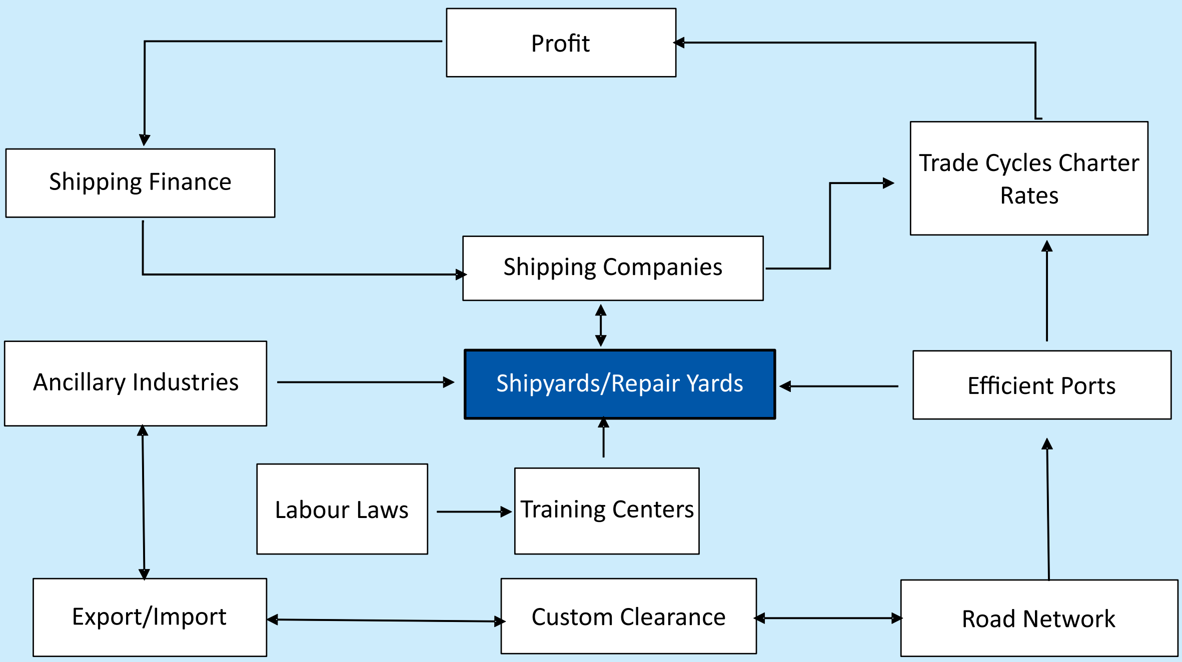
18.9 A continuous order book is vital for yards to improve efficiency.

18.10 Market Segmentation: All yards cannot and must not compete in all segments. Chinese and Korean yards encourage segmentation.

18.11 Indian yards must be classified in terms of size of ship and quality to allow for some product specialization. This will allow clusters to form and improve the ship performance.

18.12 Market Intelligence: All major maritime nations have a body that analyses and predicts future markets. Now there are 3 significant change that must be tracked. Change in consumption pattern, change in technology and fuel and effect of digitization, machine learning and artificial intelligence. This research wing is to advise shipyards is absent in India. A body that advises shipping companies in the market for ships, the global prices, the trends in the future of ship design and the areas to exploit it commercially is not existing in India. In order to understand shipping markets, one has to rely on European analysts.

**Fig. 14: The Maritime Cluster is a Derived Industry and with High Interdependence**




**19. Four significant changes that are required to the Maritime Policy 2020**

19.1 Policy Changes: Shipbuilding must be given a Strategic Industry Status. This industry has propelled growth in all the leading countries such as China, Japan, Korea, Scandinavia, Singapore, Turkey, Germany, and Great Britain each at some time in history. There is compelling reason to go into a "Mission Mode". A special cell must be made and it must involve Shipyards, Ship Owners, Charterers, Financial Institutes, Regulatory Bodies, State Maritime Departments, Fisheries Department, Road and Rail Transport and finally the Planning Commission.

19.2 Financial: Subsidies are Financial Interventions. In the case of the price subsidy of 20% for export orders given in 2016 for limited period is a case in question. It was granted at a time and a period when the shipping buyers' market did not support it. Therefore, subsidies must be proportional in time and scale with the industry it supports and what the ship owners want. Effective capital Markets must be institutionalized and asked to assist rather than stopgap financial interventions. The shipbuilding industry is mature and the global players are not allowing their monopoly to be threatened. This must be studied continuously. Therefore, we have one major institutional gap, which to have a body that studies the international market and creates a correct financial package for ship purchase in India.

19.3 Market segmentation: Shipyards should plan their Product Mix. The Governments Strategic Cell must regulate the yards in some rational way that their products are reflective of the current trends and attractive to the end user.

19.4 A foreign yard that gives a modern design cannot compete with a cheap "dinosaur design". Additionally yard rivalry that calls for diluting the design and reduces price to unrealizable levels will leads to the "Ambassador-ization" of the Industry. Where a cheap affordable design does not let modern improvements in and is unnecessarily accepted as economical.

19.5 Shipyards and owners must jointly work to find out a design that will be able to be built at a price that is profitable for both Owners and ship builders. Few yards must specialize in certain products. It will automatically help in creating clusters.

19.6 Part of the consolidation of yards in Korea and Japan is to avoid such unnecessary competition.

19.7 Finally, Public Sector yards must also take a portion of the commercial segment. Having an order book for 15 years in a select shipyard also distorts available shipbuilding capacity in the country.

19.8 Efficiency and Quality in Shipbuilding: Shipbuilding is a Trade and it must be put into force through a Competency Certificate. A pan India Recognizable Trade Certificate as a Ship Constructor will allow labour to work seamlessly in any shipyard across India and produce a product of a minimum quality. A governmental body to evaluate and disseminate Vocational Training should be in place for shipbuilding process.

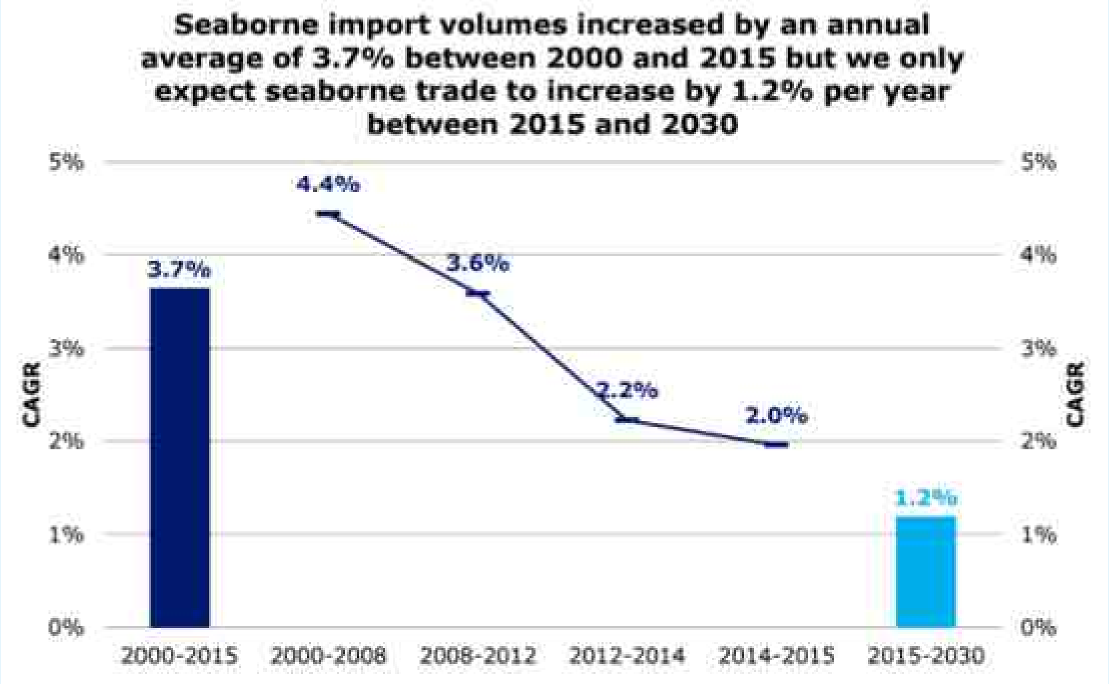
19.9 Skill is different from Trade. A 'Pipe Fitter & System integrator' is a Vocation or Trade. He has the competency to lay pipes, measure, cut, weld, and read drawings for installation. He knows all about Safety, the Equipment used and has the leadership ability to behave like a Foreman. On the other hand, Welding, Grinding or Marking is not a trade. It is a skill.

19.10 Shipbuilding Efficiency can improve, only when the Shipbuilding Process is standardized and repeated across India. This will allow us to benchmark yards across India.

**20. Revisiting the Maritime Agenda 2020 and Conclusion**

20.1 The global economy has slowed down significantly since 2010. This mean that export driven shipbuilding agenda such as capturing 5% of the global market share, must give way to capturing the available internal market. While, the ships for military orders is a captive market, the opening up of Inland waterways and Coastal shipping offer the new opportunity for growth.

Fig. 15: Export Market is currently in over supply, is it time to turn Inwards?




*Source: Clarksons, Danish Ship Finance.*

20.2 India's logistic inefficiency and high dependence on road and rail transport is being challenged to change. A governmental mandate wants water transport to be driven as the preferred mode of transport. This huge governmental will and push must be addressed in the new Maritime Agenda and in a 'mission mode'. Our logistic inefficiency can be converted into our advantage as a growth driver.

20.3 Disruptive changes such as Climate Concerns and Digitalization are creating new ship product segments worldwide. Significant changes to the fuel that we use whether LNG, Low Sulphur Diesel, Electrical or Hybrid will require many current ships to be replaced. Digitization is improving productivity. Ship prices will get cheaper quite like the automobile revolution.

20.4 Indian yards are poised in a sweet spot to take advantage of this transition. World seaborne trade will contract in the near future butting more pressure on mega shipyards. Our yards are medium sized shipyards allows us to survive even if we build small ships in the short term. We can wait for the opportunity to take on larger ships and replace the global current tonnage in the next 5-7 years. Do not fret to Time the markets, bring about the Disruption.

20.5 The four factors that hamper Indian Shipbuilding and Ship Repair remain significant. Changes to the Maritime Agenda is required in the following direction.

(a) Declare Shipbuilding a Strategic Sector. This will allow a dedicated governmental body to promote it in a 'Mission Mode'.

(b) Concentrate on making existing yards viable.

(c) Control quality, benchmark shipyards as category 1, 2 and 3. Do not become a country of riverside fabricators. Define a standard shipbuilding process and train persons with a trade certificate. Benchmark on CGT criteria, process improvements and Design expertise.

(d) Create a shipping focused efficient capital market. Link grants and subsidies to the yard management. Do not subsidize inefficiency.

(e) Credit with lower interest rates, and financial assistance to be given to ship buyers. It is not possible to compete with the road and rail lobby without significant concessions. Ships save fuel and are eco-friendly. Burning fuel has a cost to the nation.

(f) Set new goals, revise targets and update the Maritime Agenda for the next 10 years.

20.6 Our Maritime Agenda 2020 is a good start, but requires urgent revision.

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# EXPERIMENTAL INVESTIGATION ON CARBON COMPOSITE MATERIAL FOR MARITIME APPLICATION

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**1. Abstract**

1.1 Propellers are roto-dynamic fatigue machines that continuously develop thrust to overcome the resistance of ships. Propellers are designed for hydrodynamic efficiency, good vibration characteristics, and strength to take on the thrust and associated forces and bending moments they are subjected to. Propellers are also to be designed for dynamic operating conditions such as cavitation and local damages and failures due to overloading. An example is the tendency of the trailing edge to get damaged under overloading condition. The majority of propellers are made of manganese bronze and similar alloys which have high strength and toughness properties. Such metal propellers are prone to galvanic corrosion and cavitation-induced corrosion. The development and use of carbon fibre composites for low weight, high strength applications has led to research in the area of marine applications and specifically marine screw propellers. This paper addresses investigation on the design and analysis of carbon composite material for marine application. The paper outlines the design of the multiplies for favourable strength, the layup process, the structural analysis considering the orthotropic nature of the marine propeller, strength and deflection analysis. Deflection is an important characteristic since there may be hydro-elastic behavior leading to the modification of the hydrodynamic performance. The paper also describes the composite material specimen testing for Tensile and flexural condition. The results from analytical and experimental studies are presented and explore the possibility of a larger commercial application of carbon fibre composite propellers.

**2. Keywords:** Pod propulsor, Composites, CFRP, Open water tests, Static loading test, FEM. emergency stop demonstrations. A flowchart depicting above process is shown overleaf.

**3. Nomenclature**

**CFRP - Carbon fibre reinforced plastic**

**$K_T$ - Thrust coefficient**

**$K_Q$ - Torque coefficient**

**$V_A$ - Speed of advance**

**ρ - Density of water**

**$\eta_0$ - Open water efficiency**

**Q - Torque**

**n - Propeller rpm**

**d -Propeller diameter**

**T-Thrust**

## 4. Introduction

4.1 Marine screw propellers or generally propellers are designed to produce thrust from hydrodynamic action. They are subjected to high loading, pulsating forces as they rotate in the disc area, subjected to vibrations, centrifugal force, bending and axial based thrust forces. They generally work in an off-design condition due to which their properties and perform decays as it ages. The stresses and vibration shall be huge due to the heterogeneous environment. Therefore the choice of material is important and not only from the immediate thrust consideration but also on stresses, fatigue, and vibration. Conventional propeller materials include nickel aluminium bronze, manganese bronze, aluminium alloy, and stainless steel alloy. Some common drawbacks of the conventional propeller materials are corrosion, cavitation, the formation of a galvanic cell, and maintenance cost. Composite propellers may offer a solution. They are designed and constructed based on combinations of resins and reinforcement fibre. They can be engineered to get any property based on structural considerations. Composites materials are mainly known for the excellent strength properties, lightweight, improved fatigue properties, less corrosion, high thermal resistance, and low maintenance cost. Material properties of carbon fibre, aluminium alloy, Nickel aluminium bronze, and manganese bronze are compared and listed below. The carbon fiber propeller was designed using 300-gsm carbon fiber built up with cross plies in the stacking orientation 0,-45,90,45,90,0 using epoxy resin and normal temperature curing. Due to the high strength to weight ratio of the reinforcement material, it is possibly to build the propeller retaining the geometric thickness to chord ratio necessary for good hydrodynamic efficiency. The material specimen was analysed for basic strength properties in order to confirm that the hand layup process does not sacrifice the basic strength requirements. Based on the geometry of the propeller designed, it was subjected to structural analysis, load-deflection analysis and hydrodynamic performance analysis. The results are encouraging to design trial propellers for field conditions and obtain their short term and long term behaviour.

**Table 1: Mechanical properties of carbon fibre, aluminium, and steel**

| MATERIAL PROPERTIES | CARBON FIBRE (Unidirectional) | Aluminum | STEEL |
|---|---|---|---|
| Youngs modulus (GPa) | 120-220 | 68-72 | 190-210 |
| Tensile strength (MPa) | 800-1500 | 270-330 | 360-600 |
| Density (gm/cm$^3$) | 1.35-1.85 | 2.65 | 7.7 |
| Thermal Conductivity (W/m.K) | 20 | 117 | 15 |
| Low coefficient of Thermal Expansion x10$^{-6}$ (Inch/inch degree Fahrenheit) | -1 to 8 | 7-13 | 3-10 |
| Poison ratio | 0.27 | 0.33 | 0.30 |

4.2 Carbon fibre reinforced plastic (CFRP) have polymer resin matrix material which binds together the reinforcing fibre. The resin and fibre may be made available separately, and the laminate prepared to set at room temperature or cured in higher temperature controlled environment. Carbon fibre is also manufactured in the form of pre-preg material, which can be set and cured in an autoclave. The matrix polymer material is usually epoxy resin and it binds the fibres together. The stacking sequence of the fibre significantly influences the structural properties of the composite. Carbon composite has a high initial strength-to-weight ratio. Two important aspects that need investigation are the effect of absorption of moisture in marine condition and the fatigue behaviour. Hence a safe design approach is to have a higher factor of safety for the CFRP material under cyclic loading conditions. Some other associate characteristics are less compression strength, complex manufacturing techniques, low fracture toughness and moisture absorption. Considering all the above known characteristics and the unknown areas of long term behaviour, it is important to make a first-hand beginning in the design, fabrication analysis of carbon composite propeller for marine application. This paper reports a systematic study which includes specimen test, hydrodynamic performance analysis as well as strength and deflection under thrust loading.

## 5. Literature survey

5.1 Isabella et al. (1990) studied the bending method to evaluate the strength and failure strain of carbon fibre based on the mathematical framework of the flexural theory. Gilchrist et al. (1996) studied the static behaviour, fractographic observations, fatigue behaviour and finite element predictions of composite I-beams subjected to mechanical loads and also the failure under fatigue as well as impact on CFRP. Sun et al. (1994) brought out the effect of fibre misalignment and non-linear behaviour of the matrix on fibre micro-buckling and the compressive strength of unidirectional fibre composite. Young (2008) studied the hydroelastic behaviour of a flexible composite propeller in wake flow. Lin et al. (2010) studied the effect of stacking sequence on a composite blade. The blade was analyzed with different stacking sequences of the composite layup. Blasques et al. (2010) addressed the design and optimization of a flexible composite marine propeller by tailoring the laminate to control blade shape and consequently the developed thrust. Hara et al. (2011) worked on the performance evaluation of composite marine propeller for a fishing boat by fluid-structure interaction analysis. Sun et al. studied the FSI of marine propeller using BEM and FEM code. Paik (2013) made a comparative study of different composite propellers both numerically and experimentally. Das et al. (2016) studied the use of bend-twist coupling of a composite marine propeller for enhanced hydrodynamic properties. Because of the steadily widening application of carbon fibre composites, it is vital to initiate studies starting from application for small composite propellers and building up. Carbon composite propellers are also of strategic importance as non-metallic materials with high strength.

## 6. Design & construction

6.1 Thermoset epoxy resin is used as the matrix material and the single casting propeller exhibits superior strength required for the marine application. The geometry of the CFRP propeller is designed as per the Wageningen B-series consist of 3 blades.

6.2 The negative form provides a monolithic propeller with hub and three blades. The propeller casting process involves hand layup process where the epoxy resin is bonded with the carbon fibre layers in a predetermined orientation. The reinforcement and matrix materials are to be laid within the split negative form. Due to the complexity in the split mould the manufacturing of the propeller was carried out using hand layup process.

6.3 Optimum stacking sequence given by Lin et al. (2009) is followed where six layers of the carbon fibre were stacked with the orientation sequence (0/-45/90/45/90/0). Unidirectional dry fabrics with 300 gsm were used as the reinforcement and epoxy resin (LY556)mixed with the hardener HY951 in a ratio of 10:1.In addition to polyvinyl alcohol (PVA) was used as the releasing agent.

**Table 2 Geometry of propeller**

| | |
|---|---|
| Diameter (D) mm | 450 |
| Hub diameter (d) mm | 198 |
| Pitch Ratio (P/D) | 1 |
| Hub-diameter ratio (d/D) | 0.44 |
| Expanded Area Ratio (AE/Ao) | 0.35 |
| Number of Blades (Z) | 3 |
| Rotation | Left-handed |
| RPM | 748 |

6.4 To release out gases, air bubbles and clear out voids steel roller was employed after every layer. The split negative form was closed and secured with the array of bolts and nuts fastened tight. Room temperature curing was done for 24 hours. Finishing operations were then performed to give the final finished propeller as shown in Fig. 3

**Fig. 1: Negative form or mold for the CFRP Propeller (ref : 10)**

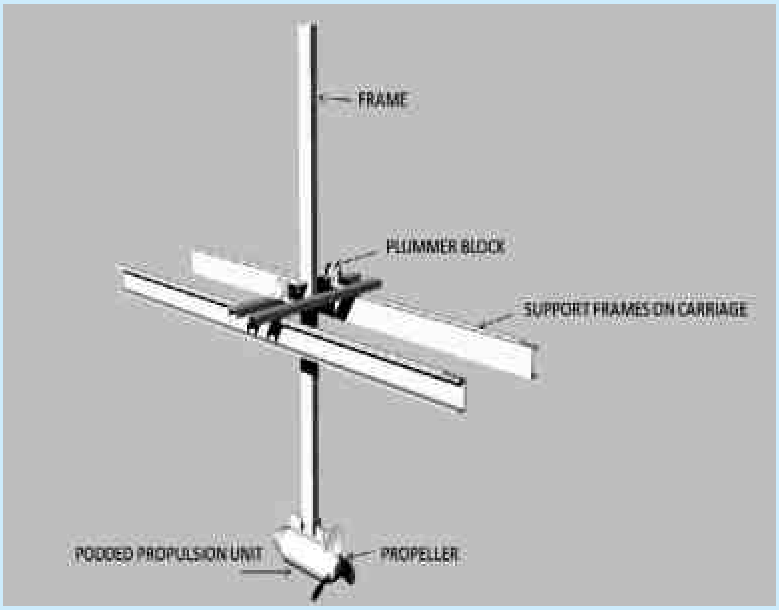
**Fig. 2: Carbon fibre and epoxy resin layup in progress. (ref : 10)**

Fig. 3: Carbon fibre propeller manufactured using hand layup process

6.5 First tests quantify the hydrodynamic characteristics as defined by the open water tests. The test set-up is shown in Fig.4. The main propulsion motor was used as the prime mover in the open water test set-up and the thrust and torque characteristics were obtained as a function of the forward speed and these are plotted in Fig.5. In the test set-up the input power was measured using electrical input quantities and the output thrust was measured using a cantilever vertical beam and load cell at the upper end based on the principle of moments. The central shaft and plummer block shown in the figure acts as the pivoting point in the cantilever arrangement for measuring the thrust.

6.6 An HBM 1t U1A type load cell was used to measure the thrust produced by the pod propulsion unit. The load cell is enclosed with full-bridge connected strain gauges with temperature error compensation. The load cell is connected to HBM PMX, which is a PC based electronic measurement system to measure the thrust generated. The PMX is configured for the experiments using Catman software, which manages the settings and calibration data of the measuring instruments.

Fig. 4: Test set-up for open water performance. (Ref : 7)



## 7. Test Procedure

7.1 The test procedure includes setting the towing carriage to a predetermined steady speed from zero which is also bollard condition to the cover maximum possible speed of the carriage for constant revolution of propeller, in this case it is 748 RPM. This is the highest rated rpm of the motor.

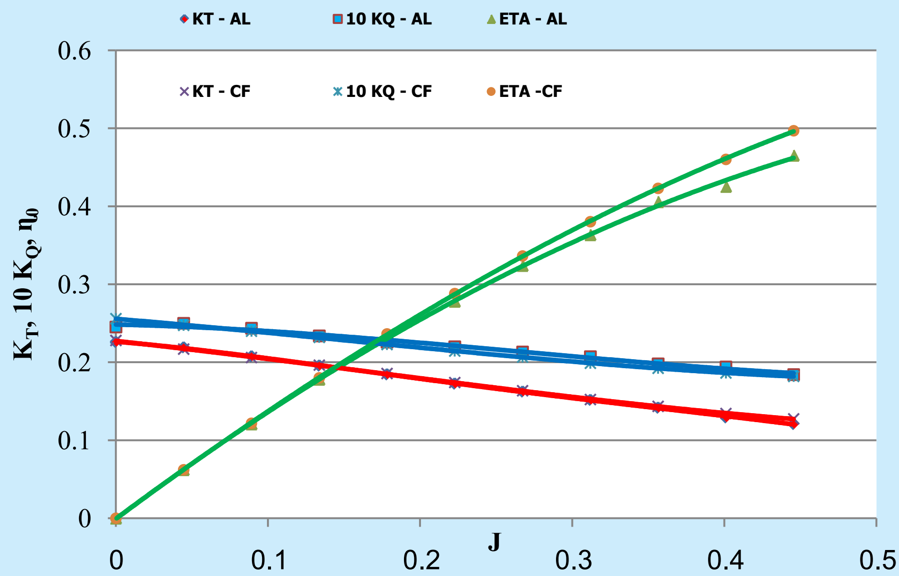
7.2 The speed of advance is non-dimensionalised as the usual advance coefficient J. The tests results are plotted as non-dimensional thrust and torque values against J.

$$K_T = \frac{T}{\rho n^2 d^4} \quad (1)$$

$$K_Q = \frac{Q}{\rho n^2 d^5} \quad (2)$$

$$\eta_0 = \frac{K_T J}{K_Q \; 2\pi} \quad (3)$$

**Fig.5: Open water characteristics of Carbon fiber and aluminum propeller at 748 RPM (Ref : 7)**




## 8. Static Loading Test

8.1 The load test was designed for a basic understanding of the deflection behavior of the material manufactured by the specific manual layup method. Loads, as obtained from the CFD studies, were applied at six sections ranging from 0.4R - 0.9R. The deflections were measured using precision height gauge with 0.01mm least count. Maximum tip deflection at full load was obtained as 5.2mm. FEM based analysis was carried out as described below. The results were compared and are given in Table 2.


**Fig.6: Blade sections with supporting structures. (Ref: 7)**

**Fig.7: A view of segment loading for static load test (Ref: 7)**

**9. Finite Element Analysis of propeller under static loading**

9.1 Static analysis of the propeller blade under thrust loading is carried out using a commercial Finite Element based software ANSYS. The geometry of the propeller is imported to ANSYS APDL V15 in .iges format and is meshed. The tetrahedral mesh is used to capture the geometry. SOLID 185 elements are used for the finite element analysis of the propeller. The stacking sequence of the carbon fibre propeller is considered as designed viz., 0/-45/90/45/90/0. To incorporate the effects of skewness and thickness variation in the finite element model solid modelling is used. Composite lamina is orthotropic in nature. Material property of the laminate is modelled by the assembled 6x6 global stiffness matrix considering the various fibre angles. The elements of the matrix are given below.

**Table 3: Stiffness matrix of composite propeller for FEM analysis.**

| | | | | | |
|---|---|---|---|---|---|
| 68.28 | 13.28 | 0.00 | -1.25 | -1.08 | 2.32 |
| 13.28 | 68.28 | 0.00 | -1.08 | 3.40 | 2.32 |
| 0.00 | 0.00 | 16.75 | 2.32 | 2.32 | -1.08 |
| -1.25 | -1.08 | 2.32 | 13.55 | 0.88 | -0.46 |
| -1.08 | 3.40 | 2.32 | 0.88 | 4.27 | -0.46 |
| 2.32 | 2.32 | -1.08 | -0.46 | -0.46 | 1.29 |

X$10^9$

9.2 The mesh file which is generated in ANSYS has been exported to STAR CCM+, and the fluid boundary element pressures are mapped to the exterior surface of the ANSYS mesh. A load file is generated, which applies the pressures developed on the propeller based on the nodal points. The boundary condition used to simulate the actual conditions of the propeller. Translational degrees of freedoms at the shaft and hub connection are arrested. From the solution of FEM analysis, the maximum deflection was found to be 5.25 mm, and it is a close match with the value obtained from the experimental static loading test. The Fig.8 shows the deflection of the blade tip.

Fig.8: Propeller deflection using FEM based software (Ref: 7)

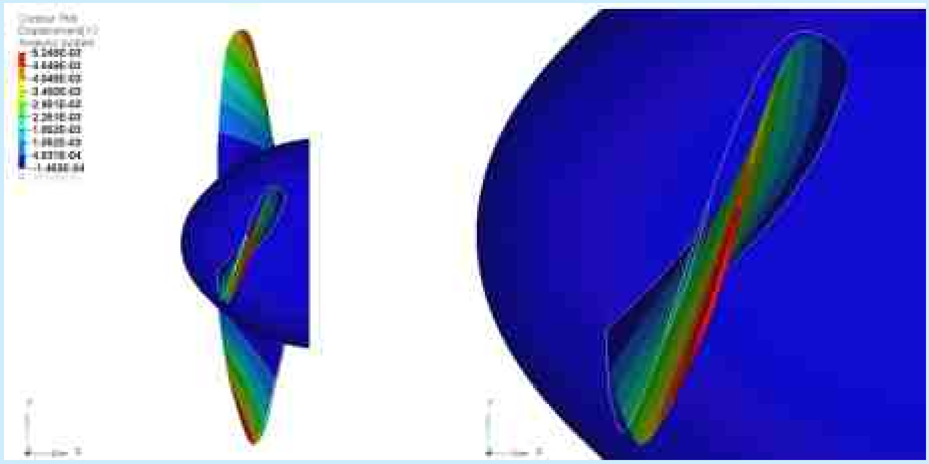


Table 4: Static deflection on a CFRP propeller. (Ref : 7)

| Serial No. | Propeller radius | Load | Deflection based on experiments | Deflection using FEM-based Software | Percentage of error |
|---|---|---|---|---|---|
| | | kg | mm | mm | |
| 1 | 0-3R | 0 | 0 | 0 | 0 |
| 2 | 0.4R-0.5R | 2.06 | 0 | 0 | 0 |
| 3 | 0.5R-0.6R | 4.28 | 0.5 | 0.69 | 0.38 |
| 4 | 0.5R-0.7R | 7.24 | 7.24 | 1.48 | 0.254 |
| 5 | 0.7R-0.8R | 10.51 | 10.51 | 2.49 | 0.164 |
| 6 | 0.8R-0.9R | 13.25 | 13.25 | 3.54 | 0.0291 |
| 7 | 0.9R-1R | 11.9 | 11.9 | 5.24 | 0.0438 |

## 10. STRUCTURAL TESTING ON THE CFRP

10.1 The structural testing on the Specimens of the carbon fiber reinforced plastics has been conducted in the Composite technology center, IITM. The test was conducted as per the ASTM standard D3039 for tensile and D 790 for flexural. The test was carried out in a UTM 40t with a crosshead speed of 2mm/min. The test was conducted on unidirectional fibers and fibers with the propeller orientations. The extension meter was used to calculate the accurate strain rate Using the following equation we can obtain the tensile strength of the fiber

$$\sigma_t = \frac{W_{load}}{b\ X\ d}$$

Where

$\sigma_t$= Tensile stress

Wload = Load on the specimen

b = width of the specimen

d = thickness of the specimen

## 11. UTM Testing - Tensile

11.1 The Below figure 9-11 shows the snapshot images of the data acquisition system that was connected to the UTM. It provides information like max load, Youngs Mod, Tensile strength, Yield Strength etc. The above test was conducted to the Unidirectional (UD), Hand layup and propeller orientation specimen of the same material.

**Fig. 9: Load Extension Curve for Specimen UD Pressure moulding**

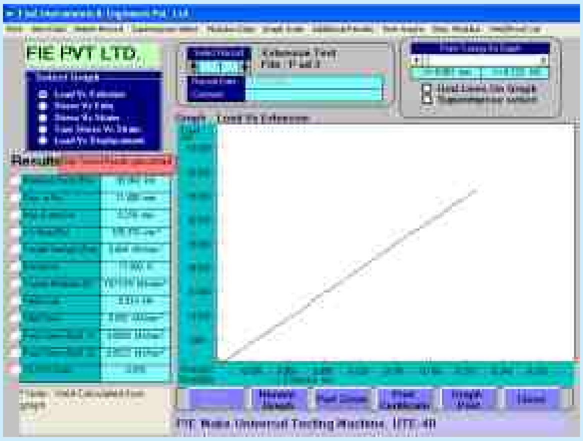



**Fig. 10: Load Extension Curve for Specimen Hand layup UD 1**

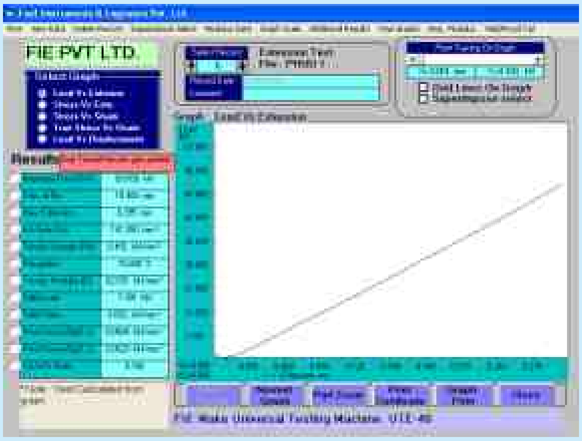



**Fig. 11: Load Extension Curve for Specimen Propeller configuration 1**


**Table 5 : Tensile test result for UD Pressure Moulding**

| Specimen no | Max Load (KN) | Tensile strength (MPa) | Youngs Modulus E (GPa) |
|---|---|---|---|
| 1 | 73.040 | 690 | 94.565 |
| 2 | 70.160 | 663 | 103.955 |
| 3 | 69.960 | 664 | 107.679 |
| Avg | | 672.33 | 102.06 |

Table 6 : Tensile test result for UD Handlayup

| Specimen no | Max Load (KN) | Tensile strength (MPa) | Youngs Modulus E (GPa) |
|---|---|---|---|
| 1 | 69.60 | 492 | 62.031 |
| 2 | 57.020 | 427 | 65.574 |
| 3 | 66.30 | 498 | 68.126 |
| Avg | | 472.33 | 65.24 |

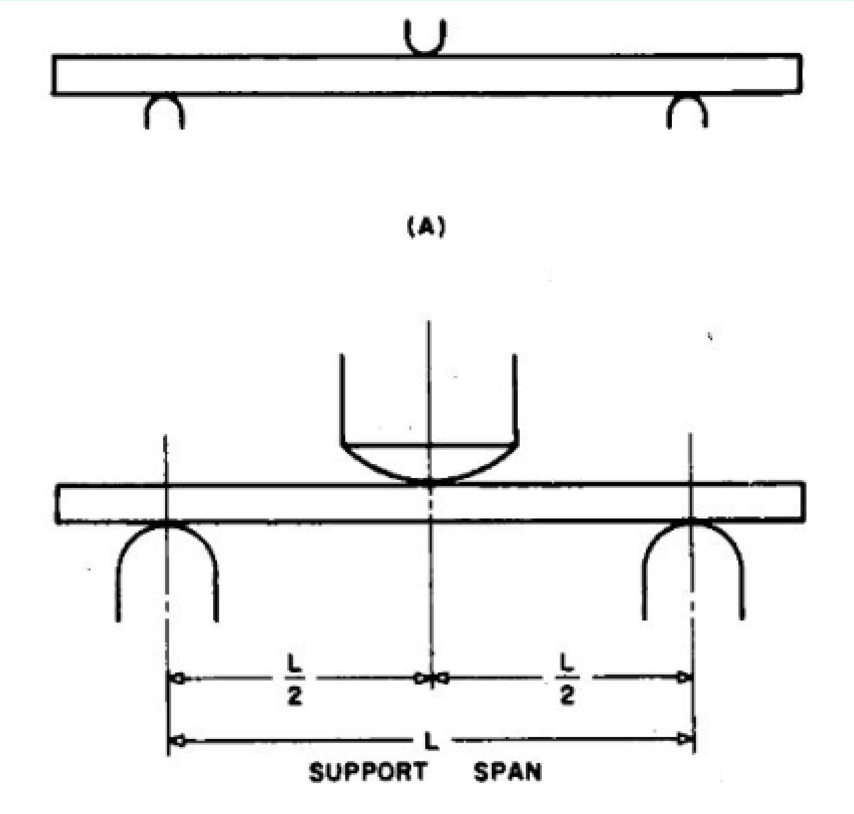
Table 7 : Tensile test result for Propeller

| Specimen no | Max Load (KN) | Tensile strength (MPa) | Youngs Modulus E (GPa) |
|---|---|---|---|
| 1 | 30.58 | 353 | 40.65 |

## 12. Flexural Test

12.1 The flexural testing of the carbon fiber is conducted in a UTM using three-point bending method. The rectangular bar specimen has been used for the test. The specimen was loaded between the midway between the support.

Fig. 12: Three-point bending method used to test flexural properties of composite material



Flexural stress and strain are calculated using the equation that follows

$$\sigma = \frac{3PL}{2bd}$$

$$\varepsilon = \frac{6\delta_{max}\, d}{L^2}$$

Where,

σ = flexural stress

P= load

L =guage length

B= width

D = thickness

ε = flexural strain

δmax = Max deflection at center of the specimen

Fig 13: Flexural testing of the Unidirectional specimen

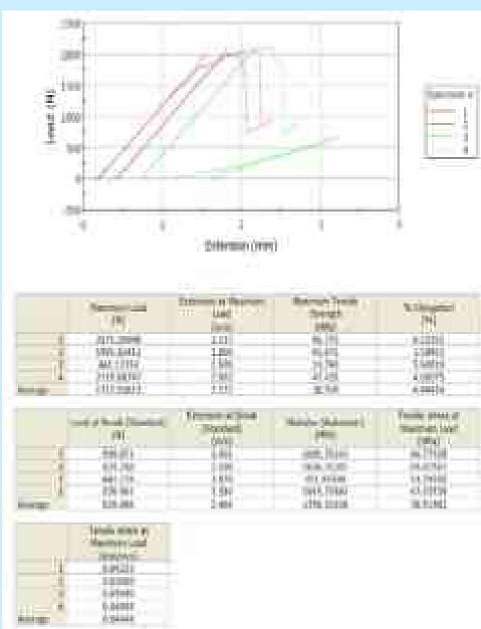



Fig 14: Flexural testing of the Propeller configuration

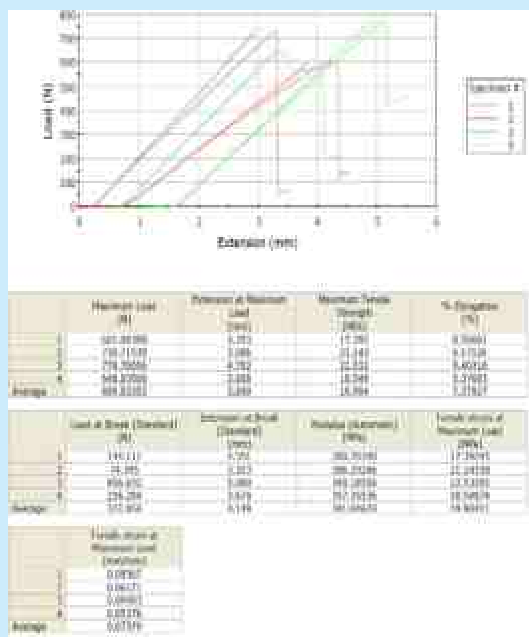



**Table 8: Flexural properties of CFRP - Unidirectional**

| Specimen | Max load (N) | Max Deflection (mm) | Flexural stress (MPa) | Flexural strain |
|---|---|---|---|---|
| 1 | 2071.209 | 2.117 | 855.6454 | 0.020831 |
| 2 | 1995.924 | 1.800 | 824.544 | 0.017712 |
| 3 | 661.1235 | 2.97 | 273.1193 | 0.029225 |
| 4 | 2119.887 | 2.222 | 875.755 | 0.021864 |

The average properties are flexural stress = 851.9815 MPa.

The average properties are flexural strain = 0.02241.

**Table 9: Flexural properties of CFRP – Propeller configration**

| Specimen | Max load (N) | Max Deflection (mm) | Flexural stress (MPa) | Flexural strain |
|---|---|---|---|---|
| 1 | 601.0831 | 4.283 | 403.8958 | **0.042145** |
| 2 | 730.7154 | 3.086 | 491.0018 | 0.030366 |
| 3 | 778.7006 | 4.702 | 523.2453 | 0.046268 |
| 4 | 648.83508 | 2.688 | 435.9826 | 0.02645 |

The average properties are flexural stress = 463.5299 MPa.

The average properties are flexural strain = 0.0363073.

## 13. Conclusion

13.1 Carbon composite propeller has been designed, fabricated and tested for both hydrodynamic as well as structural properties. Specimens were tested as per the ASTM standards in hand-layup and UD conditions for the propeller. The carbon fibre propeller for podded propulsion has been successfully fabricated with the characterization of its properties. The study establishes the feasibility and practicality of manufacturing carbon composite propeller. High strength, lightweight, non-corrosion in the marine environment are important attributes. The deflection characteristics have been quantified and found to be within reasonable limits. The results encourage trial application for further understanding of carbon composite propellers with long term implications.

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# EMERGING TRENDS IN WASTE HEAT RECOVERY AND ENERGY STORAGE SYSTEMS FOR IMPROVING ENERGY EFFICIENCY IN FUTURE SHIPS

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**1. Abstract**

1.1 This paper presents a review of the emerging trends in Waste Heat Recovery (WHR) and energy storage technologies of interest to marine vessels viz., compact supercritical-transcritical CO2 based power and/ or cooling system; thermoelectric generators and compact Thermal Energy Storage (TES) systems to enhance overall energy efficiency along with combat effectiveness of future warships. The key performance features such as efficiency, net power output, fuel savings, simple payback period, and carbon emissions saved and carbon credits earned have been evaluated for a typical LM2500 gas turbine based shipboard platform. The results show that such modular WHR systems integrated with TES systems if catered in ship design and construction will not only result in additional power density and energy efficiency of the main propulsion plant but also result in low maintenance, reduced operating cost, and enhanced operational availability of future platforms. Further, the proposed systems will result in additional endurance/ range and significant reduction in annual carbon footprints.

**2. Keywords**

2.1 Waste heat recovery (WHR); Supercritical-Transcritical Carbon dioxide; Thermo-electric generation (TEG) system; Thermal energy storage (TES) system; Operational availability.

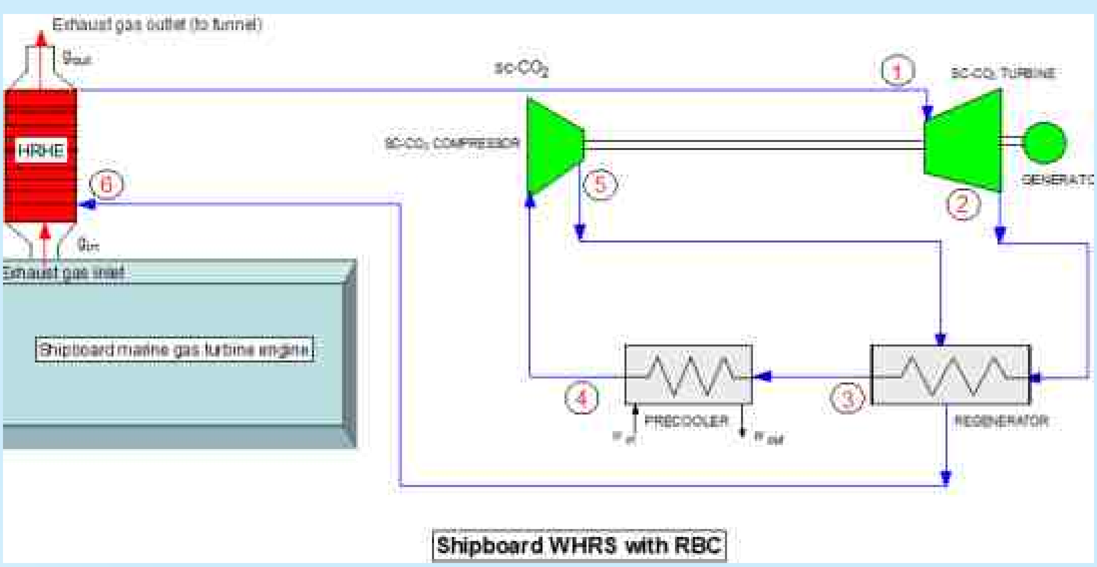
**3. Introduction**

3.1 The growing need of energy has emphasized the need for energy efficient and cost effective methods of power generation. While IC engines are the stalwarts in generating maximum amount of energy for mankind, they continue to be a largely inefficient source rejecting nearly 50 per cent of energy to the atmosphere with the largest part being exhaust gases that amounts to nearly 30-40 per cent and the remaining through coolants and radiation [1]-[3]. Further, drivers such as depleting fossil-fuel reserves and hence, rising fuel costs together with rapidly expanding fleet size and the increasing deployments have resulted in a sharp rise in the fleet's operating cost. In addition, emerging global concerns about climate change have resulted in stringent regulations requiring maritime sector to implement measures for reduction of greenhouse gases (GHGs), NOX, SOX and particulate matter (PM) emissions from the shipping. Recently, IMO has mandated strict regulations for ships to implement mechanisms such as energy efficiency index called as "Energy efficiency design index or EEDI", "Energy efficiency operational index or EEOI", and "Ship energy efficiency management plan or SEEMP", applicable for all marine vessels of 400 gross tonnage or above, engaged in International waters as per IMO's recent guidelines (2016). Among the various options available, the most sustainable and effective option having a significant potential of improving ship's energy efficiency is integrating an energy efficient modular waste heat recovery (WHR) or bottoming cycle to shipboard power plants through the combined cycles. Integration of conventional gas turbine power plant (rated above 10 MW) with a suitable bottoming (WHR) cycle can significantly decrease the mean temperature of heat rejection, and thus improve its overall energy efficiency and realise significant fuel savings of the order of 5-15 per cent, depending upon the waste heat source [6]. Recently, the supercritical carbon dioxide (sc-$CO_2$) power cycles and thermoelectric power systems have emerged as the most promising energy conversion cycles, particularly for the applications where the compactness, light weight, high efficiency and power density form the essential part of the design criteria.

#### 4. Supercritical $CO_2$ Brayton Cycle based Power Plants

4.1 The supercritical $CO_2$ cycles originally referred to as 'Feher cycles', principally use carbon dioxide (R744) as the working fluid entirely in its supercritical phase i.e. region above the critical point. Carbon dioxide ($CO_2$) has a critical point at 30.98$^o$C or 304.3 K and 73.8 bar. Recently, it has caught the attention of researchers across the world due to the unique thermo-physical properties exhibited by it in its supercritical state, such as lower critical point temperature and moderate critical point pressure, higher density during supercritical state, lowest-GWP and nil-ODP, compared to conventional working fluids. Besides low critical point, $CO_2$ has high critical density compared to conventional fluids such as steam. These features enables the sc-$CO_2$ to be associated with unique advantages such as completely avoiding the phase-change (vaporisation) process, reduced compression work, as working fluid behaves more like a liquid than a gas, leads to better expansion work output and lesser number of turbine stages. All of these features are conducive for its use as an effective and sustainable working fluid in power generation applications. The sc-$CO_2$ Brayton cycles have been reported to be extremely compact, light and superior in performance than the conventional power cycles based on several studies in the past for a large number of applications like next generation nuclear reactors, concentrated solar power (CSP), automotive, geothermal power and fuel cells etc.. [4]-[5] presented the energy and energy analysis of an advanced WHR system using sc-$CO_2$ as the working fluid in regenerative Brayton cycle for WHR in a shipboard application. Fig. 1 shows the schematic diagram of the sc-$CO_2$ regenerative Brayton cycle (RBC) based waste heat recovery system for shipboard application.

**Fig. 1: Schematic of the SC-CO2 RBC for shipboard WHR and power application**



4.2 The performance features of sc-$CO_2$ RBC based WHR simulated for a marine gas turbine (LM2500) in a typical shipboard platform is presented in Table 1. The economic and environmental performance parameters shown include estimated installed cost, annual fuel savings (in US$ and equivalent INR), simple payback period (without incentives, in year and months), carbon emissions saved (tons/yr) and carbon credits accrued (INR/yr). It is seen that, with the proposed WHR system, significant amount of carbon credits can be earned annually, that may vary from about INR 71 lakhs at the 100 per cent relative GT load (design point) to about INR 50 lakhs at 60 per cent relative GT load. Further, it is also seen that the carbon emission savings varies from around 7275 (ton-[$CO_2$]/yr) at 100 per cent relative GT load (design point) to around 5125 (ton-[$CO_2$]/yr) at 60 per cent relative GT load [4].

**Table 1: Performance features of SC-CO2 RBC based WHR system simulated for a marine gas turbine (LM2500) in a typical shipboard platform**

| Relative GT Load / Performance Parameter | (%) | 100 (*) | 87 | 73 | 60 |
|---|---|---|---|---|---|
| $\eta_{I,RBC}$ | (%) | 31.6 | 30.9 | 30.3 | 29.5 |
| $\eta_{I,TC}$ | (%) | 33.6 | 32.5 | 31.1 | 29.5 |
| $\eta_{II,TC}$ | (%) | 45.8 | 44.2 | 42.3 | 40.1 |
| $\eta_{I,CC}$ | (%) | 41.9 | 40.7 | 39.4 | 37.9 |
| $\eta_{II,CC}$ | (%) | 56.9 | 55.4 | 53.6 | 51.6 |
| Net Power Output | (kW) | 4108 | 3707 | 3300 | 2894 |
| Fuel Savings | (Million USD/yr) | 8.908 | 8.039 | 7.157 | 6.275 |
| Fuel Savings | (INR Cr /yr) | 57.9 | 52.3 | 46.5 | 40.8 |
| Simple Payback Period (without incentives) | Year | 2.47 | 2.74 | 3.07 | 3.51 |
| Simple Payback Period (without incentives) | Months | 30 | 33 | 37 | 42 |
| Carbon Emissions Saved | (ton-[$CO_2$]/yr) | 7275 | 6565 | 5845 | 5125 |
| Carbon Credits Earned | (USD/yr) | 1,09,129 | 98,480 | 87,681 | 76,876 |
| Carbon Credits Earned | (INR/yr) | 70,93,385 | 64,01,200 | 56,99,265 | 49,96,940 |

Design point is assumed as the relative GT load, corresponding to 80% shipboard GT rated load (= 16.8 MW)
The investment cost of the plant per kW taken as 2200[$/kW] [Persichilli et al.(2012)]; RBC: Bottoming cycle; TC: Topping Cycle (shipboard LM2500 GT); CC: Combined cycle: TC + RBC.

## 5. Trans-critical CO2 Vapour Compression Cooling Cycle (RVCC) based Green Air- Conditioning and Refrigeration Plants

5.1 Extensive R&D efforts are being directed worldwide towards developing new, environmental-friendly and natural refrigerants as alternatives to conventional harmful refrigerants. The recent research on $CO_2$, and due to its distinct advantages, R-744 is fast emerging as a credible natural substitute for the harmful refrigerants in compact refrigeration and air-conditioning systems. For example, R-744 is safe (non-flammable, non-toxic), has nil ozone depletion potential (ODP=0), has lowest global warming potential (GWP=1), stable, inexpensive and found abundantly in nature. In addition, it possesses favourable thermos-physical properties such as high density, specific heat, high volumetric refrigeration capacity, latent heat and thermal conductivity besides having nil recycling issues [5].

5.2 The RVCC based air-conditioning and refrigeration plants utilise closed-loop refrigeration cycle operating on $CO_2$ (R-744) as the refrigerant. RVCC is a regenerative vapour compression cycle that runs in a closed-loop cycle where the compression process occurs in the gaseous phase (like RBC) whereas the throttling and the evaporation processes occur in the subcritical (liquid & gaseous) phase. Also, the low pressure (or the evaporating pressure) of the cooling cycle is ensured below the critical point. Since the cycle operates partly in the supercritical region (compressor outlet, gas cooler and hot stream of the fore-cooler) and partly in the sub-critical region (expansion valve or throttling valve, evaporator and cold stream of the fore-cooler), this type of $CO_2$ refrigeration cycle is referred to as trans-critical-$CO_2$ regenerative vapour compression cooling cycle or RVCC. It consists of basically five main components, compressors, heat exchangers viz., fore-cooler, evaporators, gas-cooler or pre-cooler, an expansion valve or throttling valve or an ejector and an internal regenerator or fore-cooler for internal heat recovery. Fig. 2 shows the schematic layout of a simple RVCC.

**Fig. 2: Schematic layout of simple RVCC for shipboard cooling application**

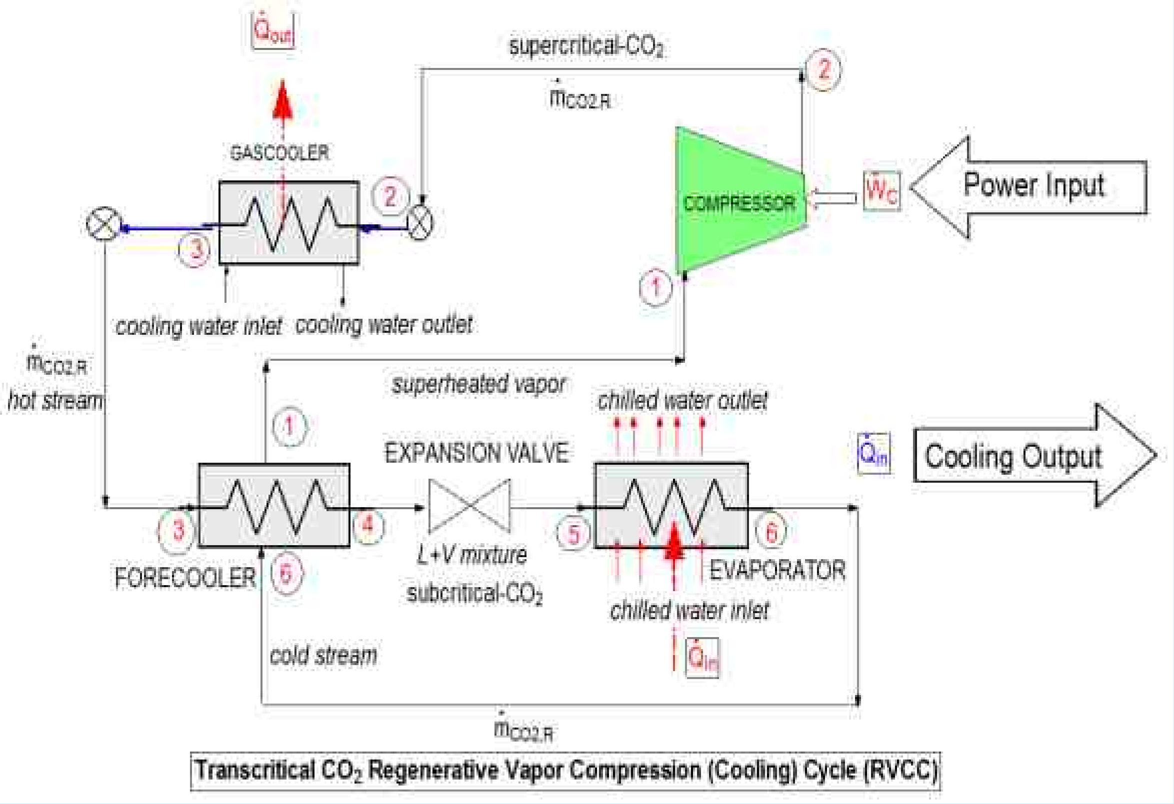
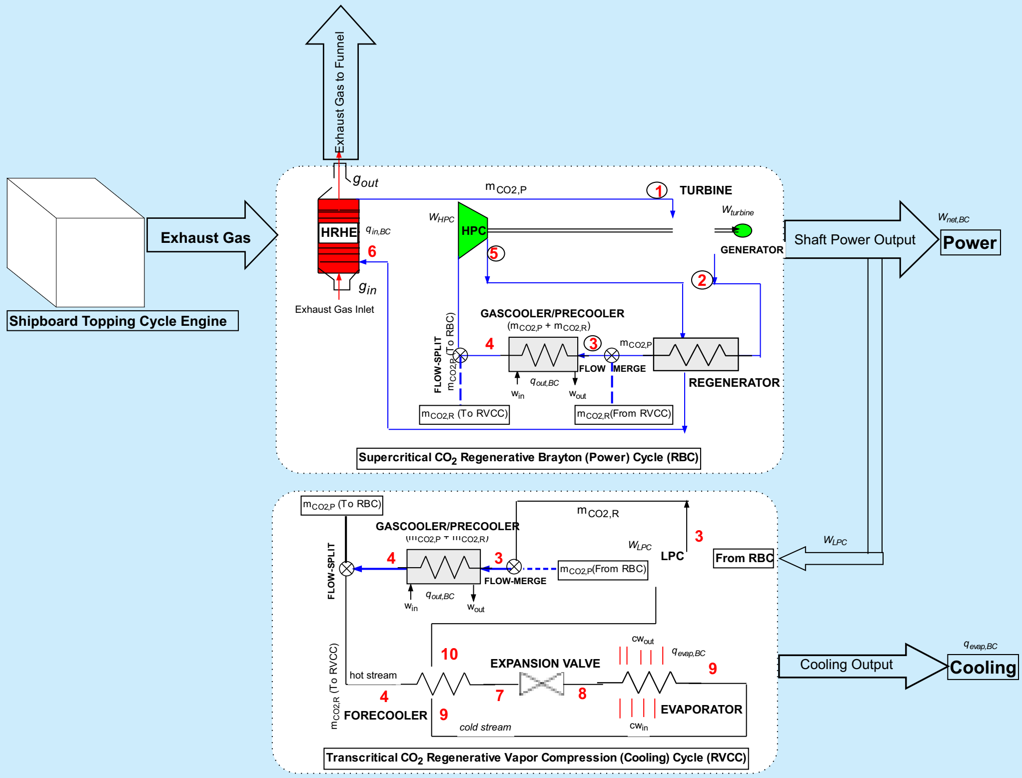


**Fig. 3: Schematic layout of novel supercritical/ trans-critical CO2 RBC-RVCC based combined power and cooling cycle for shipboard platform**

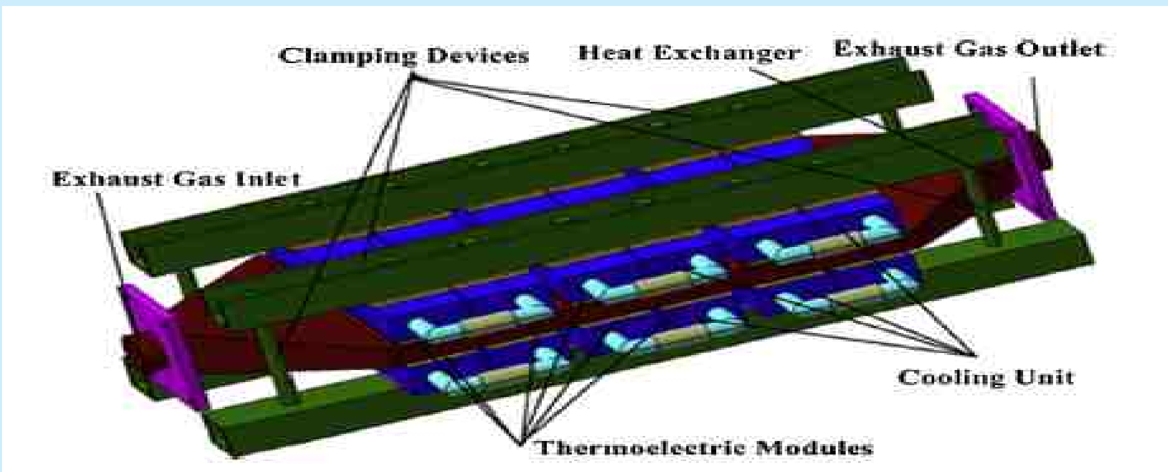



5.3 The proposed RBC-RVCC combined system is expected to be a low maintenance technology due to maintenance-free compressors and reduced size and number of cycle components as compared to conventional systems. Further, such systems will be more energy efficient and will increase operational availability. The salient advantages of RBC power system integrated with RVCC cooling system for shipboard applications are augmentation of shipboard power and cooling capability by about 18 per cent and 15 per cent of the shipboard GT's rated power respectively at its full load. Also, the overall energy efficiency of the shipboard power plant is expected to improve by almost 30 per cent [5].

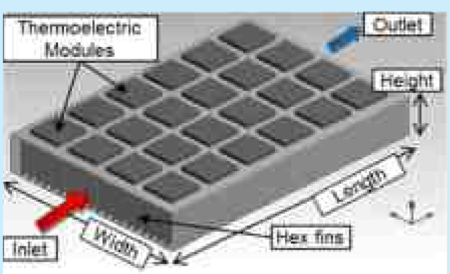
### 6. Thermoelectric Power Systems

6.1 Similar to the above mentioned WHR based compact power and cooling systems, the thermoelectric power generation is another effective step in the direction of enhancing energy conservation and green technology to improve operational effectiveness and sustainability in a marine platform. Here, the exhaust of shipboard diesel engines is used as low temperature direct heat source for generation of electricity using thermoelectric power generators. Thermoelectric power generators are the solid-state devices which convert thermal gradient directly to electric potential by Seebeck effect [7]. The Thermoelectric power generation technology offers distinct advantages, such as: (a) TE conversion is reliable and operates in silence compared with other energy conversion technologies, as it works without mechanical movement; (b) TE devices are simple, compact, safe, highly scalable; and (c) it is an environmental friendly green technology [8]. Therefore, directly converting the waste heat into electricity by thermoelectric device is considered as an attractive solution provided that the conversion efficiency (ZT) is high enough to overtake the traditional WHR technologies currently in use. A schematic of a typical ETEG is shown in Fig 4(a). The efficiency of ETEG is largely dependent on four factors (a) Hot side/ cold side heat exchanger geometry; (b) Heat exchanger material; (c) Site of installation of ETEG and (d) Cold side temperatures [9]. The three salient configurations of hot side heat exchanger geometry are: rectangular, hexagonal/ octagonal, and cylindrical as shown in Fig. 4(a), Fig. 4(b), Fig. 4(c) and Fig 4(d) respectively.

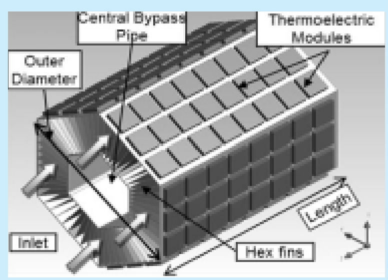
**Fig. 4: Three basic geometries of ETEG (a) Typical TEG model (b) Rectangular geometry (c) Hexagonal geometry (d) Cylindrical geometry**



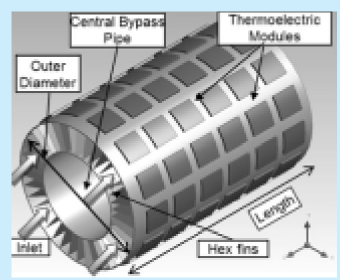

(a)




(b)




(c)




(d)

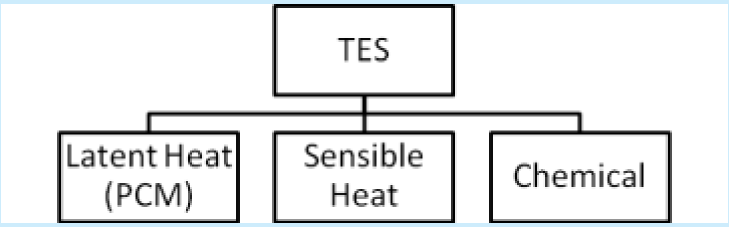
6.2 As regards to the shipboard applications of TEG power systems, [10] simulated the potential of TEG power on a medium size bulk carrier and found that there exist a potential of generation of 42.4 kW electrical power from main propulsion engine exhaust after boiler. However, the performance can be enhanced by installing the TEG closer to engine and using more efficient TE modules reviewed by all possible means of WHR and bringing out huge potential of thermoelectric system as a clean system on marine platforms. While TEG systems installed on automobiles have been reported to suffer a significant loss due to the losses caused in pumping the cooling medium for extracting heat from TE modules, similar issues are not encountered in a marine platform due to liberal supply of sea water as cooling medium. Considering the potential of TEG technology onboard marine platform, the cylindrical TEG can be viewed as a possible replacement of exhaust gas coolers onboard future marine platforms.

## 7. Thermal Energy Storage (TES) Systems

7.1 'Thermal Energy Storage (TES)' is a well-known concept which has been tested and been proved over the time for efficiently storing energy when demand is relatively less and utilising when demand is relatively more. TES systems can be mechanical, chemical or electrical in nature, based on the application. TES can be used mainly in systems requiring sudden boost of energy or simply to balance the mismatch in demand and supply, especially for heating/ cooling applications, TES have an ability to offset the difference both in time and magnitude for heat/ cooling requirements. This ability of TES can be exploited in marine applications for WHR systems. Although TES involves some losses during charge and discharge cycles, impacting the efficiency of the system, it also enables variable electricity production to provide time-shifting and peak sharing, balancing of ancillary services and avoids renewable curtailment.

7.2 Based on the energy storage and dissipation, the thermal energy storage systems can be broadly classified as latent heat, sensible heat and chemical heat as shown in Fig. 5.

**Fig. 5: Types of Thermal Energy Storage (TES) Processes**




**(a) Sensible Heat based TES**. Through the sensible heat based TES, thermal energy storage at temperature range of -40°C to +400°C is possible. Each storage method imposes its own advantages and disadvantages. If energy storage is in the form of sensible heat, specific heat of the material defies the thermal storage capacity and the enclosure plays an important role in term of thermal losses. Presently, water is used as a medium for TES for large industrial applications, but has limitations in terms of specific heat and transfer rates. The entire systems are mainly dependent on the hydrogeological conditions. Moreover, these systems cannot be used for shipboard applications considering the space limitations and the dynamic requirements for energy transfer rates.

**(b) Latent Heat/ Phase-Change-Material (PCM) based Thermal Energy Storage (TES) Systems**. To overcome the disadvantages of systems using sensible heat, the latent heat also referred to as the Phase Change Materials (PCM) based systems offer a higher storage capacity in terms of latent heat for the phase change. PCMs in addition facilitate a target-oriented temperature discharge associated to specific heat for phase change. Further use of PCM has limitations for use in application of humidity control and timely maintenance. PCM have shown a promising future for applications with space constraints requiring higher specific heat. PCM uses latent heat for changing phase of the material and invariably storing energy [11]. The most common change of phase applied is the change from solid to liquid, but using the change of phase from liquid to gas is presently experimented for and has indicated favourable results. Present day PCM technology can be used for a temperature range of -10°C to +150°C. PCM can be considered as replacement for hot water cylinders in future or as a complementary resource. PCM systems have a limitation for time shifting electricity use or for increasing self-consumption of self-generated PV electricity. PCM applications for cooling are more advanced than the heat storage.

PCM based TES systems can be utilised for future shipboard applications especially in the field of heat exchangers. But the main disadvantage of such systems is relatively high costs and their performance is sensitive to the temperature at which material changes phase. Hence, PCM based systems are viable only for temperature range for desired application based on temperature at which material changes phase. Whereas for a wider temperature range of operation sensible heat storage approaches provide a stronger alternative.

**(c) Thermo-chemical storage (TCS) based TES Systems**. To overcome the humidity control Thermo-chemical storage (TCS) which are primarily of Thermo-chemical reactions which offer even higher storage capacities can be used. TCS accumulates thermal energy in the form of heat/ cold and can be utilised based upon the demand, further it enables control on humidity [12]. Presently, TES systems based on sensible heat have been commercially proven in concept and are available readily, while TCS and PCM-based storage systems are under research phase. Few of these systems have been specifically built for an application and successfully tested.

**(d) Thermochemical Heat Storage (THS) based TES Systems**. Thermochemical Heat Storage (THS) has a low energy density, high volume of stores and high temperature storage, and hence the potential to overcome some of the inherent challenges faced by other TES technologies, However, THS is currently being experimented upon, with the bulk of the activity firmly embedded in basic research mainly in academia. THS uses the principle for separation of two substances; substances are either two liquids or a solid and a vapour. The substances are bound by number of physical principles or binding forces [13]. The storage of heat is achieved through the separation of these substances. The capacity of storage is directly propositional to the force binding the materials resulting in higher temperature required to separate the two materials and therefore to store the heat. Energy density changes with increase in temperature and is in the range of 30°C: for physical sorption caused by surface forces, above 100°C for chemical sorption caused by covalent attraction and above 200°C for chemical reactions caused by ionic forces. THS provides much higher storage capacities per mass or volume compared to sensible or latent heat storage, the role it could play is substantial. But based on the current state in research it is unlikely that THS applications will be commercialised within the next 10 years.

7.3 **TES System Variants for Shipboard Applications.** A comparison of the various variants of TES systems is summarised at Table 2. It is evident from Table 2 that TES application have been currently utilised for certain building/ construction industry requirements and is found to have a great potential in curbing Carbon emissions. Despite their distinct advantages, TES systems have not been commercialised due to higher footprints, weight and higher cost per unit volume of energy storage in comparison to conventional energy storage devices such as. Latent heat based TES utilising phase change materials (PCM) are presently used for shipboard applications, but are limited to hot water applications and very recently for Heating, Ventilation and Air-Conditioning (HVAC) applications of a very limited size. Due to its advantages of higher energy storage capacity and compactness, THS technology is seen to have a great potential and the same is widely being researched upon throughout the world for future land based as well as shipboard applications.

### Table 2: Comparison of various TES System Variants

| Ser. | Variant | Types | Advantages | Disadvantages | Possible Applications |
|---|---|---|---|---|---|
| 1 | Latent Heat | TTES, PTES. BTES,A TES | Reduce Carbon Emissions | Hydro geological Dependent | AC System, Heaters (Building / Construction) |
| 2 | Latent Heat (PCM) | Glycol, Wax, Inorganic Compounds | Higher energy density per volume | Limited temperature zone | Hot water Systems |
| 3 | TCS | Lithium, Hydrogen | Humidity control | Volatile in Nature | Battery. Fuel Cell |
| 4 | THS | Carbon | High storage capacity | Nascent technology | sc-$CO_2$ Systems |

## 8. Conclusion

8.1 Increasingly diversified roles, mission and operating profiles of future marine combat platforms and resultant sharp increase in power demands, warrant the need for energy efficient and flexible propulsion plants. This can be achieved through catering modular yet energy efficient WHR systems integrated with compact energy storage modules in ship design and construction. These systems in turn are integrated with the ship's overall power generation and management system. The emerging trends in advanced WHR and TES systems presented above therefore have a potential to address needs of future marine platforms. Additionally, due to optimal loading of all prime-movers, performance of main propulsion plants can be optimised to make them more energy efficient which also implies lower maintenance and lesser environmental related issues in future marine platforms.

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# DIGITAL TWIN FROM EARLY STAGE DESIGN

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**1. Abstract**

1.1 Application of computing technologies in ship design office has been used for decades with significant impact on the ship design process at all stages; namely the concept, early and detailed design stages. New Artificial Intelligence technologies are considered useful for a vast amount of proven ship data for both improvements in future designs and performing design activities efficiently. An Expert System for Ship Design (ESSD), with automated computing techniques and tools to interact on critical decision making during design stage providing effective results has been proposed by the authors.

1.2 The ESSD software is designed to reduce the gaps and challenges faced in performing calculations for ship design. Modularization of design packages based on ship types, specific functional requirements and required classification rules are key features of the software. With intelligent algorithms optimized, the design process to re-utilization of designs to meet new requirements, by automation methods in evaluation and modification of existing parameters becomes simpler.

1.3 This paper explains the concept 2EESD in the application of computing technologies in various components of design spiral and automation of iterative process. also provides insights on benefits achieved in terms of increase in performance and productivity.

**2. Keywords**

2.1 Computing Technologies, Artificial Intelligence, Expert System for Ship Design (ESSD), Artificial Neural Networks (ANN), Fuzzy Logic System (FLS).

**3. Introduction**

3.1 The Ideal solution for an optimal ship design is to integrate all aspects of the spiral design and effectively manage the time-consuming iterative process. The complexity of the ship design improves many folds by involving various human resources owing to the gaps in information processing, analytics and subjective approach in decision making. Traditional engineering solution strategy is not effective because of multi-level data blocking and data requirements An expert system embedded with Artificial Intelligence enabled computing techniques and tools developed with efficient algorithms is a prerequisite for optimal and productive design solutions in the current ship design process.

3.2 Expert System for Ship Design (ESSD) is such an AI scheme that undertakes the ship design method using the data acquisition of established boat information from both SeaTech libraries and also from the vast quantity of vessel information accessible on the internet in the public domain after processing and data validation. The logic and conceptual reasoning behind this data use and parameter adjustment is set by Expert system modules and data acquisition, data processing, preparation of reliable data libraries and automatic learning / feedback systems so as to improve AI tools and techniques decision-making capabilities.

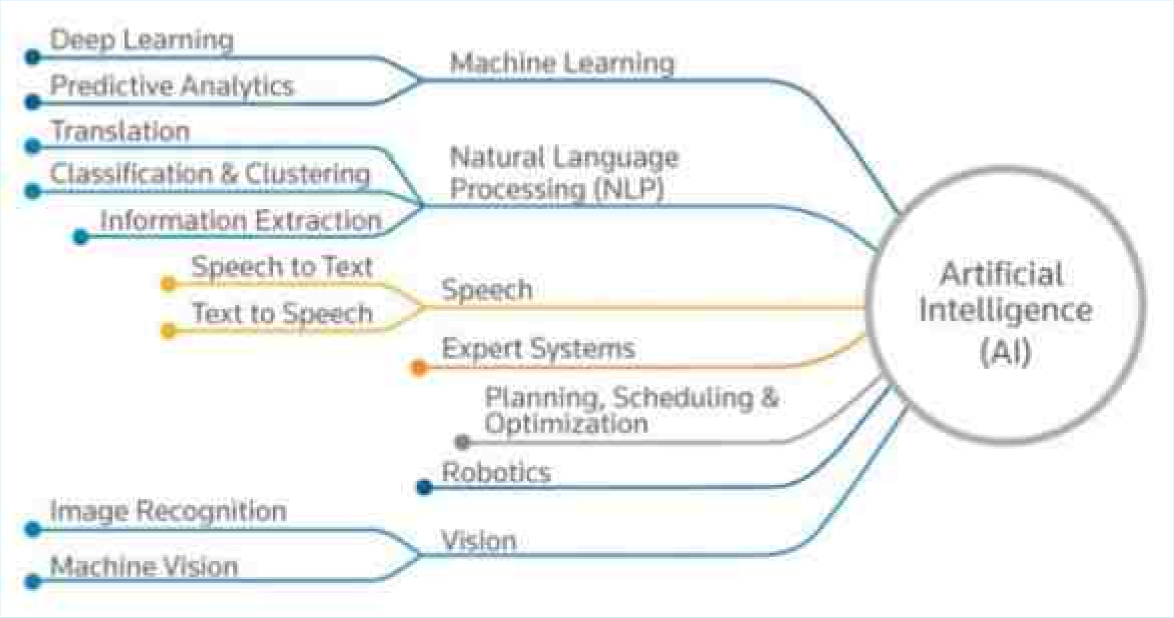
3.3 Data libraries of design parameters and trend lines, weight components, machinery and equipment databases with multiple programmed verification tools for design calculations and reference materials allow the designer technological advantage to efficiently and cost-effectively perform the entire ship design.

3.4 Further they enhance transparency and intellectual property leakage through the data protection and safety instruments. Continuous creation of a guaranteed database allows a secure origin of information sources to research and develop creative and cost-effective optimal design products for growth in the sector.

**4. Basic A.I System Concepts**

4.1 Artificial Intelligence constructs and evolves system models that are capable of simulating human intelligence in reasoning, self-learning, decision-making, and rational reaction. A.I includes a wide range of techniques, a short summary is presented in Fig 1. These methods include ML or machine

**Fig. 1: Overview of AI Technologies**

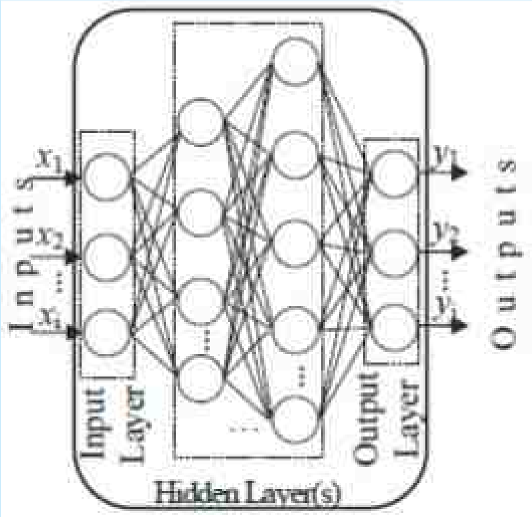



learning, DL or profound teaching, native linguistic processing (NLP) or understanding of natural language, establishes the hidden patterns in large data sets and later using complex algorithms to relate the findings between apparently unrelated variables.

4.2 ESSD uses Expert Systems that are supported by ML's Big Data Analytics through Artificial Neural Networks (ANN) and Fuzzy Logic Systems. Expert systems are based on specific domain knowledge expressly formulated by experts to emulate the reasoning process and reach expert level decision. Expert systems must make recommendations even if a portion of the necessary information is not available. This requires databases with multiple or alternative inferences.

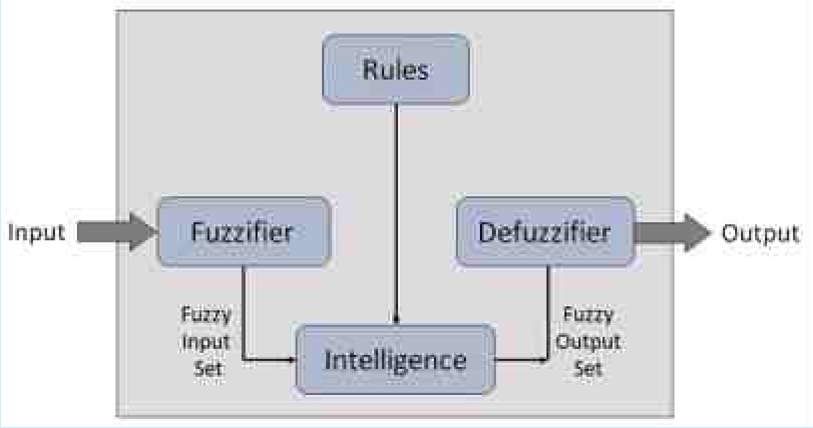
4.3 The artificial neural network (ANN) is a set of processing units called 'neurons' operating in parallel and connected to each other by weighting. ANNs use a mathematical or computational model for information processing. The weights on each connection can be dynamically adjusted until the desired output is generated for a given input. With explicit knowledge about target values the network is able to "learn" by adjusting the values between connections (weights between elements). Typically, as shown in Fig. 2, ANN consists of 3 layers an *input layer*, with a number of neurons equal to the number of variables of the problem, an *output layer*, where the Perceptron response is made

**Fig: 2: General ANN Structure**




available, with a number of neurons equal to the desired number of quantities computed from the inputs, and *intermediate or hidden layers.* ANNs are widely used to solve problems of classification, prediction, and control flow.

**Fig. 3: Typical Fuzzy Logic System Structure**




4.4 Fuzzy Logic (FL) is a method of reasoning that resembles human reasoning. The approach of FL imitates the way of decision making in humans that involves all intermediate possibilities between digital values YES and NO. The fuzzy logic works on the levels of possibilities of input to achieve the definite output.

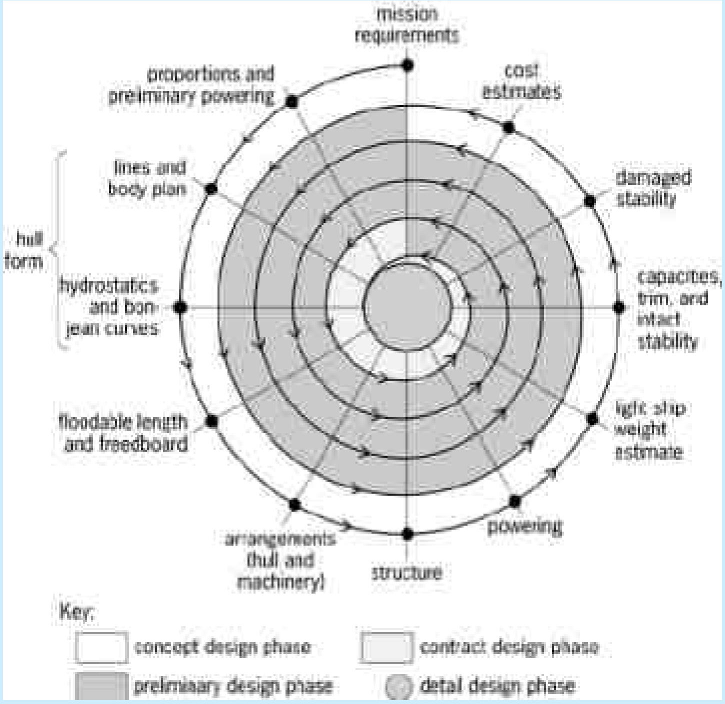
4.5 The Fuzzy Logic System consists of, as given in Fig. 3, *Fuzzification module* which transforms the system inputs, which are crisp numbers, into fuzzy sets. It splits the input signal into different steps.

Along with an xpert system *Rules* for knowledge base and an *intelligence engine* to simulate the human reasoning it process as inputs and along with the *Defuzzification module* provides the output from the system.

**5. Application of A.I in Ship Design**

5.1 Ship design is an iterative process in which ship design parameters need to be optimized to meet the requirements of the owner, performance, class rule requirements, and shipyard requirements for materials / equipment availability. Different interlaced design aspects influence each other to make the process suitable at each stage as continuous evaluation and decision-making to ensure optimum

**Fig. 4: Ship design spiral**




successful design. Fig. 4 shows typical design spiral, where hull form parameters influence the resistance and powering of a vessel. The rule requirements on freeboard, sub-division & stability have influence on cargo capacities and design scantlings and arrangement has effect on lightship weight, influencing other aspects.

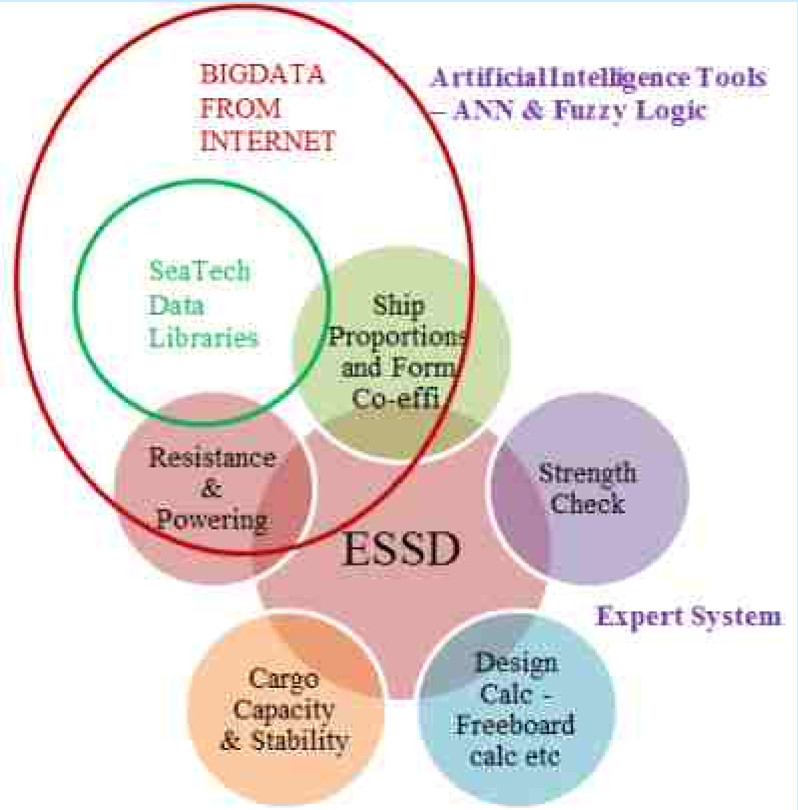
5.2 The application of artificial intelligence tools to effectively and efficiently solve for integrated ship design aspects is much needed for design offices. Expert System for Ship Design (ESSD) acts as a virtual operator in ship design, which provides complete design model for specified requirements faster and easier.

5.3 Fig. 5 provides a brief outlook of functional areas and scope of AI tools and Expert system, where the ship proportions and propulsion sizing are carried out for initial inputs from the reliable big vessel data from internet and Seatech data libraries. Using the outcome parameters, expert system further evaluates the other design aspects:

(a) Scantlings design and longitudinal strength verification; subsequently, Hull steel and LWT estimation.

(b) Cargo carrying capacity DWT and Basic Intact stability verification.

Fig. 5: ESSD system functional outlook




(c) Other design calculations – Freeboard, Equipment No., GT/NT.

5.4 The feedback system from expert system and error in desired output for speed-power and cargo deadweight is sent to AI algorithm to modify the weights and re-evaluate process automatically.

**6. ANN – Fuzzy Logic Model**

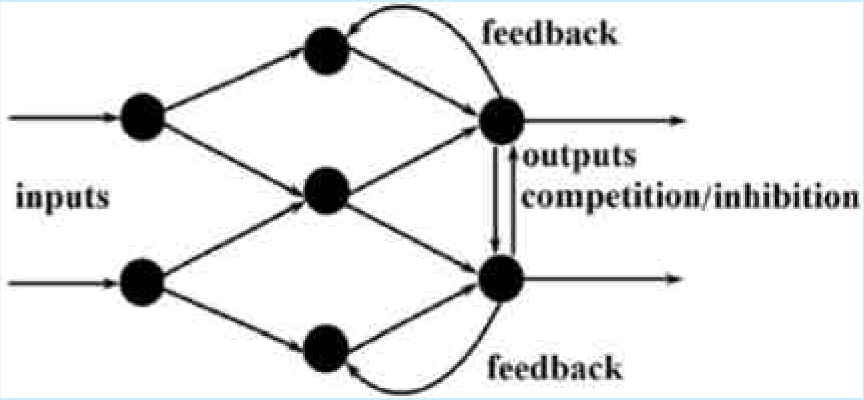
6.1 A two-layer neural network was used in conjunction with conventional naval architecture concepts and calculation techniques as guidelines for fuzzy logic system to pick up thevessel dimensions and shape co-efficients. A single layer is used only for linearly dependent input and output parameters; whereas additional intermediate layers are required in order to approximate nonlinear behaviors such as displacement –speed – power relationships. A database of proven SeaTech ship designs created for various ship types and a similar database for the internet data with predetermined dataset is collected and processed to improve accuracy.

6.2 An artificial neuron model consists of a linear combination followed by an activation function. Different types of activation functions can be utilized for the network; however the common ones, which are sufficient for most applications, are the sigmoidal and hyperbolic tangent functions. In most of the application, hyperbolic tangent transfer function is a better representation compared to sigmoid transfer function.

$$y\,j = f\,(\Sigma wji\;xi\,) \quad \text{(a)}$$

6.3 Referring to Fig. 2, the neurons in the input layer is to distribute the input signal xi to neurons in the hidden layer. Each neuron j in the hidden layer sums up its input signals xi after weighting them with the strengths of the respective connections wji from the input layer and computes its output yj as a function f of the sum, given by

**Fig. 6 Feedback System Schematic**




6.4 where *f* can be a simple threshold function such as a sigmoid, or a hyperbolic tangent function. The output of neurons in the output layer is computed in the same manner. Following this calculation, a learning algorithm is used to adjust the strengths of the connections in order to allow a network to achieve a desired overall behavior. Fig. 6 gives the schematic arrangement for feedback system with back-propagation algorithm.

6.5 As values are sent from one layer to the next, a weight is assigned to each interconnecting line and is multiplied by the values. Each neuron on the hidden layer sums all inputs, and the combined input is modified by the function. The output value of the transfer function is passed directly to all neurons in the next layer, again with a weight assigned to each value.

6.6 Values of the interconnecting weights, pre- determine the neural network's computation reaction to any arbitrary input pattern. As information is passed forward from the inputs towards the outputs, interconnecting weights are adjusted by a back-propagation algorithm during the learning phase so that known outputs will best match predicted outputs.

6.7 Learning was undertaken from databases created for SeaTech proven ships and from the database of internet ships to generate fuzzy rule base. As mentioned above, the available data set was divided into two sub-sets: the first was used to generate the fuzzy rule base, and the second was intended as a control data sub-set. Following the creation of the fuzzy rule base, the model acquired was evaluated on both subsets of data. The estimate of the required design parameters for the subsets was also determined using artificial neural networks, as well as by multiple linear regressions. The training of the neural network was done using simulated algorithm. After the testing, the fuzzy logic approach provides the closest estimate of the design parameters generated in a given database.

**7. Case study of Application of A.I Tools on Bunker Tanker Ship Type Database**

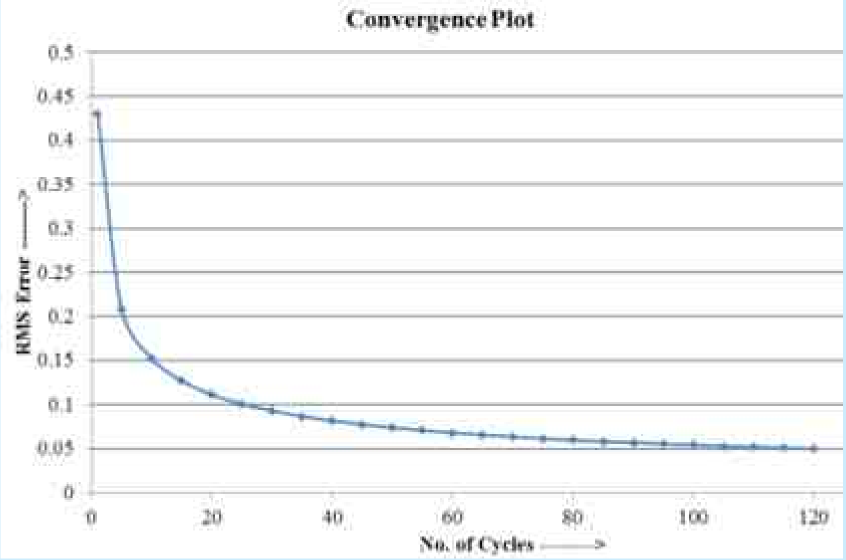
7.1 A case study to estimate lightship weight (LWT) and dead weight (DWT) outputs from internet data collected through A.I tools is performed on a sample of 15 ships bunker type database and partial ship data listed in Table 1.

### Table 1: Partial list of Testing Data for Case study

| Ship No. | L (m) | B (m) | D (m) | T (m) | DWT (T) | Displ. (T) | Engine Power(kW) | No. of Engines |
|---|---|---|---|---|---|---|---|---|
| V1 | 70.13 | 12.17 | 6.1 | 5.1 | 1650 | 2750 | 750 | 1 |
| V2 | 66.51 | 12 | 5.8 | 4.24 | 1798 | 2744 | 444 | 2 |
| V3 | 69.95 | 11.9 | 5.95 | 4.97 | 2129 | 3261 | 1520 | 1 |
| V4 | 71.27 | 12.5 | 6.65 | 4.91 | 2750 | 3900 | 684 | 2 |
| V5 | 79.45 | 12.5 | 6.3 | 5 | 3000 | 3971 | 746 | 2 |
| V6 | 70.4 | 14 | 7.6 | 5.76 | 3100 | 4289 | 2160 | 1 |
| V7 | 86.65 | 14.1 | 7.2 | 5.7 | 3577 | 5254 | 1850 | 1 |
| V8 | 81 | 15 | 8.6 | 6.3 | 4498 | 6320 | 1850 | 1 |
| V9 | 75.4 | 16 | 8.2 | 6.6 | 4650 | 6000 | 736 | 2 |
| V10 | 103.5 | 17.2 | 9 | 6 | 4915 | 8219 | 3000 | 1 |
| V11 | 99.95 | 16 | 8 | 5.988 | 5667 | 7975 | 2720 | 1 |
| V12 | 95.2 | 18 | 8.8 | 5.95 | 6200 | 8500 | 750 | 2 |
| V13 | 102 | 19.2 | 9.3 | 6 | 6600 | 9945 | 2800 | 1 |
| V14 | 103.08 | 18.2 | 10 | 6.7 | 6603 | 9918 | 2610 | 1 |
| V15 | 94.96 | 19.05 | 10.5 | 7 | 7277 | 9945 | 2970 | 1 |
| V16 | 106.47 | 17.6 | 9.4 | 7.2 | 7616 | 10966 | 1720 | 2 |
| V17 | 116.65 | 19.05 | 10.5 | 7 | 9596 | 12930 | 4320 | 1 |

7.2 Where L = Length between perpendiculars, B= Breadth, D= Depth, T= Draft, Δ= Displacement, LWT= Lightship Weight, DWT= Deadweight and PB= Engine Power are parameters set taken as input layer. Two intermediate/hidden layers are constructed, where one hidden layer nodes with geometric proportions L/B, B/D, D/T and L/T as nodes with initial weightages. The second layer is formed with form co-efficients Cb, Cm, Cp, Cw, Fn as nodes. The output layer is with DWT Displacement and Engine Power as output parameters.

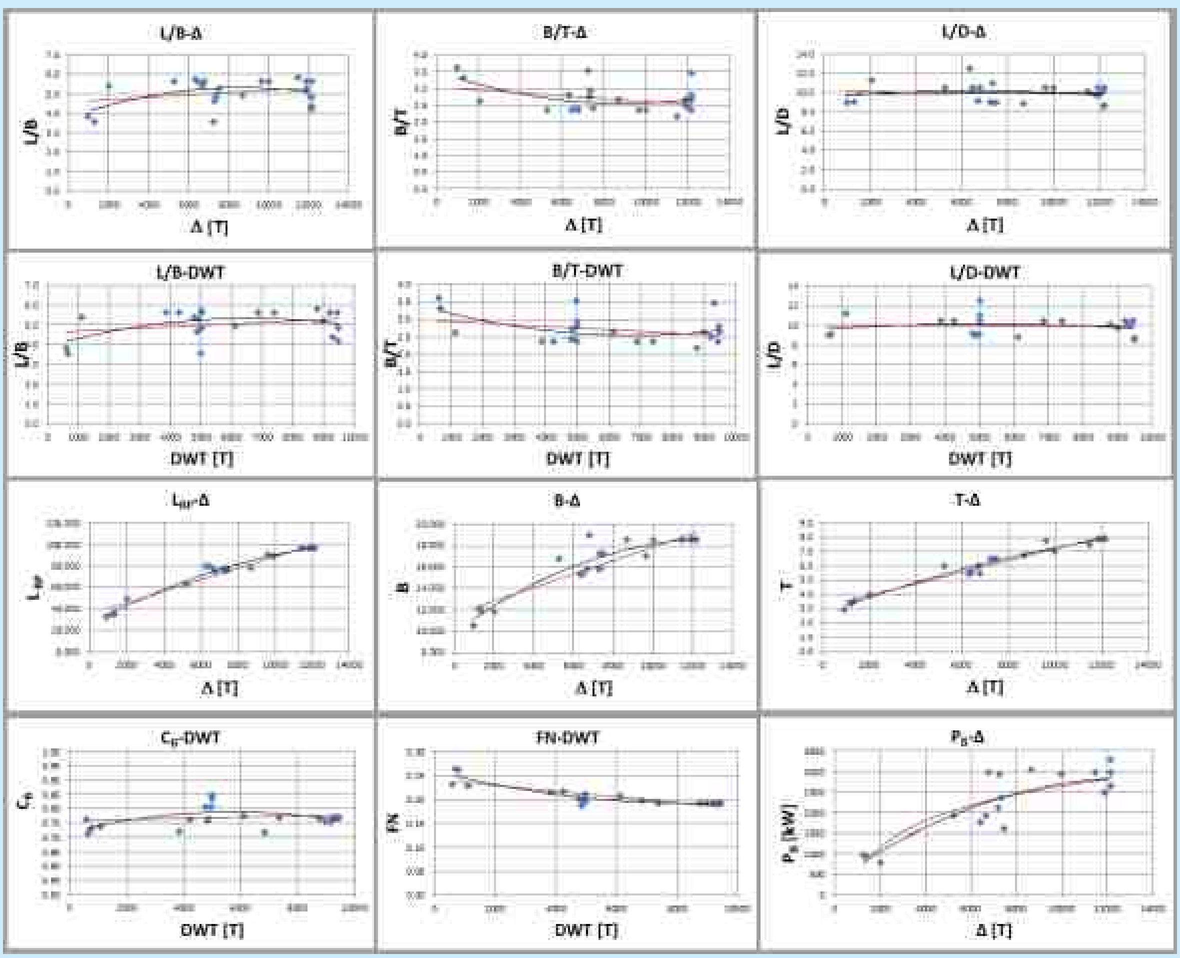
**Fig. 7: Convergence Plot**



7.3 A data of 15 ships from SeaTech database was taken as teaching set of data and the 50 ships data collected as testing set. To train the neural network the teaching set data was passed, where each cycle of feed evaluates the error from the network process and output parameter given in output layer. For ANN model to begin with, the activation function b =1.5 and teaching factor h =0.5 are considered. The learning of error for each cycle is feedback to the hidden layers through back propagation to adjust the weights and refine the process.

7.4 The learning process can be used as tool to determine the network structured correctly for solving the intended task. Convergence of the system was defined as when the output reaches the desired point statistically or error value reduces each cycle to acceptable limit defined. Fig. 7 shows the convergence plot for the designed ANN, where 120 cycles of teaching process are completed for RMS error with a target limit of 0.05.

**Fig. 8: Comparison of ANN output with SeaTech Database**




7.5 The outputs obtained for DWT and Δ from the ANN are compared with SeaTech database vessels and Fig. 8 shows variation of trend lines for teaching set and testing set data under various ship parameters. The maximum deviation of these parameters is given in Table. 2.

7.6 Evaluating the results on principle particulars of ships with it's displacement and DWT, the results show deviation in L, B, T of in 4.6%, 4.6% and 7% respectively indicating the network can be used for selection of principle dimensions of the vessel. The maximum deviations observed in the breadth of the ship, which may be a result of specific owner requirements and optimization can further be carried out in future ship designs.

### Table 2: % Deviation of ANN Output from Teaching Set Data

| Parameter | Max. Deviation (%) |
|---|---|
| L/B-Δ | 11.5% |
| B/T-Δ | 9.2% |
| L/D-Δ | 0.7% |
| L/B-DWT | 5.5% |
| B/T-DWT | 8.8% |
| L/D-DWT | 2.0% |
| LBP-Δ | 4.6% |
| B-Δ | 4.6% |
| T-Δ | 7.0% |
| CB-DWT | 8.5% |
| FN-DWT | 6.3% |
| PB-Δ | 9.5% |

7.7 From Fig. 8, on ship proportions L/B, B/T and L/D with respect to Δ,the maximum deviations of 11.5%, 9.2% are observed at lower displacements range upto 2000Tons and it can be contributed due to less number of vessels in that range. At higher displacements the deviation is about 5%. With respect to DWT, results are similar while draft restrictions and the nature of cargo may have an influence on the deviations.

7.8 Referring to CB, Froude no. and engine power output, it is observed that the effect of deviations in first layer nodes of proportions get compounded at second layer nodes of form co-efficients, which results in proportionally higher deviations of 8.5%, 6.3% and 9.5% in Power output.

7.9 In overall view, neural network produces fairly acceptable results. Further study with increase in no. of nodes with large dataset to improve the accuracy has to be investigated.

## 8. Conclusions

8.1 Application of fast growing computing and automation technologies is very essential for marine industry and especially ship design offices to meet the challenges and provide solutions in the era of digital transformation. Artificial Intelligence technologies and tools have greatest potential to provide intelligent and smart methods for ship design processes to make them more efficient. Utilization of these technologies also enables innovative design concepts for future.

8.2 A.I techniques using artificial neural networks and fuzzy logic systems are capable of producing reliable and accurate results applied to early stage of ship design. The characteristics of self-learning from iterative process as in ship design spiral and establishing relationship through data under guided expert system rules are key factors in application of A.I technologies.

8.3 The important advantage of A.I technologies is in tapping the vast pool of unorganized data over internet. Utilizing limited data sources from company as teaching set, the unorganized data can be processed and trained to produce valuable information in decision making and improving/ optimizing design work.

8.3 Establishing the best suitable neural network for the desired output parameters requires a model setup with careful review of inputs and outputs, number of layers, number of nodes in each layers and their connections. It is also important to have suitable amount of data in teaching and testing sets in order to achieve convergence in the learning process. For the feedback loop back, propagation algorithm is considered to adjust the weights during network training process, which can be explored using other techniques.

8.4 Finally, trained A.I tools like artificial neural network can be utilized in ship design process for its ability to follow expert rules and capability to derive meaningful patterns from complex unorganized data into a productive data source to assist in early ship design efficiently and productively.

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# THE FUTURE OF NAVAL VESSELS: SEASTEMA VISION OF CYBER- ENABLED SHIPS AND THE ROLE OF ARTIFICIAL INTELLIGENCE

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**1. Abstract**

1.1 The operational scenarios for worldwide Navies are rapidly evolving, the mission profiles are subject to changes often and all Navies need to optimize operational costs. The combination of these two aspects leads towards the request of advanced technological solutions enabling increased flexibility and crew reduction.

1.2 Seastema has a strong heritage in meeting these emerging requirements starting from the European Program FREMM (Multi-Mission Frigates ), until today with the new programs of Multi-Mission Offshore Patrol Vessels for the Italian Navy designed according the abovementioned guidelines.

1.3 Based on such experience and Seastema technological vision, this paper introduces the concept of a Total Ship Operational Environment and the use of Artificial Intelligence for Decision Support, Cyber-Security and Auto-Remote control of ship operations to achieve flexibility, information availability and operational cost reductions for the ships of the future.

**2. Keywords**

2.1 Integration, Artificial Intelligence, Machine Learning, Cyber Security, Increased Automation, Crew reduction, Auto-Remote Control.

**3. Introduction**

3.1 Worldwide operational scenarios for Navies are rapidly evolving under the pressure of deep changes in the geopolitical situation, of the proliferation of weapons able to severely damaged important naval assets and of the corresponding changes in the engagement strategies.

3.2 With this respect the growth in sophistication and pervasivity of IT technologies represent both an opportunity and a threat.

3.3 The complexity of the recent large naval platform is generating an increasing automation of onboard processes and also an increasing utilization of Decision Support Systems (DDS) which leverage on Artificial Intelligence (AI) to aid the operators in the integrated management of the platform systems.

3.4 Besides this technogical drive, the other key factor in the increasing of automation is crew reduction not only to decrease OPEX but also as a response to the widespread difficulty in manning a large-sized ship with a well-prepared crew.

3.5 The above two factors, when coupled with the aforesaid changes in the engagement strategies which and naturally lead to the renewed and growing interest of the Navies in the operational deployment of unmanned surface vessels (USV) not only limited to small vehicles but and mostly to much larger units (Large USV or LUSV): in particular, the US Navy intends to lauch in the next five years a series of medium-to-large size USV including at least two corvette-sized LUSV of about 90m length.

3.6 To balance the opportunities created by the increasing of automation, there are also the threats posed by the fact that the naval vessel is becoming more and more a Cyber-enabled digitally interconnected system and thus is exposed to ever growing risks of Cyber attacks which may impair its overall operational capabilty.

3.7 SEASTEMA, with its long experience as tehcnological integrator and leading national provider of naval automation systems, is well positioned to illustrate the state-of-the-art of naval automation technologies and the expected future trends of evolution.

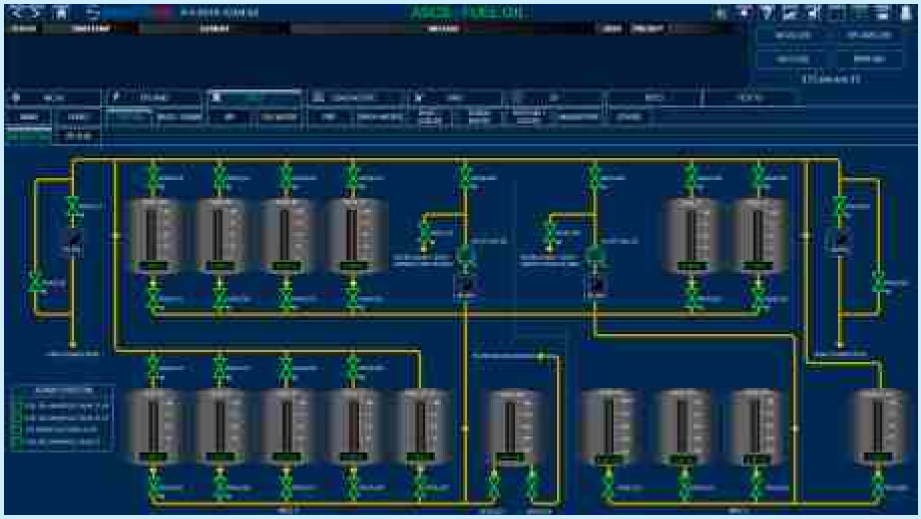
**4. From Integrated Platform Management System to Total Ship Management Environment**

4.1 The technological evolution trend of the automation system, both in terms of increasing scope of integration and increasing interconnection and incorporation of IT technologies, is illustrated through the experience of SEASTEMA in several projects.

4.2 The IPMS of SEASTEMA is a state-of-the-art suite of Control and Monitoring modules, the core of the system being composed of the following:

(a) MNCAS (Machinery and propulsion Control & Alarm System)

(b) EPCAMS (Electric Power Alarm & Monitoring System)



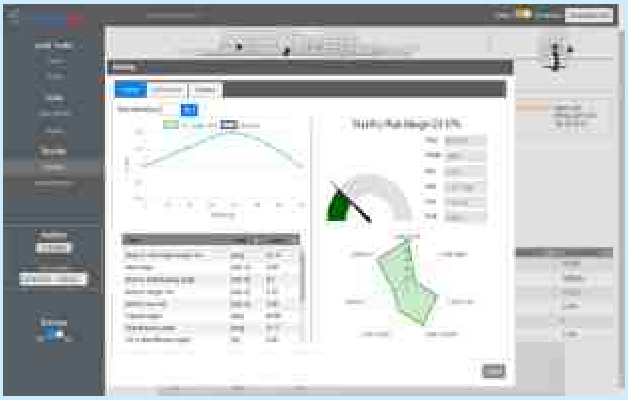

(c) ASCS (Auxiliary and hull Services Control System)

4.3 The modular architecture of the system allows customizing the automation system according to the specific operational requirements of the naval operator.

4.4 As a further confirmation of the heavy reliance of modern automation on up-to-date IT technologies, a complete suite of Decision Support Systems (DDS) is typically included into the standard IPMS package to aid the operator in filtering the information flow from the IPMS and provide hard evidence and suggestions for decision-making, exploiting whenever applicable Machine Learning techniques.

(a) BDCS (Battle Damage Control System)

BDCS includes SEASTEMA's own On-Board Stability Software (OBSS) assisting the operator in the management of vessel safety regarding ship stability, both in normal (intact) and emergency (damage) situations:

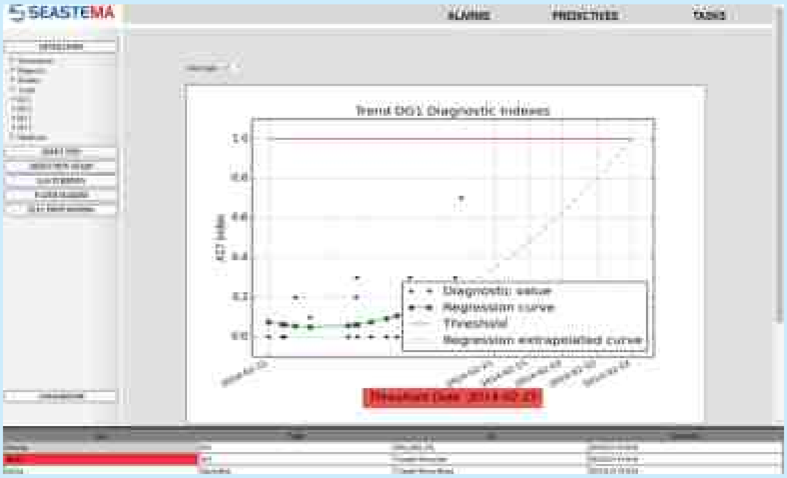


(b) ICAS (Integrated Condition Assessment System)

4.5 ICAS has the primary scope to support maintenance operations onboard by assessing the heath status of critical equipment, in particular the Propulsion Plant and the Power Plant, through continuous performance data monitoring, collection, storage and trend analysis.

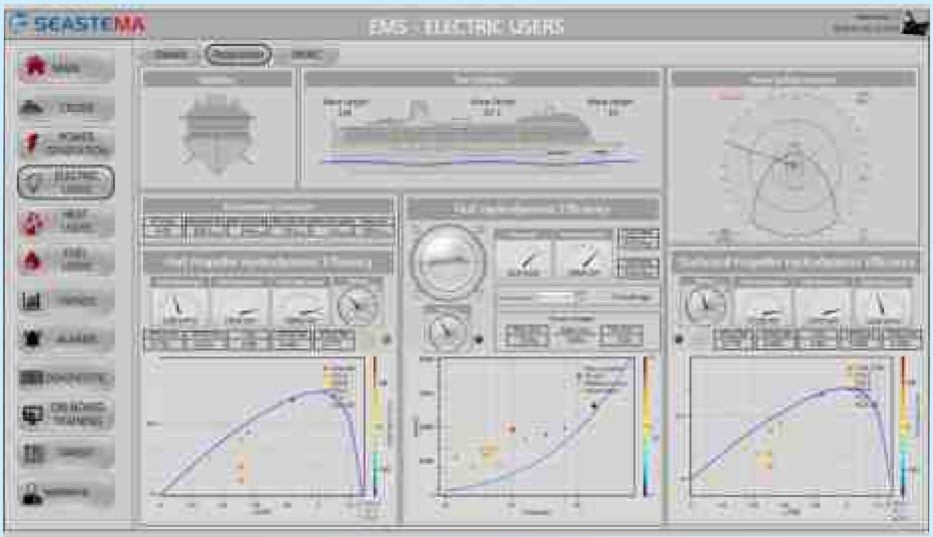
4.6 It is able to perform the fusion of process and vibration data and to assess in quasi real-time the health status of complex machinery based on Machine Learning techniques to autonomously set-up performance benchmarks.


4.7 Data Trending techniques allows projecting the results of the diagnostic analysis forward in time in order to predict machinery health status in the near-future.



(a) EMS (Energy Management System)

4.7 EMS adopts similar approach and techniques to ICAS, including self-learning algorithms for baselines set-up, but is focused on energy efficiency performance rather than on machinery condition.



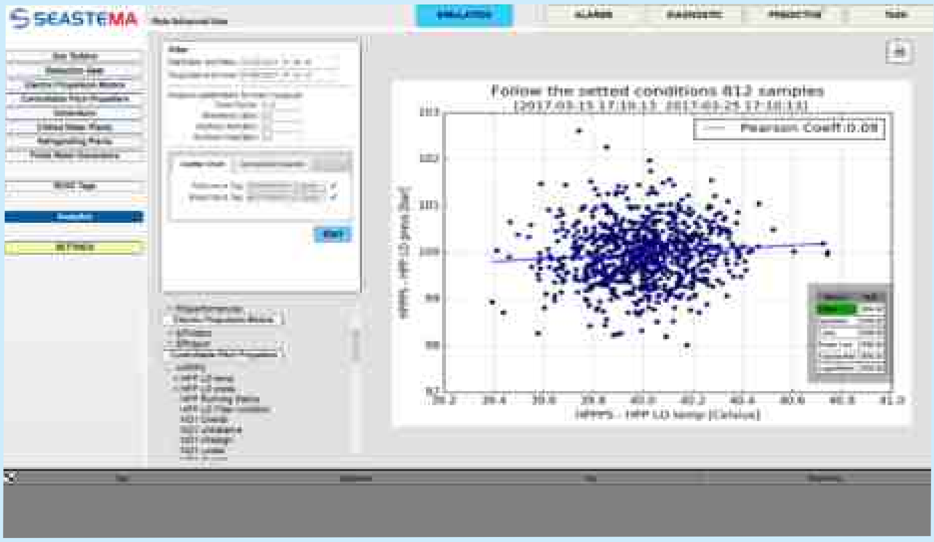

(a) OBTS (On-Board Training System)

4.8 OBTS provides a HW replica of the IPMS workstations and a SW replica of the IPMS control systems in order to train onboard the IPMS operators in a safe virtual environment which reproduces the real control functions without interacting with the real systems.

4.9 SEASTEMA also provides a bridge solution between IPMS and the on-shore logistic/ training centers of the naval operator. In particular:

(a) L-CBM (Land-Based CBM) system

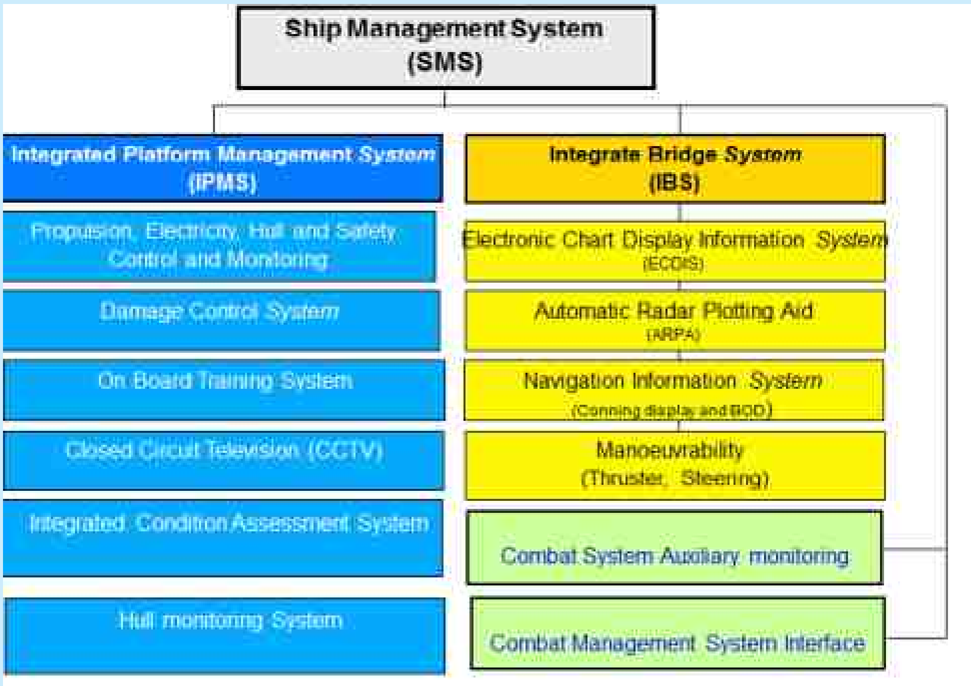
4.10 L-CBM is the ashore counterpart of ICAS, ensuring a quasi real-time or periodical synchornization of ship-shore databases, but with respect to the onboard version operates at fleet level and offers a wider Data Mining software environment.



(a) LBTS (Land-Based Training System)

4.11 The LBTS is the ashore counterpart of OBTS and allows in principle to reproduce the full IPMS physical lay-out and functional environment.

4.12 The next evolution step of the IPMS was represented by the integration of the Navigation System over the same network infrastructure for the FREMM Project, allowing a certain exchange of information from IPMS to CMS (Combat Management System), thus leading to the SMS concept (Ship Management System).




4.13 The further evolution step was originated by the new fast offshore patrol vessels (PPA) commissioned to Fincantieri by the IT Navy and led to the concept of TSME (Total Ship Management Environment) integrating the three main naval ship systems: Platform, Navigation and Combat.

4.14 The physical hub of this integrated system is the Enhanced Cockpit, a two-people bridge console allowing Pilot and Co-Pilot a complete conduction of the Ship, including the Weapon Systems.

4.15 As a matter of fact all the operations of a naval combatant, such as navigation and platform control, tactical management, communications and combat management, are centralised on the bridge in a special custom console designed according to the concept of Aircraft Cockpit.

4.16 All these operations are automated at such level that allow operators to concentrate as a priority on the ship handling, while monitoring the tactical situation and combat.

4.17 The main features of the Enhanced Cockpit are:

(a) Operational Integration of Combat Management and Ship Management System

(b) Enhanced integrated and harmonized HMI

(c) Enhanced integrated Caution and Warning Alarms

(d) Enhanced integrated ergonomics seats and console

(e) Fully redundant configuration in terms of networks and back-up panels

4.18 By leveraging on this challenging experience, SEASTEMA is now desiging a lighter cockpit concept, intended for Patrol Vessels and small combatants:

4.19 The architectural base of this system is the SEASTactics, a fully integrated and cost effective solution specifically designed for Patrol Vessels and vessel operating in low intensity warfare scenarios. The SEASTactics provides a common layer for centralized, integrated command and control interface for Navigation, Automation, Communications and Tactical Mission systems (with hardware based on VME technology).

**5. The concept of Cyber-enabled Ships**

5.1 As illustrated in the previous paragraph, the levels of digital interconnection and ICT complexity of recent naval combatants have transformed the ship in a Cyber-enabled system.

5.2 This technological trend is naturally leading to the concept of auto-remote operations of undermanned or unmanned naval vessels.

5.3 The most relevant cyber-enabling technologies are the following:

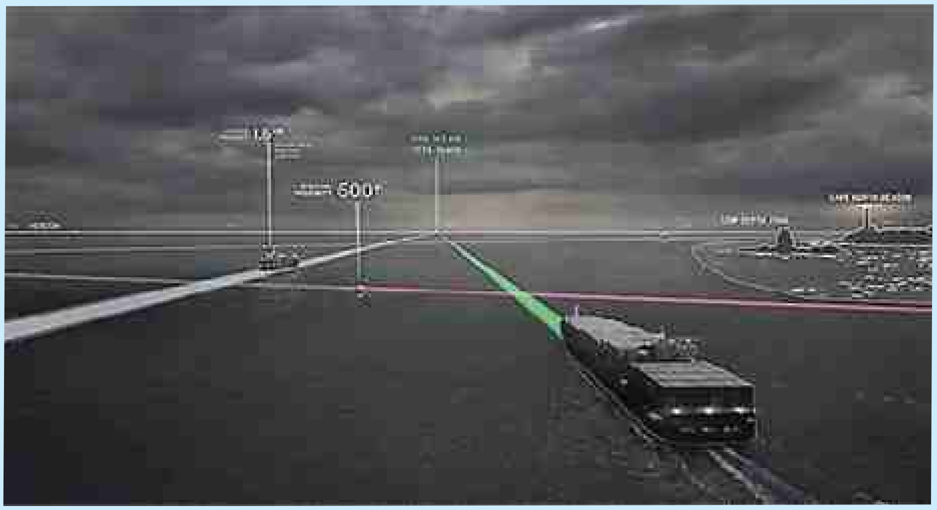
(a) Shore Control Center (SCC)

(b) Automatic Navigation and Collision Avoidance Systems

(c) Situational Awareness (SA) and Collision Detection

(d) Ship-Shore secure communications

5.4 The SCC integrates all the functions required for remote monitoring and control of the unmanned vessel from ashore. In particular, the SCC incorporate the Cockpit concept allowing one Pilot, with a Co-Pilot, support to completely operate the ship. It is expected that SCC will heavily rely on VR and AR technology to offer the remote operator an augmented virtually reproduction of the physical environment surrounding the ship.



5.5 SA as oriented to Collision Detection is strongly interconnected with Automatic Navigation as oriented to Collision avoidance. Both these functions involve a series of individual technologies as shown in the diagram below for Collision Detection:

- Navigation system
  - Sensing
  - State estimation
    - IMU/GPS estimation
      - Noise & accumulative errors elimination
      - Dealing with model uncertainties
      - Accommodating sensor faults
      - Multi-sensor fusion
    - Estimation based on other sensors
  - Environment perception
    - Passive estimation
      - Monocular vision
      - Stereo vision
      - Infrared vision
        - Image stabilization
        - Image defogging
        - Wave information perception
        - Multiple-camera perception
    - Active estimation
      - LIDAR-based perception
      - Radar-based perception
      - Sonar-based perception
  - Situation awareness

And for Collision Avoidance:

- Guidance system
  - Path planning
    - Global planning
      - Optimization methods
      - Heuristic search algorithms
    - Local planning
      - Line-of-sight methods
      - Potential fields
    - Hybrid planning
  - Path replanning
    - Protocol-free methods
    - Protocol-based methods

5.6 Sea Shore communications play a central role in the management of auto-remote operations.

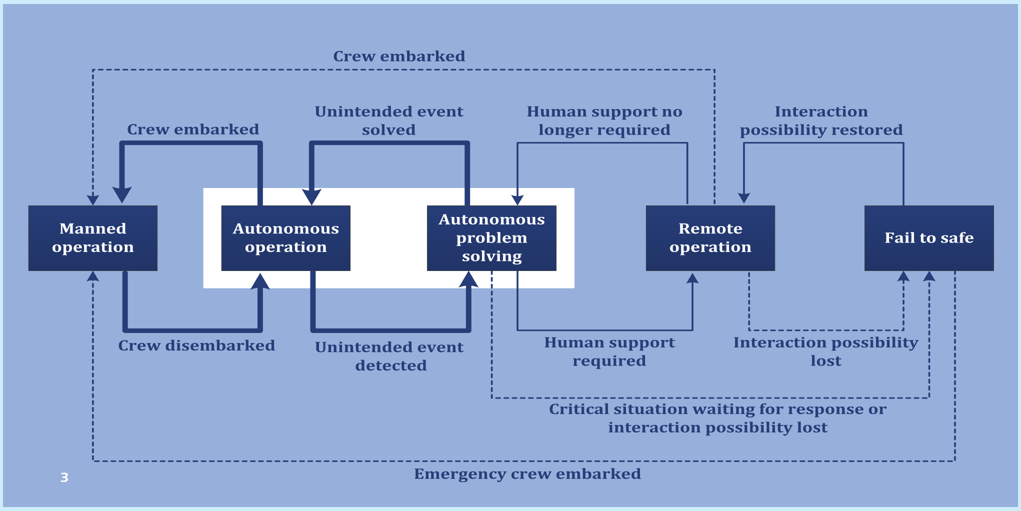
5.7 The "open" commercial satellite link is not sufficiently reliable and efficient to ensure an SA in restricted and busy waters, so in the coastal area broadband radio technologies such as 4G / 5G or UHF antennas will have to be used. In the case of NASS applications it is plausible instead to use a dedicated satellite link but the possibility of having an alternative coverage, even if partial, must always be considered.

5.8 In this regard it is necessary to consider the emerging technology of the so-called "tethered” UAV systems that are autonomous aerial drones connected by cable to the mother ship. These UAVs can be passive, ie "kites" or "activists" or rotary wing vehicles. This enabling technology is "on horseback" between the SA systems and the communication systems, since the payload of the "tethered" drone can both include sensors and communication reabs thus acting as a bridge between the USV and the ground station and thus extending the range of LOS radio communications potentially up to almost 100 NM of the coast according to the maximum reachable altitude.

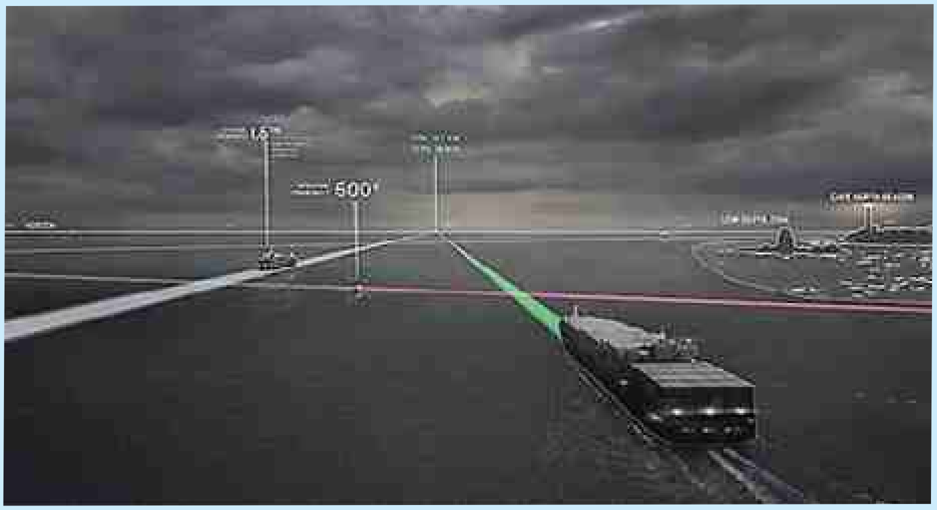
5.9 Regarding communcations, a critical issue is represented by cyber-security, in particular for telemetry since a cyber-attack could disturb the command and control, provide false information to the on-board systems or to the operator of land or even allow a hacker to take complete control of the boat. Undoubtedly this criticality becomes of primary importance in the case of an unmanned military vehicle with a remote weapon system.

## 6. The Role of Artificial Intelligence in present and future naval platforms

6.1 Among the enabling technologies of auto-remote operations, AI undoubtedly plays a key role.




6.2 In particular, SA requires the processing and merging of data from different sensors in order to accurately reconstruct the environment around the ship and extract information about surrounding objects and the potential risk of collision with the own ship.



6.3 The SA requires the resolution of two related but distinct problems: the location of the boat and the determination of possible obstacles. Localization techniques have reached an excellent level of development in the field of autonomous land vehicles.

6.4 Naval applications present characteristics and challenges different from those faced in the terrestrial environment.

6.5 The first and most important difference is the greater reliability of global positioning systems when used at sea rather than in an urban environment. However, this advantage is penalized by the lack of fixed features that can help localization. In the terrestrial environment it is in fact common to use particular topographical and environmental features built into the localization algorithms.

6.6 The second fundamental aspect is the identification and tracking of obstacles; also in this case the marine context requires the development of dedicated techniques.

6.7 The introduction of AI-based techniques allows the problem to be solved systematically and in two phases. In the first phase sensor fusion techniques (sensor fusion) that concert information coming from different sources (longrange radar, short-range radar, sonar, and vision systems) determine the type, position, speed and current direction of the obstacles.

6.8 In a second phase, using Machine Learning (ML) and Prediction techniques, the future position of the obstacle is predicted in a probabilistic way: in each instant along a prediction window, a probability distribution is calculated that represents the possible positions of each stumbling block.

6.9 The ML techniques allow us to learn, starting from the behavioral histories of the obstacle, the type of navigation followed by it and ultimately provide a more accurate description of the future trajectory of the obstacle.

6.10 Information from SA module is the basis for route planning.

6.11 The availability of a probabilistic description of the future course of the obstacles makes it possible to automatically plan the course of the boat by considering and balancing several objectives, including conflicting ones. For example, in the mercantile field, the goal could be to optimize travel times taking into account consumption and navigation rules in busy waters; in the military sphere, the goal could be the calculation of an interception route that considers the characteristics of the weapon systems of both the target and the autonomous vessel, leading to the implementation of ATEWASA systems, Autonomous Threat Evaluation, Sensor Allocation and Weapon Assignment .

6.12 AI techniques are also needed to handle standard VHF communications with unmanned entities, for example interpreting VHF communication from a manned ship and responding accordingly. AI techniques, such as Cognitive Radio, are also necessary to manage broadband communications with the center of the earth. A further advantage of the described techniques is their scalability to multi-vessel scenarios in the case of availability of broadband communication. In fact, it is possible to integrate the information of the sensors of other vessels into the algorithms described above and to develop a control of the distributed traffic which, without the need for a central control node, plans the trajectories of each individual vessel in concert leading to an optimization of the traffic. This type of distributed control scenario is particularly advantageous in heavily trafficked water areas such as ports.

**7. Conclusions**

7.1 Technology is today available to realize high level of integration for a Naval Ship and to concentrate on many functions in a single operator station, but there are many other critical factors that must be taken in to consideration and that can be the key of success or failure in such projects.

7.2 The degree of digital interconnection and ICT sophistication and pervasibility of recent naval combatants have nowadays already reached the complexity threshold level which transforms the ship in a Cyber-enabled system.

7.3 This digital transformation has many opportunities but also a big threat: as a matter of fact the same enabling technology represents also potentially a most dangerous weapon.

7.4 Cyber-enabled digitally interconnected system are infact exposed to ever growing risks of Cyber attacks which may impair its overall operational capabilty.

7.5 On the other hand AI could play an essential role in mitigating this risk by appying Machine Learning technique to the automatic detection of cyber attacks (autonomus IDS) and to the autonomous implementation of cyber countermeasures (autonomous SOC).

# SIGNATURE ASSESSMENT OF NAVAL SHIPS: ONE MODEL APPROACH

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**1. Abstract**

1.1 Different signature aspects are considered to be important features when new navy combatants are designed. The traditional methods to assess different signature related phenomena are very time consuming since each of the signature prediction requires different models with various input requirements. Also the manual work required to build up the numerous computer models may introduce errors in view of various computational tools. Assessment of different signatures will be necessary when the design changes during the ship design process. Moreover, specialized studies such as hydrodynamic and strength assessment of the vessel are required to be carried out during the design phase. These studies require additional inputs and are generally dealt with separately in traditional design. This paper proposes a one model approach which can be used for all the studies and the overall computational time can be reduced. The iterations as expected during the design phase can be handled well with this approach by incorporating the additional inputs as and when available.

**2. Key words**

2.1 CAD, FEM, CEM, RCS, Electromagnetic signature, Acoustic signature

**3. Introduction**

3.1 **The susceptibility of a Naval ship depends on its detectability**. All ships emit electric and magnetic fields, which propagate through the water. These emissions can be measured using passive underwater sensors, and can be used to distinguish between different classes of ship or even individual ships. Such information can in turn be used to trigger remote detection systems, or even trigger “smart” mines. These detection systems pose a great threat to naval ships.

3.2 Most modern naval ships include some form of signature suppression measures to reduce the ship susceptibility to the threats mentioned above. In some cases the suppression may be very basic, while in other ships, great care has been taken in the ship design process to achieve a very low signature. The trend in recent years with new ship design programs is towards a more systematic and comprehensive approach to signature suppression in the early design phase. With improvements in modern computational resources the latest numerical tools are used to predict magnetic signatures using CEM (computational electromagnetics) methods which permit the study of important but otherwise difficult to measure effects. Using computer modelling capability in the early design phase enables in an improved design with lower signatures and improved survivability.

3.3 Stealth requirements and safe operational needs renders the ship to be undetected for a wide range of frequencies when illuminated with radio frequency (RF) energy. The radar cross section (RCS) is measured by the backscattered energy from the target. This determines how detectable the ship is by a receiver radar. The stealth needs have stringent requirements to be complied with. The accuracy and application of prediction methods for a range of frequencies, the need for design improvements and feasible shape modifications are a pre-requisite to improve stealth of the ship. Implementation of correct prediction method for RCS prediction is very important.

3.4 Noise on-board and underwater ships is another important aspect. Noise on-board is important for the comfort and habitability for passengers and crew. Noise underwater is an issue that receives increasing attention from the international community. This is due to the increase of underwater ambient sound levels over the last decades and concerns about the impact on marine life. Also, acoustic signature is important for naval and research vessels, due to operational requirements concerning detection and interference with acoustic equipment. For combatant vessels underwater radiated noise is another stealth requirement and needs attention at early design stage.

## 4. Numerical simulations

4.1 Traditionally model testing is done for resistance prediction of a vessel which is used till today in the initial design phase. With the advancement in computer technology, various aspects apart from resistance can be studied using methodologies such as computational fluid dynamics (CFD). Similarly, detailed such as flow studies, impact load assessment, etc. Strength assessment can be carried out using finite element based methods (FEM), and includes direct strength assessment, fatigue and vibration studies, etc. However, these methods are relatively time consuming and require higher computational facilities, along, with a need for validation of the methodology.

4.2 Apart from CFD and FEM studies as mentioned above, signature predictions of the vessel is important for naval vessels. These predictions cannot be made with model testing. Rather the ranging facilities are available which measure the signatures after the vessel is built. Thus very less can be done to correct or to minimize the signature, if any deviations are noted during ranging. However, the numerical methods can very well be used for prediction in the initial design phase. Based on the models already prepared for CFD and FEM studies the signature predictions can be taken up. The inputs as available at that time can be utilized and the broad understanding of the signatures of the proposed design can be made. Additional information as and when available can be incorporated in the numerical model and more accurate predictions can be made.

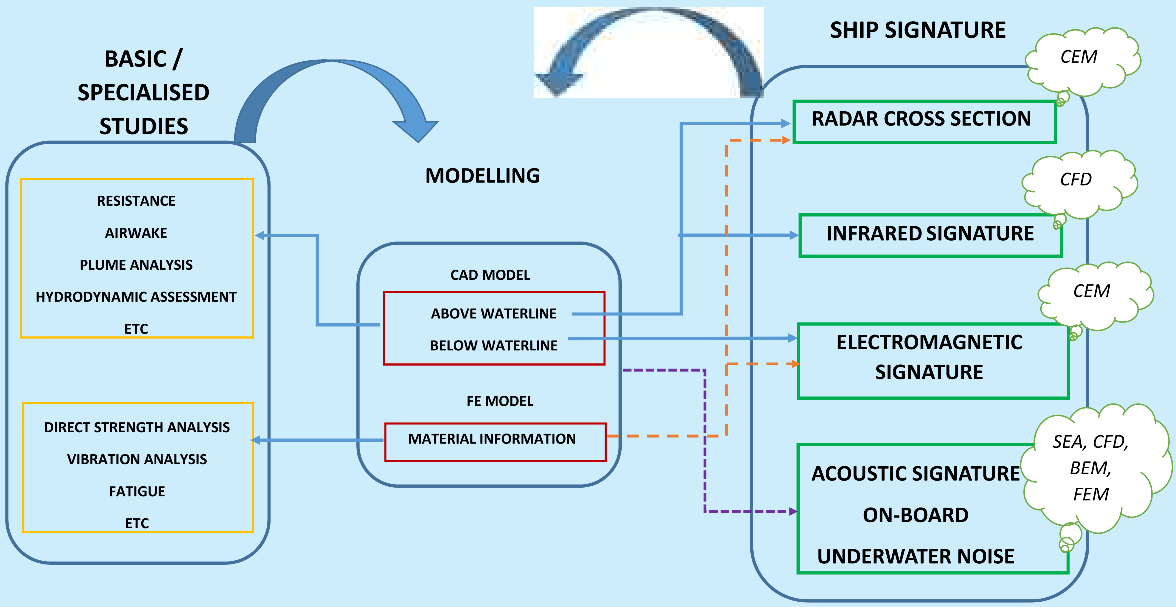
## 5 One model approach

5.1 Fig. 1 shows the one model approach of numerical studies for ship design. CAD model is prepared from the lines plan and other available information. It can be separated onto two parts as above waterline and below waterline model for various studies. Complete CAD model is generally required for FEM based studies. FEM model includes the material properties as well as geometric properties such as thicknesses of the CAD surface.

5.2 Further, same models can be used as it is or with additional inputs for various signature predictions. Models can be refined in due course and few of the studies can be re-performed as the design advances. However, it should be noted that the techniques use numerical simulations such as CFD, FEM, etc. that are computationally intensive and computational time is proportional to the complexity of the numerical model.

5.3 Sample vessel (viz. Ship-1) studies are carried out to predict various signatures of the vessel. Fig. 2 to 7 shows the results of these studies. In the presented work, iterations for design evolution are not carried out, however, it is very much possible as depicted in Fig. 1.

## Fig. 1: One model approach




Electromagnetic signature [1], [2] and [3]

**Fig. 1: Electric Potential on Ship-1**

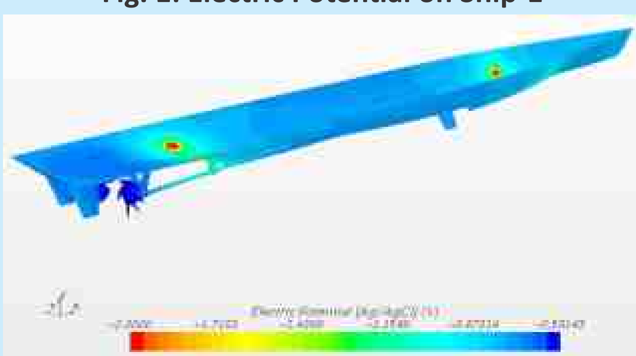


**Fig. 2 : Magnetic Flux Density Variation along depth on Centreline Plane of Ship-1**

- Only underwater model used from CAD.
- Thickness & material properties from FE Model.
- Details of main machinery (weight) can be incorporated

## RCS prediction [4] and [5]

**Fig. 4: Total RCS comparison with LEPO and RLGO (Frequency = 1 GHz; Plane Wave Theta = 90 deg) for approximated superstructure of Ship-1**

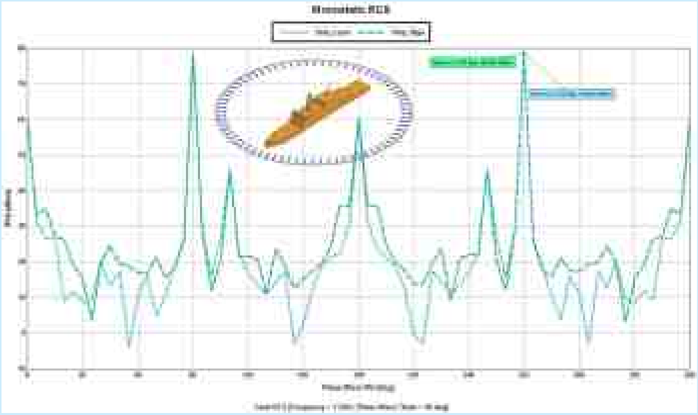
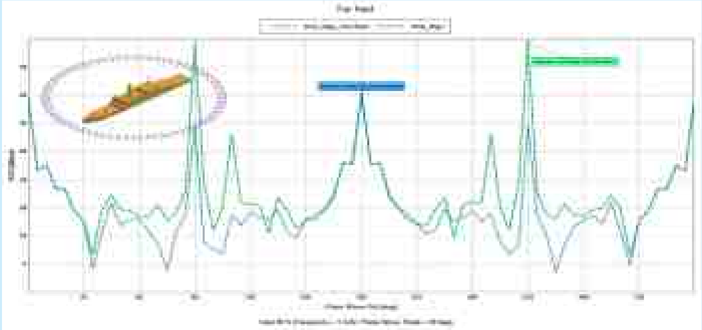
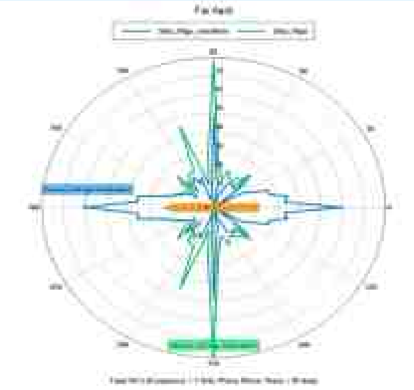



**Fig. 5: Total RCS with and without RAM for approximated superstructure of Ship-1**



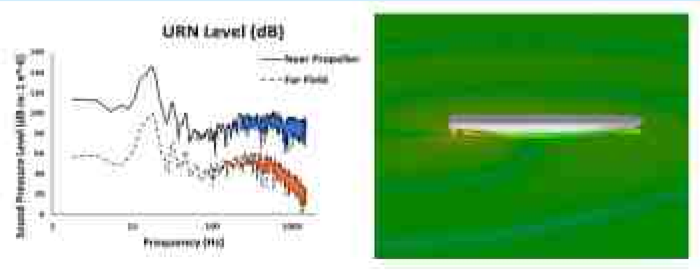

- Only above WL model used from CAD.
- Thickness & material properties from FE Model
- Comparison of results utilizing two approaches viz. LEPO (Large element physical optics) and RLGO (Ray launching geometric optics) are made in Fig. 4
- Reduction of RCS using radar absorbing material (RAM) is shown in Fig. 5 – 6. RCS reduction with shaping is also possible, however, not presented in this paper.

**Fig. 6: Total RCS polar plot with and without RAM for approximated superstructure of Ship-1**




## Acoustic signature [6], [7] and [8]

**Fig. 7: URN prediction for Ship-1 (with bulbous bow)**




- Complete CAD & FE model for On-board noise.
- Complete model for URN.
- Details of main machinery (weight) can be incorporated
- SEA (Statistical Energy Analysis) technique used for on-board noise, typically high frequency noise. Combination of CFD, FEM and BEM (boundary element method) is used for URN prediction.

## 6. Conclusions

6.1 This paper presents one model approach for various numerical studies with focus on signature prediction of the vessel. These studies are computationally intensive. Software tools based on various techniques e.g. CFD, FEM, BEM, SEA, etc. are available. Special skills are required for handling these tools and for interpretation of results from these tools. In this regard it is proposed to use the model initially prepared for basic studies for various signature predictions. Initial model can be refined or updated as required for the specific signature prediction. This approach can reduce the overall time spent in design process.

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# ADVANCED ULTRASONIC TESTING-AN ALTERNATIVE FOR RADIOGRAPHIC TESTING IN MODERN SHIP AND SUBMARINE CONSTRUCTION

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Lt Cdr (ND)-SDG

## 1. Abstract

1.1 Non-Destructive Testing methods play major role in ensuring quality of welded joints of steel structures in modern ship and submarine construction. Radiographic Testing (RT) has been used as the most reliable method for identification and characterization of volumetric defects in weld joints for past few decades. However, personal hazards associated with x-rays/gamma-rays and increased production lead time and cost, owing to its complex set-up and limited access to constrained spaces has led to the search for other advanced and more environment friendly NDT methods. Further, with the increase in the thicknesses of the structures, higher intensity radiography sources are required for testing. Hence there exists an urgent need to find an alternative to Radiographic testing. Advanced Ultrasonic Testing (AUT) has emerged as a reliable alternative to RT for many industries and ship builders across the globe. AUT method uses a combination of Phased-Array Ultrasonic Testing (PAUT) and Time of Flight Diffraction (TOFD) techniques for detection and characterization of weld defects. This paper attempts to describe the role of AUT in modern ship/submarine building, its advantages and limitations with respect to conventional UT and RT methods and challenges involved in adopting this method with effectiveness.

## 2. Introduction

2.1 Welding technology and methods of Non-Destructive Testing constitute the backbone of modern ship building industry. Non-Destructive Testing (NDT) is the most effective and widely used tool for monitoring the quality of the weld joints of a vessel. Reliable and time efficient methods for detection of weld joint defects in critical steel structures is an important deciding factor in ensuring quality and timely delivery of the end product. A number of NDT methods are used in ship building and other industries for defect identification. Broadly, these methods can be divided into two types, namely, methods used for detection of surface/near surface weld defects and those used for detection of sub surface defects. Surface defects can be located using Visual Inspection (VI), Dye-Penetrant Inspection (DPI) and Magnetic Particle Inspection (MPI). Whereas, Radiographic Testing (RT) and Ultrasonic Testing (UT) are NDT methods used for detection and characterization of sub surface defects.

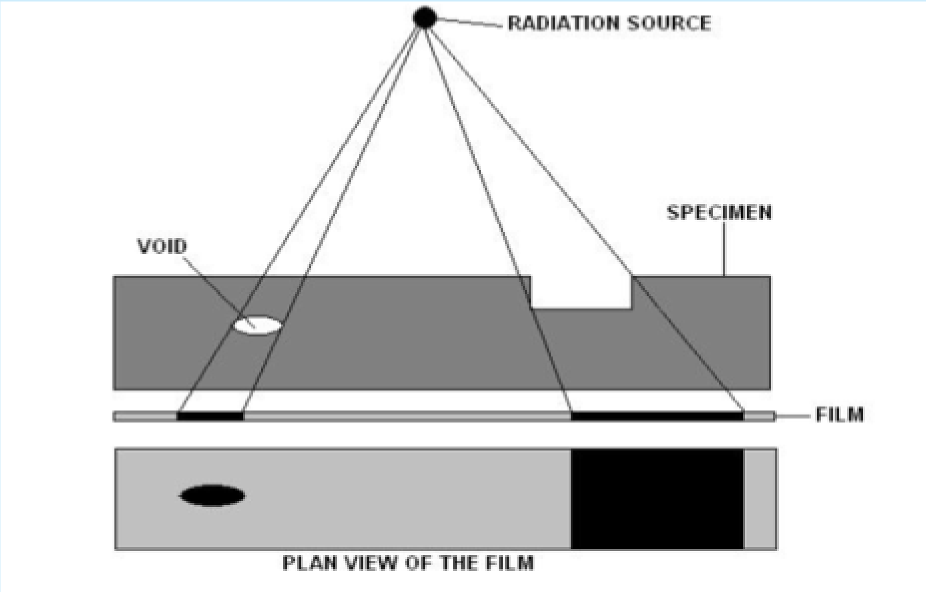
2.2 Radiographic Testing has been used for industrial inspection for over 100 years. A key factor in their durability has been the ease and effectiveness of the inspection procedure, including the availability of optical-quality images that facilitate interpretation of results. Due to concerns such as the radiation hazard posed by radiographic imaging systems, the high cost of radiography as compared to ultrasonics, many industries have expressed interest in replacement methods for radiographic testing (RT). Conventional Ultrasonic Testing (UT) is used for testing of welded joints of high thickness and as an additional precaution to RT method for lower thicknesses. It is a more reliable tool for volumetric sizing of defect and identification of depth of flaw in through-thickness direction of welded joint.

2.3 Advanced ultrasonic testing methods like, Phased Array Ultrasonic Testing (PAUT) and Time of Flight Diffraction (TOFD) can potentially provide superior results to conventional UT while retaining the benefits over RT. Furthermore, modern PAUT and TOFD equipments can create and store a complete electronic record of the inspection process and results, including geometric location information.

### 3. Radiographic Testing – *Principle, application and limitations*

3.1 Radiographic Testing (RT) method of weld joint inspection relies on principle of transmission and absorption/attenuation of small wavelength energy waves (x-rays and gamma rays). Pores/inclusions or material discontinuities or gradients will result in different attenuation values, resulting in differences in the optical density in radiographs. The result of this process is an optical-quality image that can be easily interpreted, particularly with the availability of reference radiographs.

**Fig. 1: Working principle of Radiographic Testing.**




3.2 Radiographic Testing (RT) is very reliable technique for detection of subsurface defects like, incomplete penetration, incomplete fusion, porosity, inclusions etc. It has the added advantage of having recorded data in form of radiographic film for easy retrieval and future reference. However, there are few limitations associated with it. In the case of RT, the weld joint under inspection should be accessible from both sides. Further, detection of planar defects with major axis situated in the direction of radiation is difficult using RT and distance or depth of location of defect in the weld pool cannot be determined using RT method.

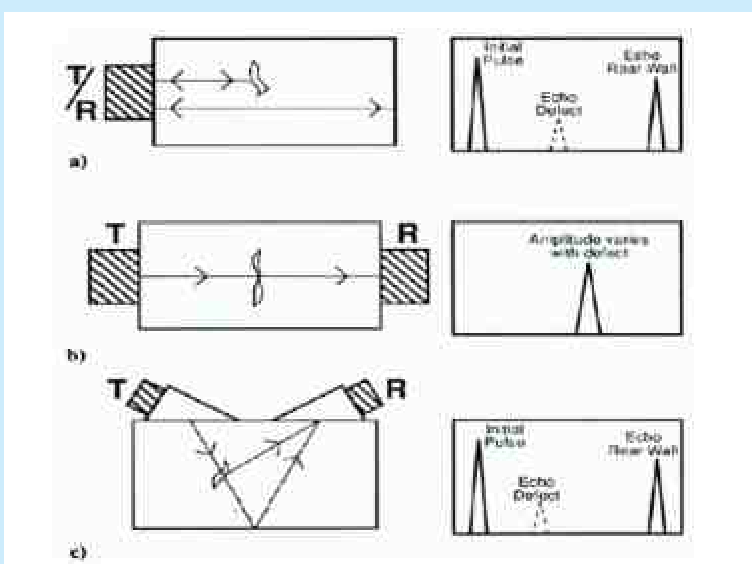
3.3 **Environmental constraints with RT**. Depending on the power source (isothope) available, the range of acceptable definition increases as the power increases. However, in most countries, there is a limit to the power you can use. In Australia, you can only release sufficient power to X-ray up to 60 mm thick in 12 hours. In some countries, you can X-ray up to 150 mm. The limit adopted in Australia (and in most European countries) is 40-50 mm. In Europe and Australia the strength of the X-Ray power source is obviously limited for safety reasons. Restrictions on strength of permissible radiation source may be implemented in India as well in the future. Considering these factors, there is a need for hazard–free and equally effective alternative for NDT.

**4. Conventional Ultrasonic Testing**

4.1 Conventional Ultrasonic Testing (UT) is a method in which high-frequency sound waves are introduced into materials for the detection of imperfections or flaws in the material. The sound waves travel through the material and are reflected at interfaces such as surface boundaries, grain boundaries, cracks, and pores. The reflected acoustic energy is converted to electrical signals which are recorded and analyzed to determine the presence and location of flaws or discontinuities. Fundamentally, UT uses echo-location approach to determine the presence and position of flaws. A single-element acoustical probe – known technically as a monolithic probe is used to emit an ultrasonic beam in a fixed direction. To test or interrogate a large volume of material, a conventional probe must generally be physically turned or moved to sweep the beam through the area of interest.

4.2 UT is typically performed in either through-transmission mode (two transducers located on opposite sides of the component) or pulse-echo mode (one transducer located on one side of the component). For noisy materials (cladding, stainless steels) a dual transducer is commonly used where one transducer is used for transmitting and the other transducer sitting next to it is used as the receiving transducer. The dual mode (pitch-catch) is far more common than the through transmission mode. The through transmission mode only measures signal attenuation, while the pulse-echo mode can measure both transit time and signal attenuation. As a result, pulse echo (PE) can provide information on flaw location, length, and flaw depth. Another advantage to using pulse echo is that only single-sided access to the component is sufficient because one transducer can be used as both the transmitter and the receiver.

**Fig. 2: Typical UT Techniques: (a) pulse-echo (b) through-transmission and (c) pitch catch.**

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5.3 **Conventional UT vs RT**. Conventional UT has a number of advantages over RT in that it is more portable, can easily penetrate to larger depths, is nonhazardous, requires accessibility to only one surface, and is more capable of determining the depth location of flaws. However, UT requires considerable operator skill to manipulate the probe and interpret the received signals. Importantly, most UT systems provide no recorded medium, such that results can only be interpreted in real-time on the spot, with no opportunity for further review at a later time or date. Conventional UT method is capable of detecting defects in the weld joints like, incomplete penetration, cracks, porosity, inclusion etc. However, accurately detecting surface and near surface abnormalities is a challenge with conventional UT technique. In thinner wall vessels or objects, radiography is most suitable for detecting both volumetric and planar Indications. Ultrasonic Testing technology has made considerable advancement in last few decades; the same will be discussed in succeeding paragraphs.

## 6. Developments in field of Ultrasonic Testing

6.1 UT inspection of welded structures has been around for over 40 years. Conventional UT consists of a single probe for inspection, with manual scanning of the weld. In the 1970s automated techniques for scanning the weld and displaying the data were introduced, with advances in the late 1970s including time-of-flight diffraction techniques for flaw detection and sizing. Multi-probe automated ultrasonic testing systems were introduced in the 1980s, with phased-array systems introduced in the late 1990s. A brief summary of these different techniques is discussed below :-

(a) **Manual Ultrasonic Testing (MUT)**. This technique is performed by an operator manipulating an ultrasonic probe over the work piece and visually monitoring the screen of an ultrasonic flaw detector. Typically the operator would use different angle-beam probes and scanning directions to detect all orientations that are possible for flaws. Sizing of flaws is typically carried out by measuring the probe movement for the presence of the signal until it falls by a fixed amount as the probe is traversed across the flaw (dB-drop technique). The maximum amplitude technique, on the other hand, uses the distance the probe is moved to maximize the amplitude of the first and last peak signals from an A-scan (pick up tip-diffracted signals from the flaw extremities).

(b) **Automated Ultrasonic Testing (Automated UT)**. The automated UT is similar to MUT in regards to the use of angle-beam probes for detecting and sizing of flaws. Multiple angle-beam probes are used to obtain full coverage of the required volume. The main difference with MUT is the ability to record position with the use of encoders and scanning frames to move a single probe over the surface in a fixed pattern.

(c) **Computer Assisted Ultrasonic Testing (CAUT)**. The actual scanning of the CAUT system is identical to the automated UT described above. Computer-assisted UT can additionally use computer algorithms to flag potential flaws. The data however is still reviewed by an inspector if it has been flagged for further review. The evaluation of the data can be performed remotely.

(d) **Time-of-Flight Diffraction (TOFD)**. TOFD technique uses two probes, one for transmitting and the other for receiving. The UT beam produces a diffracted signal from the flaw extremities, which act as point sources, as well as a reflected signal. The diffracted signals appear as signals arriving at different times at the receiver. This technique is used to improve the depth sizing estimates of a flaw based on geometrical calculations of the signal arrival times. The disadvantages are where the different signals cannot be resolved in time (small flaws, flaws close to the inspection surface) and the amplitude of the diffracted signals can be low.

(e) **Phased-Array Ultrasonic Testing (PAUT)**. PAUT uses a multiple-element probe unlike the manual or automatic UT systems, where the output pulse from each element has its own time delay to produce a constructive interference at a specific angle and a specific depth. These time delays can be incremented to sweep the beam over the desired range of angles. PAUT displays images in real time showing the depth and location of the indications relative to the probe and with the computer software is able to display the ultrasound signal response overlaid on the test piece.

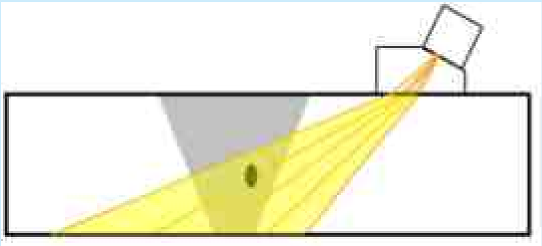
## 7. Advanced Ultrasonic Testing (AUT) – *PAUT and TOFD*

7.1 Conventional UT uses a single element transducer that releases only one pulse at a time to detect defects in material (as shown in Fig. 2). In case of scanning thick material or material with greater volume, a monolithic probe will be required to be physically moved and turned for ensuring complete volume coverage, including specific areas of interest. This is a time taking process and chances of error are higher. Advanced Ultrasonic Testing methods like PAUT and TOFD have capability to overcome this limitation. PAUT and TOFD techniques and their advantages and limitations are discussed in details in succeeding paragraphs.

7.2 **Phased Array Ultrasonic Testing (PAUT)**. PAUT utilizes multiple elements on a single transducer which provides the flexibility to electronically control parameters like, focal point, inspection spot size and angle of incidence. In contrast to conventional UT, the beam from a phased array probe can be moved electronically, without moving the probe, and can be swept through a wide volume of material at high speed.

7.3 Phased Array Ultrasonic Testing (PAUT) can potentially provide superior results to conventional UT while retaining the benefits over RT. Furthermore, modern PAUT equipment can create and store a complete electronic record of the inspection process and results, including geometric location information.

**Fig. 3: Phased Array Ultrasonic Testing technique.**

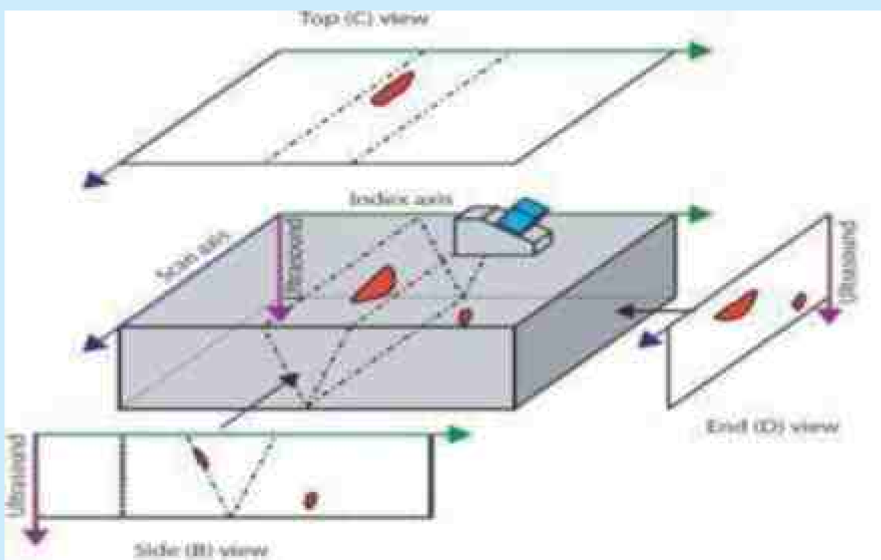


7.4 Phased Array technique also provides a combination of various scans in the same equipment set-up. B-Scan is a side view, C-Scan is a top view and the D-Scan is a cross-sectional view (as shown in Fig.5). These views make characterization of flaw very convenient, without any requirement of access from the other side of the sample under scanning.

**Fig. 4: Typical PAUT scanning techniques: (a) Straight scan (b) Sectoral scan**

7.5 **Important features of PAUT.** Phased arrays permits optimizing defect detection while minimizing inspection time. Phased arrays offer significant advantages over traditional radiography of welds. Some of the important features of PAUT are :-

**Fig. 5: PAUT scan results with different views.**




(a) Electronic scanning permits very rapid coverage of the components, typically an Order of magnitude faster than a single probe mechanical system.

(b) Great flexibility in parameter range and compliant with all known codes.

(c) Inspection can be carried out as soon as weld is cool.\

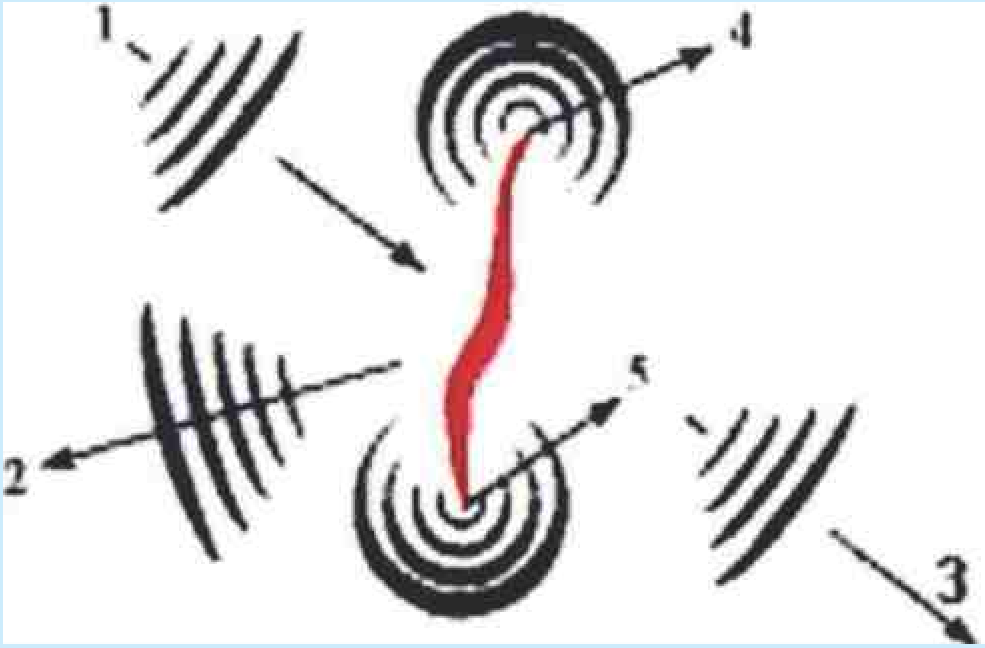
(d) Better defect detection and sizing as compared to RT and conventional UT.

(e) No safety hazards.

7.6 **Time-Of-Flight Diffraction (TOFD)**. Time-Of-Flight Diffraction (TOFD) technique is based on diffraction of ultrasonic waves on tips of discontinuities, instead of geometrical reflection on the interface of the discontinuities. When ultrasound is incident at linear discontinuity such as a crack, diffraction takes place at its extremities in addition to the normal reflected wave. This diffracted energy is emitted over a wide angular range and is assumed to originate at the extremities of the flaw (as shown in Fig.6). When flaw is detected during the scanning, Signals from the upper and lower tips of the flaw are displayed as scan images. The conventional UT relies on the amount of energy reflected by the discontinuities.

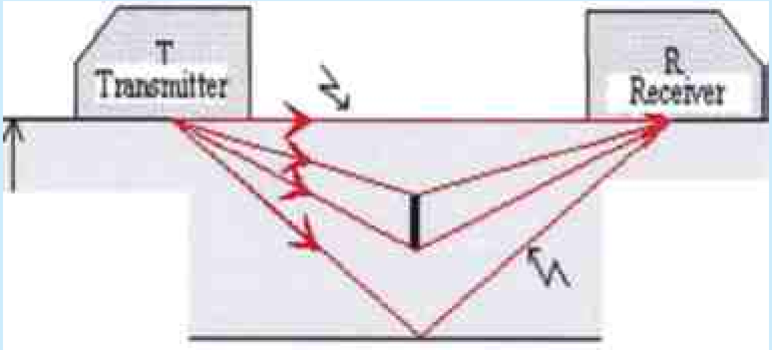
7.7 In addition to energies diffracted by defects, the TOFD method will also detect a surface (lateral) wave travelling directly between the probes and also a back wall echo from energies that reach the

**Fig. 6: Principle of Time-Of-Flight Diffraction (TOFD).**




back of the test piece without interference from defects. The TOFD technique uses a pair of probes in a transmitter-receiver arrangement (Fig.7). Usually longitudinal probes are applied with an angle of incidence range of 45° to 70°. The diffracted signals are received via the receiver probe and are evaluated with the Ultrasonic System. The difference in the flight of the diffracted wave fronts carry the information on the spatial relationship of the tips of the defect and hence the extent of the defect. TOFD method only evaluates diffracted echoes.

**Fig. 7: Transmitter- Receiver arrangement of TOFD.**



7.8 It is common in Non-Destructive Testing that one technique does not fit in to fulfill all tasks. For heavy wall weld inspection using TOFD, we also have some inherent issues to overcome. These are:-

(a) TOFD has a certain dead zone at the surface (limited detection in HAZ area) and near Back wall also. Additional techniques need to be used to ensure coverage of these areas.

(b) As the wall thickness increase, one TOFD transducer pair with proper beam spread and sensitivity is not capable of examining the entire weld volume. So, as the wall thickness increases, multiple TOFD transducer pairs will have to be used.

7.9 AUT vs Conventional NDT.AUT (PAUT and TOFD), offer several advantages over conventional NDT (which comprise UT and RT in case of Shipbuilding) which are summarized below: -

(a) By suitably configuring the Scan Plan, all types of weld defects can be detected using PAUT and TOFD, which makes these techniques more effective and reliable. These techniques are also very versatile and adaptable to most of inspection conditions.

(b) In case of RT, characterisation of cracks whose axis lies in direction parallel to travel direction of x-rays or gamma rays is not possible. This limitation can be overcome using PAUT and TOFD. Crack and lack of fusion are the most critical defects in weld joints that are responsible for failure of the weld joint. PAUT and TFOD combination detects these flaws with relative ease.

(c) Due to the wide range of angle of transmission, the probability of defect detection is higher PAUT as compared to conventional UT and RT.

(d) Certain defects which are difficult to detect using RT, like planar defects can be more accurately and effectively detected.

(e) PAUT and TOFD have better defect characterization of critical defect like weld root crack as compared to RT.

(f) PAUT and TOFD are radiation free and hence is more environment- friendly.

(g) Conventional RT requires shielding and clearance of the area to be radio-graphed and thus adversely affects the cycle time.

(h) RT power source is slowly getting limited for safety reasons and hence there is a need to adopt greener technologies such as AUT.

**8. Codes for Acceptance of AUT in lieu of RT**

8.1 Advanced Ultrasonic Testing as a combination of PAUT and TOFD is gaining popularity in many industries including ship/submarine building in recent years. Piping industries, offshore industries, energy sector and ship/submarine building is seeing a rising trend in acceptability of AUT as NDT method for inspection of critical weld joints. To date, five ASME Code Cases have been published that allow the use of ultrasonic inspection in lieu of radiography for weld inspection. ASME Code Case 2235 allows for the substitution of Phased Array (PAUT) & Time of flight diffraction (TOFD) in lieu of radiography for the examination of heavy wall pressure vessel welds & Nozzles accordance with ASME Section I, para.PW-11; Section VIII Division 1, para.UW-11 (a); Section VIII Division 2, Table AF-241.1. It allows the replacement for Pressure Vessels and Power Boilers welds greater than 13 mm wall thickness.

8.2 ASME Code Case 2235 is of particular relevance to submarine hull structural weld joints. However, the code case only provides guidelines for implementation of AUT in lieu of RT and may not be directly applied for NDT of submarine structural weld joints. Further, acceptability criteria for weld defects will have to be defined prior implementation of AUT in submarine hull construction.

## 9. Case study on use of AUT – *Heavy engineering industry*

9.1 **Electric Power Research Institute (EPRI), USA.** EPRI had performed research to assess the effectiveness of UT to detect fabrication related flaws for austenitic piping welds. This work was undertaken as part of attempt to extend the code case N-831 limits from ferritic piping welds to austenitic piping welds. The salient features of this research work are as follows:-

(a) Fabricated stainless steel mockups in accordance with N-831 requirements.

(b) Mockups examined as single side access.

(c) All flaws were detected and sized within N-831 criteria.

(d) Demonstrated PAUT as effective for stainless steel fabrication flaw detection and sizing

9.2 EPRI research has successfully established possibility of replacement of RT with AUT and the report provides technical basis for revising code case N-831 to include austenitic piping.

9.3 **Bridge welding - Department of Transport, Florida, USA**. University of South Florida, USA, had carried out a study on data collected from steel bridge welds under real-world conditions in a fabricator's shop, in Feb 2014. Three different non-destructive testing (NDT) techniques were used on each weld inspection, these being Radiographic Testing (RT), conventional Ultrasonic Testing (UT), and Phased Array Ultrasonic Testing (PAUT). These data were then compared to determine whether PAUT might in future be adopted under the American Welding Society (AWS) D1.5 code as a suitable substitute for the currently required RT. Salient features of the report are as follows:-

(a) Rejection rates using PAUT were similar to those of RT and UT, thereby allaying concerns that the potentially more sensitive PAUT might result in unnecessary rejections.

(b) In a rare case, an edge flaw resulted in PAUT acceptance despite RT rejection.

(c) Additional testing was performed on three custom-designed test plates with built-in edge flaws. These plates were inspected using a procedure that also included supplemental manual and raster scanning. Using this testing procedure, PAUT came into total agreement with RT and UT regarding all plate defects.

9.4 Report concluded that PAUT would make a suitable substitute for RT (and UT) in bridge weld inspection, provided an appropriate procedure is followed. Considerable cost savings could be realized by making such a change.

9.5 Application of AUT in Indian Oil Refinery.Indian Oil Corporation Limited (IOCL) had undertaken different case studies at one of its refineries in 2017 in order to establish necessity of replacement of RT with PAUT and TOFD. The results of case studies are as follows:-

(a) **Case 1**. PAUT was carried out at Diesel Hydro-treating Unit (DHDT) of one of Indian Oil Refineries for defect identification of weld joints during fabrication in NB 6", 8"and 10" pipeline. PAUT was done by using Omni Scan MX- 2 and interpretation was done by level III UT expert. PAUT was carried out instead of conventional radiography technique, this lead to huge saving in production loss due to stoppage of work during shutdown of refinery and radiation hazard was eliminated.

(b) **Case 2**. PAUT was used in refinery for detection of thermal fatigue cracks at the hydrogen quench location at OHCU Reactor Effluent line. PAUT showed reduction in scanning time and data which can be stored for trending, reporting and comparison purposes.

(c) **Case 3**. PAUT techniques were used in circumferential crack detection and sizing of heavy walled Category "D" nozzles and nozzle welds. Nozzle welds represent several heavy wall pressure vessels ranging in thickness from 50.8mm to 110mm. PAUT showed significant reductions in scanning times and crack imaging proving to be a valuable asset for complex geometries.

9.6 IOCL case study results proved that PAUT and TOFD are superior to RT for evaluation of weld defects. These results were published in form of technical paper and presented at CORCON seminar at Mumbai in September 2017.

**10. Case Study on Use of AUT – *Submarine Construction***

10.1 **PAUT for Submarine Pressure Hull, PNU, South Korea**. Pusan National University (PNU), South Korea, had carried out an analysis on the disadvantages associated with using conventional NDT methods, namely RT and UT, for inspection of submarine pressure hull weld joints. Thereafter, it has laid emphasis on use of PAUT in order to supplement these disadvantages. As part of the study, 17 different types and dimensions of welding defects in specimens of thicknesses 30T and 40T made of HY-100 steel were examined using RT, UT and PAUT. These methods were used to find out location, length and depth of each type of defect separately. Result of NDT is indicated at Table 1 & 2 for 30 T and 40 T specimens respectively.

**Table 1: Experimental result for defects using RT, UT and PAUT for 30T specimen.**

| Defect Type | NDT | Defect length (mm) | Defect Location (mm) | | Defect depth (mm) |
|---|---|---|---|---|---|
| | | | X- axis | Y- axis | |
| Crack | RT | 3 | 26 | Undetected | |
| | PAUT | 30 | 20 | -3.4 | 4 |
| | UT | 10 | 25 | -1 | 4-5 |
| Crack | RT | 17 | 59 | Undetected | |
| | PAUT | 18 | 58 | -3.4 | 4 |
| | UT | 6 | 62.5 | -1 | 4-5 |
| Crack & Porosity | RT | 32 | 81 | Undetected | |
| | PAUT | 34 | 80 | -3.4 | 4 |
| | UT | 7 | 85.5 | -1 | 4-5 |
| IP & Porosity | RT | 16 | 119 | Undetected | |
| | PAUT | 36 | 118 | -3.4 | 4 |
| | UT | 35 | 121.5 | -1 | 4-5 |
| IP | RT | 161 | 154 | Undetected | |
| | PAUT | 162 | 154 | 0.6 | 7.1 |
| | UT | 162 | 154 | 0.6 | 5 |

**Table 2: Experimental result for defects using RT, UT and PAUT for 40T specimen.**

| Defect Type | NDT | Defect length (mm) | Defect Location (mm) | | Defect depth (mm) |
|---|---|---|---|---|---|
| | | | X- axis | Y- axis | |
| IP | RT | Undetected | | | |
| | PAUT | 6 | 0 | -3.4 | 4.5 |
| | UT | 4-5 | 0 | -3 | 4.5-5.5 |
| IP | RT | Undetected | | | |
| | PAUT | 9 | 6 | 4.4 | 6.5 |
| | UT | 64-5 | 6.2 | 4.2 | 4.5-5.5 |
| Crack | RT | 17 | 65 | Unknown | |
| | PAUT | 24 | 58 | 2.2 | 6.6 |
| | UT | 22 | 57 | 2.5 | 4.5 |
| Porosity | RT | 15 | 118 | Unknown | |
| | PAUT | 11 | 122 | 2.2 | 7 |
| | UT | 10 | 122.5 | 2.5 | 4.5 |
| LF | RT | 155 | 165 | Unknown | |
| | PAUT | 162 | 155 | -4 | 5 |
| | UT | 160 | 155 | -4.5 | 4.5 |

10.2 Performance of the probe used for PAUT was analysed for defect identification. It emerged that PAUT probe with 64 piezoelectric elements each of width 5mm, capable of generating ultrasonic waves of angle 40 – 70 degrees at a frequency of 5 Hz was optimal for defect identification and characterization. Comparative result of defect identification using RT, UT and PAUT had the following important observations:-

(a) RT was unable to detect some crack defects due to beam scatter on the edge of the defect. Thus, relative detection capability of defect decreased as the specimen size increased.

(b) Using PAUT, detection of crack as small as 1 mm was possible, owing to high number of piezoelectric elements in the probe.

(c) PAUT showed relatively poorer volumetric defect identification as compared to RT. But, with increase of probe elements to 64, size of some of the volumetric defects was increased by 2mm over RT.

(d) Crack detection capability of RT was poorer than PAUT and the detection capability decreased with specimen thickness.

(e) Conventional UT showed deviation in case of mixed defects or defects located at low heights depending on skill of the operator. Identification of mixed defects of 1mm height was also possible using PAUT.

(f) Conventional UT was not able to record and store A-scan (wave pattern) results. RT was able to carry out passive analysis of data using film of C-scan (plan view). PAUT automated analysis of data and it was possible to record and store A, B, C and S scan data.

(g) PAUT scan (using electric linear scan) was about seven times faster than conventional UT scan (using raster scan).

10.3 Use of PAUT method for NDT of submarine pressure hull supplemented disadvantaged of RT and UT. Technical enhancement in defect identification and characterization was possible using PAUT. Increase in probe elements to 64 in number, resulted in increased precision of defect identification. Thus, according to this study, by applying PAUT method, significant benefits can be expected in terms of enhanced quality assurance in submarine hull construction

10.4 **AUT for Hull Butt Welds, Virginia Class Submarine, USA**. Project on use of PAUT and TOFD in lieu of RT and conventional UT was taken up by the firm General Dynamics Electric Boat (GDEB), USA, for hull butt welds of Virginia Class Submarine (VCS) and Ohio Replacement (OR) submarine hull. The aim of this project conducted between April 2013 to June 2016, was to establish effectiveness of PAUT and TOFD as a substitute for RT and conventional UT. The project was taken up in two stages. First stage was focused on determining technical feasibility of inspecting hull butt welds using PAUT and TOFD. Second phase compared the effectiveness of conventional UT against PAUT for inspection of as-welded bull welds of VCS. The important outcomes of this project are as follows:-

(a) NDT of hull butt weld joints using PAUT and TOFD resulted in GDEB projecting a commendable saving of 318K USD, driven by factors of reduced inspection time.

(b) GDEB also applied this concept of hull inspection on OR submarine and came up with a plausible saving of 476K USD.

10.5 Following the successful result in saving considerable amount of money by implementing PAUT and TOFD for hull inspection in VCS and OR submarines, steps have been taken to adopt this technology for inspection of hull of other platforms of US Navy.

**11. Challenges in Replacing Radiographic Testing with AUT**

11.1 Literature survey reveals that AUT can successfully replace RT for NDT of weld joints. Moreover, it emerges that all known limitations of Advanced UT in detection of defects can be eliminated by formulating specific procedures and Scan Plan. Certain challenges in replacing RT with AUT is presented below:-

(a) **Formulation of Revised NDT Procedures**. Use of PAUT and TOFD based AUT in lieu of RT requires formulation of new scan plan and NDT procedures which in turn requires extensive study of each type of weld joint. Formulation, evaluation and validation of the revised NDT procedures for each type of weld joint is a long-drawn process, which involves the following: -

(i) Analysis of the current NDT plan, joint geometries, types of defects envisaged, criticality of joint and acceptance norms.

(ii) Formulation of a Scan Plan and NDT procedures for each type of joint using AUT, which can detect all possible defects (especially the type of defects usually detected by RT).The revised procedures should clearly define the equipment and accessories such as fixtures, scanners, encoders etc and the qualification level of operators and interpreters.

(iii) Preparation of a revised NDT plan with AUT and without RT for these specific types of weld joints.

(iv) Validation of the new NDT scheme on Welded Coupons.

(v) Training of personnel to adopt new NDT procedures.

(vi) Field evaluation of the new NDT scheme for a predetermined period, along with RT.

(b) **Reliability**. Under typical inspection conditions, AUT detection rates and Probability of Detection (POD) appear to be similar to or better than RT detection rates and POD for planar and volumetric flaws. Depth sizing reliability of AUT depends on the specific technique used, such as PE, TOFD, etc. However, depth sizing using RT is difficult. Thus, RT and AUT have roughly equivalent capabilities for length sizing. AUT has a distinct advantage in depth sizing and through-wall flaw location, making it equally (if not more) reliable to RT.

(c) **Issues Related to Inspection**. UT and RT each have problems with specific types of geometries and materials. UT has significant issues in inspecting coarse-grained structures, as well as extremely thick materials where the acoustic attenuation is higher. RT has difficulties in inspecting very thick sections as well, although it does not appear to be as affected by coarse-grained material. However, RT requires access from both sides of the specimen/joint under test and portability of equipments is more convenient in case of AUT. Thus, inspection is relatively comfortable using AUT.

(d) **Human Factor**. RT inspection records are seen as easier to interpret (because the record is optical-quality images). AUT data interpretation is somewhat more difficult. However, both require significant examiner training because all volumetric NDE is very skill-dependent. AUT will require more skilled inspector for handling the probe and is therefore, relatively more human skill dependant than RT.

(e) **Record Keeping**. RT film is a permanent record of NDT inspection and can be stored and used for future reference conveniently. AUT unlike conventional UT can generate inspection data and the same can be stored for future reference. However, interpretation of results of AUT may require more skilled inspector.

(f) **Health and Radiation**. RT will result in exposure of the RT technicians and operators to harmful radiation. The potential for radiation exposure also means that the inspection area must be closed off to other activities until the RT inspection is complete. RT inspection is also influenced by residual radiation in operating plant components. AUT is free from any radiation hazard.

(g) **Cost**. The replacement of RT with AUT will reduce costs due to a reduction in consumables as well as improved productivity that is expected to result with other activities allowed in the inspection area. Moreover, reduction in overall time required for inspection will also add to savings in production cost.

## 12. Conclusion

12.1 Radiographic Testing is a time-tested and reliable technique of NDT of weld joints. It is however, a time consuming and hazardous method (due to likely exposure to radiations especially, while scanning thicker samples/plates) and should be replaced with a safer, more convenient and equally effective method. Advanced Ultrasonic Testing (AUT) method using PAUT and TOFD techniques has shown great potential to be a suitable alternative to RT for industries engaged in detecting and sizing of weld defects for analyzing structural strength. Few ASME Code Cases provide approval for acceptance of AUT in place of RT for defect identification and characterization. The studies undertaken by PUSAN State University on the use of PAUT for inspection of Submarine Pressure Hull welds and the study by General Dynamics Electric Boat, USA on the use of PAUT and TOFD in lieu of RT, indicates the possibility of replacing RT with AUT. However successful implementation of AUT in lieu of RT in ship/ submarine construction would be possible only after accurately defining revised NTD Procedures, Scan plan and the acceptance criteria for weld defects in critical structures and proving the same through experimental and field studies.

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# NSTL: CENTRE OF EXCELLENCE IN HYDRODYNAMICS – SUPPORTING INDIGENOUS SHIPBUILDING

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**1. Abstract**

1.1 NSTL has developed capabilities in various niche technologies for application in development of naval weapon systems and supporting a wide spectrum of technologies and products for the Indian Navy – be it the torpedoes, decoys, Fire Control Systems, or Hydrodynamic Testing of new hull forms of ships and submarines. NSTL is a one-stop "integrated solutions provider" in the area of Naval Hydrodynamics. With its capability to undertake entire range of Hydrodynamic model testing, it has emerged as an indispensible partner in Indian Navy's journey from a Buyer's Navy to a Builder's Navy, and its "Make in India" story. The spectacular journey over the last 30 years has resulted in creation of truly world class facilities and infrastructure comprising of High Speed Towing Tank, Cavitation Tunnel, Wind Tunnel Facility and Seakeeping and Maneuvering basin, which are counted among the six or eight such facilities in the world. NSTL has also built up capability to undertake design of a wide variety of propellers, propulsors and new hull forms for a number of naval applications. The experimental facilities are complemented by a mature Computation Fluid Dynamics (CFD) and Full Scale Sea Trials capability. The skills, expertise and competence that has been painstakingly built over the last 50-years has made NSTL a Centre of Excellence in Hydrodynamics. This paper presents the capability and contributions of NSTL towards indigenous development and construction of next generation of naval vessels in India.

**2. Keywords**

2.1 Hydrodynamics Research, Ship hull design and development, model testing of ships, full scale sea trials, NSTL, DRDO

**3. Introduction**

3.1 The field of Naval Hydrodynamics is the research aimed at understanding the physical phenomenon that determine the hydrodynamic and hydro-acoustic performance of naval vessels (i.e. ships, submarines, torpedoes, Autonomous Underwater Vehicles (AUVs) and other underwater bodies). Though ships and boats have been built for over a thousand years, it is only in the last 100 years that an understanding of 'Naval Hydrodynamics' and how it really works, has emerged. Scale model testing is only about 100-120 years and we have not fully understood the phenomenon as yet.

3.2 In order to cater to the Naval R&D requirements including studies on hydro dynamic parameters for warship & submerged vehicles, Naval Science & Technological Laboratory (NSTL) was established fifty years ago in 1969 under the umbrella of Defence Research and Development Organisation (DRDO), and is celebrating its Golden Jubilee in 2019. Over these fifty years, with its world class facilities and infrastructure, NSTL has developed capabilities in various niche technologies for application in development of naval weapon systems and supporting a wide spectrum of technologies and products for the Indian Navy – be it the torpedoes, decoys, Fire Control Systems, or Hydrodynamic Testing of new hull forms.

3.3 NSTL has achieved self reliance in the Naval Hydrodynamics and has emerged as an integrated solutions provider in the country, for all its customers. Navy has adopted a vision that NSTL shall be its development partner to support the design and construction of next generation of strategic submarines and naval vessels, in view of its world class facilities, significant contributions in the entire spectrum of hydrodynamics, and in recognition of the skills, expertise and competence that has been painstakingly built up at NSTL.

**4. Achieving self reliance in the niche area of Naval Hydrodynamics**

4.1 NSTL was tasked to address the narrowly focused needs of the country in the niche area of Naval Hydrodynamics through sustained Capacity and Capability building. The requirement of creating the infrastructure and facilities for undertaking research in 'Experimental Hydrodynamics' at NSTL was conceptualized in the 1980's, primarily with the strategic intent of supporting the Naval requirements, and achieving self reliance. NSTL has incrementally built up the ability to address the narrowly focused needs of the country in the niche area of Naval Hydrodynamics through sustained Capacity and Capability building.

4.2 The spectacular journey of NSTL has over the last 30 years has resulted in the creation of truly world class facilities and infrastructure of High Speed Towing Tank (HSTT)-1990, Cavitation Tunnel (CT) -2000, Wind Tunnel Facility (WTF)- 2003 and Seakeeping and maneuvering basin (SMB) -2014, which are counted among the six or eight such facilities in the world. Specifications of the experimental hydrodynamic test facilities at NSTL, in brief, are presented in the Table 1.

4.3 NSTL now has the capability of undertaking the entire range of Hydrodynamic model testing. In addition, over the last ten years, NSTL has also built up the capability to undertake the design of a wide variety of propellers and propulsors for a number of naval applications. In addition to the experimental facilities mentioned above, the maturity of the Computational Fluid Dynamics (CFD) capability as well has resulted in NSTL emerging as a one-stop "integrated solutions provider" in the area of Naval Hydrodynamics with the wide range of high quality studies and product development undertaken to support the design efforts of the NSTL, Indian Navy as well as other sister labs of DRDO.

**Table 1: Hydrodyanamic Test Facilities and their specification**

(a) Tank Dimensions: 500m (L) x 8m (B) x 8m depth of water

(b) Carriage Speed: Ahead 20 m/s (max), Astern 4 m/s (max) (With an accuracy of 0.1 % of the set speed between 2 - 20 m/s)

(c) Wave Generator: Dual flap type, capable of generating regular and irregular waves (unidirectional) as per ITTC

*Capabilities:* Resistance, Propulsion, Planar motion tests

**Fig. (a) High Speed Towing Tank**

(a) Test Section : 1.0 m x 1.0 m x 6.0 m

(b) Total Impeller Motor Power : 700 kW

(c) Working Section Max. Velocity : 15m/s

(d) Pressure (absolute) : 0.1-3.0 Kgf/cm2

(e) Min. Cavitation Number : 0.03+10/V2

(f) Tunnel Back ground Noise : 90 dB (ref. 1 mPa in range 1 – 100 kHz, 1/3 Octave)

(g) 5.2m (L) acoustic trough,

*Capabilities:* Propeller openwater and behind hull, cavitation and flow visualisation tests

**Fig. (b) Cavitation Tunnel**

(a) Test Section : 1.5 X 1.5 X 4.0 m

(b) DC motor : 125 KW, 750 rpm max

(c) Tunnel Fan : 12 bladed CFRP fan with diameter 3.04m

(d) Maximum speed at Test Section : 55 m/sec

*Capabilities:* Wake survey, Force measurement, boundary layer , flow visualisation tests

**Fig. (c) Wind Tunnel Facility**

(a) SMB is 137m long, 37m wide and 5mdeep.

(b) Model scale of 1:20 to 1:40 and having model length of 3-5 m

(c) Main Carriage(X): 6 m/s (max)

(d) Sub-carriages

Sway (Y) : 4m/s (max)

Yaw (ϕ) : 30deg/sec (max)

Surge(ΔX) : 1 m/s (max)

Speed accuracy : <0.1% of set speed

*Capabilities:* Seakeeping in regular and irregular waves, Turning circle trials with propulsion, free running model tests

**Fig.(d) Seakeeping and Maneuvering Basin (SMB)**

4.4 In addition to the world-class experimental facilities, the Hydrodynamic Research Directorate at NSTL is organised into five core groups, as follows:-

(a) **Marine Vehicles Powering Group**. The work includes design of hull and propellers as required for the projects and their evaluation through conduct of tests in the hydrodynamic test facilities including CFD/theoretical analysis. To improve product performance and design efficiency, Simulation Based Design (SBD) approach has been adopted by this group for ship hydrodynamics.

(b) **Marine Vehicle Dynamics Group**. Responsible for prediction of dynamic performance includes the maneuvering and seakeeping aspects of the hull-propeller-control surface configuration of the vehicles. SBD experts merge the traditional fields of resistance, propulsion, seakeeping and maneuvering, with inclusion of environmental effects to revolutionize the design process of the marine vehicles.

(c) **Instrumentation Group**. The group designs and develops new equipment/dynamometry required for the hydrodynamic evaluation at the Hydrodynamic Research facilities and fullscale trials.

(d) **Facility Maintenance Group**. The division carries out regular maintenance of various workshop machinery and upkeeping of material stores. The studies done by this division includes the identification of equipment/machinery for better utilization of the facility.

(e) **Full scale Sea Trials Group**. NSTL is the nodal agency to carry out the full-scale sea trials of IN ships and submarines. The full scale sea trials includes validating the predictions of speed-power, maneuvering and sea keeping performance on of full scale vessels wrt model scale tests in the laboratory. In addition , and Cavitation Observations are also carried out as part of full scale sea trials

**5. Significant Contributions of NSTL in the Marine Hydrodynamics**

5.1 NSTL has made very significant contributions, in the field of marine hydrodynamics, which are enumerated below:-

(a) **Contribution to Warship & Submarine Building Programme of Indian Navy.** Hydrodynamic model testing of the scale models of naval vessels is a very important part of the product development cycle of the next generation of warships and submarines. In the absence of the capability to undertake these model tests over the entire spectrum of Hydrodynamic Testing within the country, the Navy has been going abroad (KSRI Russia, SSPA Sweden and MARIN Netherlands) for over forty years. Apart from the expenditure in Foreign Exchange, it also entailed sharing the sensitive and classified design data of the hull form of the naval vessels with the foreign labs. Model tests of various warships and submarines were conducted at hydrodynamic test facilities for predicting the hydrodynamic characteristics like powering, Seakeeping and maneuvering. And apart from validating the designs of the customers, NSTL has carried out a no. of model tests for developing a variety of advanced hull forms for the warships.

(b) **Strategic Intent of Indian Navy**. NSTL is an indispensible partner in Indian Navy's journey from a buyer's Navy to a Builder's Navy, and its “Make in India” story. In view of the capacity, capability, competence and confidence that has been build up at NSTL, Indian Navy has adopted intent of undertaking the scale model tests over the entire spectrum of Hydrodynamic Testing of its next generation warships and submarines at NSTL, and not go abroad any more. This intent of IN originates from a number of factors, most notably the following:-

(i) Good agreement of the model test results of IN ships undertaken at NSTL (at HSTT and SMB) with the results from foreign facilities has been observed. This indicates that the capability and expertise in the areas of Naval Hydrodynamics that has been painstakingly built up at NSTL with a strategic intent of becoming self reliant in the niche area, has almost been achieved.

(ii) Build up of capability to support the indigenous design of propeller/propulsor for next generation of naval vessels.

(iii) Ability of NSTL to assist Indian Navy in undertaking the initial design and testing, and making sure that the naval vessel shall perform as per its performance specification.

(c) **Contribution to Torpedo Programme of NSTL**. NSTL played important role in the development of light weight and heavy weight torpedo development projects by carrying out model tests for predicting resistance and in deriving the hydrodynamic derivatives required for controlling motion algorithms. CFD at NSTL matured enough to undertake studies like flow through advanced propellers and advanced simulation studies like article ejection of underwater weapons.

(d) **Contribution to AUV Programme of NSTL**. NSTL has designed developed India's first Flat Fish Autonomous underwater vehicle. In-house expertise in hydrodynamic design and design evaluation using hydrodynamic facilities of High Speed Towing Tank, along with CFD analysis were utilized in this project.

(e) **TLRV**. TLRV (Torpedo Launch and Recovery Vessel), a 50 m long catamaran ship of 650 t displacement, has been designed by NSTL. It is first indigenous catamaran vessel of its kind, that is designed and constructed in India. The vessel capable of Launching Light Weight Torpedoes (LWT), Heavy Weight Torpedoes (HWT), is being operated by Indian Navy, and is being used for conducting the sea trials of NSTL products.

(f) **Propeller Design**. Propeller is a niche technology area, in which the NSTL has achieved significant capability and expertise. The propellers of every NSTL developed torpedoes, decoys, AUVs etc. have been designed and developed inhouse. In addition, the pumpjet technology has been developed indigenously, and the same has been deployed on indigenous torpedoes (ALWT). Design and model tests of propellers for Submarines and Ships has also been undertaken. The significant outcomes are as follows:-

(i) Pumpjet Propulsor for Torpedo

(ii) Contra-rotating Propellers for Torpedo

(iii) Integrated Motor Pumpjet (IMP) for Torpedo

(iv) Pumpjet Propulsor for submarine

(v) Skewed Propeller for submarine

(vi) Reserve propulsor for Submarine

(vii) Ducted Propellers for AUV and Decoy

(viii) Composite Propellers

(g) **Full Scale Sea Trials**. This group has evaluated the speed-power, maneuvering and sea keeping performance of every new construction naval ships and submarines, against their design specifications. Cavitation observations on the propellers also been carried out on certain naval ships and recommended the design changes in the propeller.

(h) **Contribution to Sister Labs of DRDO, ISRO and Other Organisatons.** In addition to Indian Navy, many DRDO labs and reputed scientific organizations like ISRO have approached NSTL for hydrodynamic/CFD solutions. NSTL has conducted studies & tests for space capsules, aero-planes, parachutes, underwater escape suits, SONARs, pumps, pipes, mines, decoys and lot more. It has tested more than 400 bodies since its inception for Indian Navy, Various DRDO Laboratories, ISRO, shipyards & marine firms. Model tests were carried out for Light Combat Aircraft (LCA) at hydrodynamic test facilities to simulate the wing in ground effects. Contributed in the development of horizontally and vertically launched underwater fired missiles through hydrodynamic model testing for cavitation, resistance and maneuvering characteristics. NSTL actively participated and played a key role in the National Programme of Ship design for efficiency and economy, conducted by Ministry of Shipping, India along with IITs, IRS and Shipyards in the country.

(j) **Research in hydrodynamics**. Though NSTL is engaged in the applied research activities and contributing to the product development, basic research projects for its continuous technology development are also undertaken. Science and Technology projects have been completed and the research outcome has already been implemented in the hull and propeller development of Ships and Torpedoes. Research studies were carried out for the design and development of futuristic hybrid hull forms such as SECAT, FoilCAT etc. A 10m FoilCAT demonstrator vehicle was developed and lake tests were also carried out. Research has been done on the 'artificial ventilation of foils for high speed applications'. Hydrodynamic model studies have been carried out to develop the energy saving devices such as of stern wedge, flap etc on different types of ships. And research has been carried out on the effect of energy saving devices on the improvement of propulsive performance. For reducing the wave making drag by the surface ships, detailed studies carried out on the wave-piercing bows.

### 6. Future Plans

6.1 In order to remain at the forefront of Naval Hydrodynamics in the country, NSTL has vast plans of expanding its capabilities of hydrodynamic design, development of hull forms, propellers for the military surface, submerged vehicles and weapons. In order to serve the Nation more efficiently and effectively through its hydrodynamic research activities, NSTL has the following approaches:

(a) Augmenting existing test facilities with new test facilities

(b) Upgrading the existing test facilities

(c) Encouraging the academia available in the country, to participate in the research

(d) Collaborate with International agencies for venturing into advanced technologies

(e) Development of advanced marine vehicles, and next generation of warships and submarines.

### 7. Conclusion

7.1 NSTL has achieved self reliance in the niche area of Naval Hydrodynamics, and has contributed to nation building and "Make in India" programme due to its continuous efforts in development of world class test facilities, significant contributions in the entire spectrum of hydrodynamics, the skills, expertise and competence that has been painstakingly built up at NSTL over the last 30-years, synergetic collaboration with academia, industry and other research establishments in the areas of hydrodynamics and maritime technology. And thus, contributing to the indigenous development and construction of Ships and Submarines in India.

# SHIPBUILDING FOR INDIA - AN ANALYSIS

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**1. Abstract**

1.1 Population of Israel is less than the number of people that travel in Mumbai's local train, on any given day; and still Israel is one of the largest exporters of defense products to India. Primarily, the reasons are our failure to develop into a nation capable of manufacturing and we have failed to build a base that can drive India's industrial progress. Shipbuilding is a key industry that can allow a nation to develop its manufacturing base and has been utilized by the nations like Japan, Korea, and China, to evolve them into a manufacturing driven economy. In this paper, we present an analysis of the shipbuilding and identify new emerging markets in shipbuilding markets for India.

**2. Keywords**

2.1 Shipbuilding, industrial growth, manufacturing, economy, and markets

**3. Introduction**

3.1 If one walks across any major road in India, the person is expected to see hoardings depicting, Samsung, Hyundai, Daewoo, Kia, and Mitsubishi, etc., as shown in Fig. 1. The person will relate them to cars, consumer electronics, mobile phones, etc., without even realizing for a moment that they all started with building ships and utilizing the shipbuilding to build their manufacturing base, later diversified into all that are now associated with them.

(a) **Observation 1**. It implies that we as a nation never thought of shipbuilding as a means to build our manufacturing base.

Ships and floating structures are the one of most complex engineering structures whose design and analysis time runs in months and production may take anywhere between months to years, as shown in Fig. 2. E.g. an aircraft carrier for US navy will cost around 2-3 billion US $ and take around 10 years to build. Assuming a 10 % profit, the amount of profit is 200 to 300 million US $.

(b) **Observation 2**. Can we think and guess about the changes that millions of dollars profit can make to India?

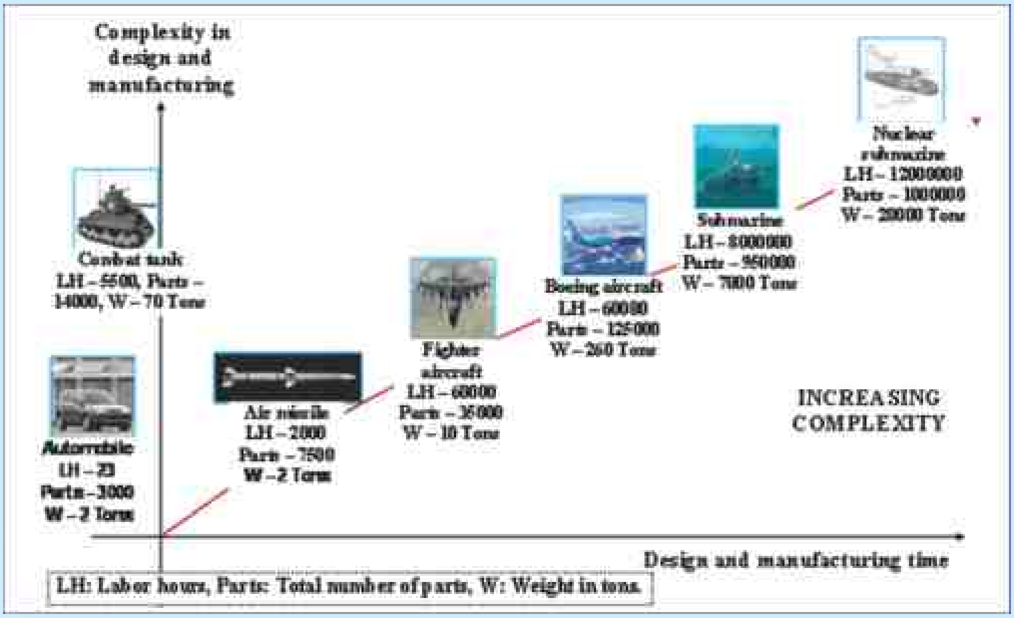
A ship is a large watercraft that travels the world's oceans. Requirements are sufficiently deep waterways, and aims are to carry passengers or goods, or in support of specialized missions, such as defense, research and fishing. Current status as of 2016: 49, 000 - Merchant ships (total 1.8 billion dead weight tons). Of these - 28% Oil tankers, 43% Bulk carriers, and 13% Container ships, Hoffmann et al. (2016). Defense forces: World's 104 navies, Korean People's Navy of North Korea - Surface vessels (967), People's Liberation Army Navy of China (714), the US Navy (415), Islamic Republic of Iran Navy (398), and Russian Navy (352), Indian Navy (100), from Editors (2016). Not many navies have any aircraft carrier ship but most of the world's navies have submarine.

(c) **Observation 3**. Can we design and develop new age submarines, submersibles, and other ships to satisfy the owners' requirements?

Private shipbuilding is virtually closed in India and the existing shipyards in private sector are also surviving on mainly defense ships. This scene is alarming on multiple fronts, e.g. it shows that the Indian shipbuilding lacks competitiveness.

**Fig. 1: Importance and complexity of shipbuilding and ships.**


**Fig. 2: Complexity in design and manufacturing of modern engineering structures, adapted from Gordon (2009).**



However a deeper analysis reveals more complex picture. Shipbuilding is a labor intensive industry and the major cost components are related to materials, e.g. steel plates. It is surprising to know that Indian shipyards - in the private sector - do not use Indian steel because of high cost, lack of availability of proper size and thick, less than the desired configuration, etc. Indian defense PSUs use steel by SAIL, India but that is because either the specifications are of a particular grade (e.g. in air defense ship) or cost not being a consideration. This scene cannot continue.

**Observation 4:** Indian shipbuilding cannot be revived unless and until or materials' industries become competitive.

## 4. Analysis, Design and Construction of Ships

4.1 In our opinion, the emerging directions are the following:

(i) Design for complete life cycle - from conception to design to manufacture to decommissioning;

(ii) Modularization of design - to reduce the design cycle lead time and unit cost of design; and

(iii) Optimization covering the entire life cycle and at each of the stages in lifecycle in the environment of integration, e.g. for more details see Goldan (1985), Sharma and Kim (2010), Gallala (2013), and Misra (2015).

(a) **Observation 5**. Is Indian approach going in this direction?

We believe that currently important challenges are the following:

(i) Mid body: Can we achieve a CB of 1 and still apply air lubrication?

(ii) Fore body: Can we design an optimum bulb?

(iii) Aft body: Stern shape (Different options?)

(iv) Integration of CAD, CFD and FEA, etc. for a design that is efficient and economic.

(v) Cost of developing new design alternatives to be minimized.

(vi) Development of design methods that are easy to implement, related to the basic ship particulars, and open to different types of ships.

(vii) Ship that utilizes renewable power sources, alternative fuels, and have easy mechanism for cleaning.

(viii) Design and develop methods for applications to ships and underwater systems based upon 'energy, efficiency, and economy'. This is E3/EEE concept.

(ix) Explore bio-inspired designs.

(x) Develop ports that are long, deep and less costly.

(xi) Think 'GAS'. Gas carriers are expected to be next big opportunity for investment.

(xii) Integrate rudder and propeller.

(xiii) Design bulbs for a range of Fn and CB.

(xiv) Can we operate a un-manned ship?

(d) **Observation 6:** Have we even realized that there can be no Make in India unless and until there is Design in India?

## 5. Market in New Shipbuilding

5.1 Because of serious bottlenecks in the supply chains of cargo transport India has failed to evolve as either a major shipping or shipbuilding nation. In container shipping, the Indian scene is not very good. Presently, the medium to large size container ships are neither designed nor manufactured in India. The share of Indian companies in world container transportation is negligible (i.e. there are only ten container ships of total 11,000 TEU capacity under Indian flag [1]; and out of these ten, three of 1600 TEU each belong to a public sector shipping company, and seven to a private sector shipping company). Since, the container ships of SCI (i.e. Shipping Corporation of India, India) are of small to medium size, they operate in international waters; and those of SSL (i.e. Shreyas Shipping Limited, India), are feeder vessels. In the world transportation market, the orders placed for new container ships are expected to increase the global capacity by sixty per cent over the next five years or less.

5.2 The shipbuilding market for container ships is highly competitive. It is mainly because the major shipyards in this category are from China and South Korean; and they operate in a very competitive environment. Therefore, it is difficult for any new shipyard (i.e. for example a private sector Indian shipyard) to enter in the shipbuilding market for container ships. A possible approach to gain entry into the shipbuilding market for container ships is to explore the market for feeder vessels (i.e. around 400 – 700 TEU), and after that to move up in the value chain for the bigger container ships. Since, the labor cost is low (i.e. estimated labor costs, in India = 1192.00 $ US, and in South Korea = 10743.00 $ US per year [1]), in India, and the limited technical expertise presently available with Indian shipyards and design organizations suitable only for the design of smaller container ships; so it will be easier for an Indian shipyard to explore and enter into the market and get an order for a feeder vessel. A possible approach to gain entry into the shipbuilding market for container ships is to explore the market for feeder vessels (i.e. around 400 – 700 TEU), and after that to move up in the value chain for the bigger container ships. Since, the labor cost is low in India, and the limited technical expertise presently available with Indian shipyards and design organizations suitable only for the design of smaller container ships; so it will be easier for an Indian shipyard to explore and enter into the market and get an order for a feeder vessel. It is our firm belief that in the larger interests of Indian economy India needs to utilize its maritime resources efficiently and economically. Apart from shipping which mainly contributes to the economic and efficient transport thereby increasing the competitiveness of Indian industries, additionally Indian shipyards too need to explore their role in shipbuilding. At a fundamental level India has the infrastructural capabilities (i.e. reliable network of sub-contractors and vendors to supply materials and human resources, integrable supply chains of manufacturing, skilled workforce, expertise in basic sciences and engineering, infrastructure of logistics and connectivity); so India can gain entry on the map of the world of shipbuilding. The demand forecast of Indian container traffic for the Indian shipyard means that now it has the opportunity to explore and enter the container ship building market with a competitive design. Additionally, there is a strong demand (i.e. arising because of tonnage replacement, tankers for domestic supplies in growing Asian economies like China, Japan, and India, and very large to ultra large container ships for economies of scale) of new ships and this poses a extremely favorable situation to the Indian shipyards to attract new orders for shipbuilding.

## 6. Markets in Ship Conversion Products

6.1 A new shipyard which is planning to increase its business and technical expertise needs to explore not only the shipbuilding market of new constructions but also the market for ship repairs and conversions. Since, it is desired to have a improved bottom-line profit and technical expertise first before exploring the market for high profit margin ships (i.e. very large or ultra large container ships, very large crude oil tankers, passenger ships, LNG/LPG carrier ships, and chemical carrier ships), so it will make a sound strategy to enter and gain access into low profit oriented but technical skills enhancing emerging market of ship repairs and conversions.

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(a) **Case Study 1:** A private sector shipyard in a developing country (i.e. for example India) which specializes in building supply and support ships (i.e. side loader container ships, bollard pull tugs, and mini bulk carrier ships) decides to explore the new emerging markets.

## 7. Discussion

7.1 Within the bounds of technical constraints of infrastructure, equipment and technology which are available at the shipyard, technically the shipyard can offer some comprehensive repair, overhauling and conversion services (i.e. jumboising, ship conversion, refurbishment, modernization, upgradation, retrofitting and rebuilding). And, recently, since the new researches have shown the hazardous environmental effects of ocean going ships, so the norms and regulations have been made stricter (i.e. for example new EU maritime safety regulations like "Erika" and "Prestige" have come into force; and new design rules for bulk carriers that demand strengthening of certain parts of the steel structure for ships contracted after 1st July 2003, which leads to an estimated increase of 3 - 6% in steel weight); and with time these will become ever more strict and their enforcement rigid. Therefore, clearly there is an emerging and growing market for ship repairs and conversions. The major opportunities are in the areas of conversion of tankers to FSO/FPSO and upgradation; tankers, cargo vessels, and reefer ships into livestock carriers, and expanding capacities of livestock carriers; whaling factory ships into fish cannery vessels; lay barges into derrick barge; drill ships into a drilling tenders; ore carrier ships into a drill ships; cargo ships to offshore supply ships; and ore bulk carriers to self unloading ships. The minor opportunities are in the areas of conversion of propulsion systems (i.e. for example change of propulsion system of drill ships from steam to diesel, and change of marine diesel-burning main engines into residual fuel systems etc.) and installation of heavy lift deck cranes, and heli deck etc., as desired on the ships. The shipyard will take some of the opportunities from the major and minor opportunities that are mentioned which will be compatible with its technical expertise and infrastructure.

## 8. Conclusions

8.1 We presented an analysis of the shipbuilding and identify new emerging markets in shipbuilding markets for India. Some of the challenges listed above are being currently being investigated by us. We hope and believe that one fine day India will achieve its potential through an efficient development of the 'Defense, Industrial, Public and Private Partnership (DIPPP)' and our industrial bases will be comparable with China, Korea and Japan and our defense products will be Designed in India and Made in India. Hopes die hard in a democracy, more so in a functional democracy.

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# STANDARDISATION IN SHIPBUILDING

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**1. Abstract**

1.1 Adoption of standards helps in establishing long term development plans based on accumulated knowledge and experience in design, construction, operation, maintenance and recycling of marine structures including commercial ships, warships and offshore structures. Standardisation helps in implementing cost control measures of these operations. Since these operations involve multiple agencies, a common set of standards which are universally acceptable are imperative for effective implementation throughout the life cycle of the structure. Different standards used in shipbuilding and an introduction to different methods of works breakdown structure for through life operations are discussed.

**2. Keywords**

2.1 Standards, standardisation goals, SWBS, SFI

**3. Introduction**

3.1 Shipbuilding standards include specifications for procedures for design, fabrication, installation, parts, sub-assemblies/ assemblies, testing and inspection, work processes, documentation of work instruction methods, training materials and administrative forms, formats, planning charts, presentation aids, etc. Shipbuilding standards provide guidelines for the industry to establish long range development plans based on the knowledge and experience on standardisation procedures. Standardisation will have a favourable effect on the cost of construction, operation, maintenance, recycling etc. The basic goals and objectives of developing shipbuilding standards are the following:-

(a) Reduction in design and engineering cycle time costs

(b) Reduction in manufacturing lead times for critical materials

(c) Implementation of outfit unit construction

(d) Development of automation in the industry

(e) Accurate control concepts.

**4. Necessity for Standards in Shipbuilding**

4.1 The major sources of standards used in shipbuilding are the classification societies and the regulatory bodies. Properly developed and technically valid standards help in retaining expertise that has been acquired by the shipyard through experience. By capturing this experience in documented standards, a shipyard can gain significant productivity benefits without re-inventing the best way to do jobs every time a key employee leaves the yard.

4.2 Standards are beneficial for communication. When a standards program is functioning properly, the yard is assured that the same message is communicated at all levels with lower chances for misinterpretation. The use of standards can have significant communication benefits for the purchase department who deal with suppliers on a daily basis.

4.3 The implementation of standards can contribute directly to improvements in quality throughout the shipyard. Indeed, it may be very difficult to achieve quality improvements in many areas without first implementing a Standards Program. For example, welding process standards and certification standards for welders are extremely essential for the welds to pass a quality inspection. Many management systems cannot function effectively without some system of standards for performance planning and measurement.

4.4 An effective Standards Program is essential for cost control, as well as to quality assurance. A well thought out standard method of accomplishing a task, if practiced consistently, will contribute significantly to being successful the first time, and to being able to improve the process with repetition, which ultimately leads to the lowest possible cost of consistently producing a product that meets the specified quality and performance requirements.

4.5 Standards should be a result of conscious decisions made by the organisational management, and not developed piece-meal as a collection of unrelated decisions made at various times by various personnel with disparate philosophies and vested interests.

**5. Types of Shipyard Standards**

5.1 Shipbuilding standards can be classified in many methods because they can include specifications for parts, sub-assemblies and assemblies, procedures for design, fabrication, installation, testing and inspection, documentation of work instruction methods, work processes, training materials, administrative forms, formats, planning charts, presentation aids, etc. The major shipyard standards are as follows:-

(a) Based on level of implementation

(i) International standards - These are standards enforced by government rules/ regulations. Standards interrelated to international standards, rules/ regulations (ISO, IMO, IACS, Defence Standards etc.) and/ or owner's regulations. Examples are units, codes, lifesaving equipment, fire appliances, anchors, valves, etc.

(ii) National/ Industry-wide voluntary standards - These are standards established by private organizations accepted by the industry (ASTM, SNAME, SSC, etc.) Examples include design criteria/ specifications, fittings, equipment, quality, testing/ inspection, performance etc.

(iii) Organisational in-house standards are the ones established by individual companies to meet company's peculiar requirements. Example design/ engineering, production, testing/ inspection, materials, modules, manuals, etc.

(b) Based on functions

(i) Products standards - These are for basic fittings, equipment, etc., commonly used in ship's systems. (Examples - anchors, doors, pipe joints, lighting fixtures etc.).

(ii) Design/ engineering standards - These are standards for design criteria, specifications etc. for ship's systems. (Examples - standard specifications, calculation forms, analysis methods, etc.).

(iii) Functional performance standards include standard specifications for machinery and equipment, materials, components etc. (Examples - standard performance specs for life boats, navigation equipment, pumps, generators, switchboards, valves, paints, etc.).

(iv) Testing/ inspection standards - Testing/ inspection processes, acceptance levels, etc. are in this category. (Example - standard protocols of sea trials, systems, standards for surface treatment and painting, etc.).

(v) Production process standards cover construction methods, outfitting methods, welding processes, etc. (Examples - standard processes for hull construction, pipe fabrication, shaft alignment, etc.).

(vi) Accuracy/ tolerance standards describe acceptance level of accuracy tolerance in production. (Examples - accuracy of hull structure, pipe joints, shaft alignment, etc.).

(vii) Material and Equipment Standards. Standard material items/ equipment are direct results of standard design details which should be used in every case, wherever applicable. Examples include threaded fasteners, electrical components, motors, controllers, cable etc.

**6. Steps Involved in Standardisation**

The major steps involved in a standardisation process are the following: -

(a) Conduct a background survey of the shipbuilding industry to investigate their needs for Standardisation.

(b) Categorize standards by their influence to the industry (i.e., national, industry, company levels) and by their Functions (i.e., products, design/ engineering, performance, Testing/ inspection, production, accuracy standards)

(c) Organize and categorize standards items in a form of a "tree structure".

(d) Select and prioritize standards items from the "tree structure", and classify into short-term, mid-term, long term goals.

**7. Standardisation Goals**

7.1 Direct primary emphasis is possible at short term priority goals to achieve maximum benefits. Secondary emphasis is on development of mid-term (5-7) years and long-term (l0-20 years) goals to serve as planning guidelines for ongoing and future efforts. Standardisation goals for a shipbuilding project hence are broadly classified as short term, mid-term and long-term, as indicated below.

(a) Short-term goals: These goals, extend 2-3 years, and comprise of the following standards.

(i) Products standards

(ii) Functional performance standards

(iii) Short term design/ engineering standards

(b) Mid-term goals extent from 5 to 7 years, and have the following components.

(i) Long-time design/engineering standards

(ii) Basic testing/inspection standards

(iii) Basic production process standards

(c) Long-term goals extent from 10-20 years, and they consist of the following standards.

(i) Long term design/ engineering standards

(ii) Long term testing/ inspection standards

(iii) Long term production process standards

(iv) Accuracy/ tolerance standards

**8. Standards for Shipbuilding Project Management**

8.1 Multiple agencies are involved in the design, construction, operation, maintenance and recycling of ships (both commercial ships and naval ships) and offshore structures. These agencies normally have their own organizational standards. It is essential to have a common set of basic standards acceptable to all agencies for effective project management and cost reduction.

8.2 Standards for managing a complex project like shipbuilding or ship operation/ maintenance etc. is by breaking it down into individual components in a hierarchical structure called work breakdown structure, or the WBS, which divides the work in a logical way into manageable pieces. During the life cycle of a ship from concept design till recycling, information must be exchanged within an organization and between organizations. A standard system is essential for such information flow. Commonly used standard systems, both for commercial ships and warships are explained here.

**9. Commercial Ships**

9.1 The SFI group system was developed at the Norwegian Ship Research Institute (Senter for Forskningsdrevet Innovasjon - SFI), now known as MARINTEK. The SFI Group System is a classification system for technical and cost information of merchant ships and offshore structures. The SFI Group System was developed as functionally oriented in 1972. The basic criteria for designing the SFI Group System were global applicability for users and different types of ships and offshore structures, capability for future expansion and simplicity. The SFI Group System is based on a logical specification for accurately collecting direct costs during the various phases, and for organizing the return costs for estimating the cost of similar design, planning and production that can easily be used for ships in the future.

9.2 The SFI Group System is built up as a three-digit decimal classification system with ten main groups at the highest level. At this time only eight main groups are in use. Each of the main groups (one digit numbers) consist of ten groups (two digit numbers) and each group is further subdivided into ten subgroups (three digit numbers). The main groups are used as follows: -

(a) Ship General - Includes costs which cannot be charged to any specific function onboard like launching, trial trips, guarantee work etc.

(b) Hull - Includes hull and superstructure as well as cleaning and painting of the ship.

(c) Equipment for Cargo - Includes equipment and systems related to the ship's cargo, such as hatches, cargo winches, cargo pumps and piping.

(d) Ship Equipment - Equipment and systems which are peculiar to ships, like navigation equipment, anchoring equipment. It also includes fishing equipment and weapon systems along with other working equipment for special types of ships.

(e) Equipment for Crew and Passengers - Equipment and systems for crew and passengers, such as furniture, elevators etc.

(f) Machinery Main Components - Primary components in the engine room, such as main engine, auxiliary engines etc.

(g) Systems for Machinery Main Components - Main propulsion systems, such as fuel and lube oil systems, starting air system, exhaust systems.

(h) Ship Systems Comprises auxiliary systems - Bilge and ballast systems, fire fighting and wash down systems, electrical distribution systems.

(j) Special systems

9.3 With its flexibility and functional orientation, the SFI Group System can be used for any shipyard classification problem. It can be used consistently in areas like indexing of specifications, drawing identification, purchase requisition and order numbering, work package identification, labour and material cost collection, test agenda identification, technical manual identification, recommended spare parts list identification, estimating, guarantee work identification, general filing index etc. After several years of use, the information retrieval capabilities of the shipyard are greatly enhanced.

**10. Warships**

10.1 The initial efforts for standardisation of groups of naval ships were chronicled in the document 'Classification of Group Weights for HM Ships (Excluding Submarines)', where 8 groups were defined such as Hull, Protection, Equipment, Armament, Machinery, Aircraft equipment, Fuel and Feed water. Each group is subdivided into subgroups, and a major factor that is not in favour of standardisation in this scheme is an element called incidentals which appears for equipment, armament, machinery, fuel and aircraft equipment groups. A clear definition of incidentals is not available, and it leaves a certain extent of uncertainty for standardisation efforts.

10.2 Classification of Group Weights for HM Ships was conceived in the era of ships with armoured protection and steam propulsion systems, and is almost obsolete now. Ship Work Breakdown Structure (SWBS) was promulgated by the US Navy/ NATO as a standardised structure used to value, design, and understand a ship. A general description of SWBS which does not include aspects like crew, operating and support costs, training, technical packages etc. is indicated as follows.

(a) Group 100 covers general hull structure, which is the backbone of the ship, providing the shell for which the rest of the ship fits into.

(b) Group 200 is the elements of propulsion plant, including conventional combustion engine, nuclear propulsion, or a combination of multiple systems.

(c) Group 300 covers the general electric plant that provides power to all the systems in the ship such as lighting, air conditioning, combat systems, backup generators etc.

(d) Group 400 is for command and surveillance system which allows communication both within the ship and to outside sources.

(e) Group 500 covers the auxiliary system, providing air conditioning, fresh water, heat, fuel and lubrication, and ship control.

(f) Group 600 includes the outfit and furnishings like paint, living spaces, working spaces, stowage, and special purpose areas of a ship.

(g) Group 700 is the armament systems that provide offensive and defensive capabilities in a ship, including missiles, guns, rockets, etc.

(h) Group 800 deals with Integration and Engineering and includes elements like ship drawings, 3D models, quality assurance, certification standards, facilities, and training.

(j) Group 900 deals with Ship Assembly and Support Services and covers all the dockside services that are required to build a ship and ensure it is sea worthy, including scaffolding, insurance, launching, sea trials, and other elements.

Groups 800 and 900 are for items which are not integral parts of the ship.

**11. Conclusion**

11.1 Setting standards for material, machinery, and components reduces the costs of construction, operation, maintenance and recycling of ships (both commercial and naval) and offshore structures.

Multiple agencies are involved in the above phases, and each of them can have their own organizational standards. However, it is imperative to have a common set of basic standards acceptable to all agencies for effective project management and cost reduction. SFI and SWBS systems are ideal for cost reduction in the respective fields.

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# MATLAB CODE FOR SELECTION OF DOUBLE-STAGE RAFT MARINE ENGINE MOUNT

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**1. Abstract**

1.1 Stealth characteristics of a naval ship involves a reduction of its vibration and hence noise signatures. One of the methods used for the reduction of structure-borne noise of ships is by provisioning of mounts for all engines between the engine bed and the hull girders. Design of two-stage raft mountings is an ongoing research in NSTL, Vishakapatnam, which has successfully undertaken the fitment of a two-stage mount for an HP air compressor and a significant vibration reduction of 25db was achieved. This article aims at the development of a MATLAB based algorithm to facilitate the selection of double stage engine mounts for a given engine operating at a specific rpm. The algorithm aims to analyze the effects of changes in various system parameters like stiffness and damping on the dynamic response of the two-degree system and then optimizing the parameters of the mounts based on the system of discrete modelling. In this MATLAB code, the user will be required to provide the known parameters of the engine and the raft foundation of the marine engine mount. The code will be used to optimize the vibration levels and help the designer to select suitable mounts and mass of raft. This analysis will predict the response of marine engine vibration when it will get mounted on a double stage isolation system.

**2. Introduction**

2.1 An engine is a large concentration of mass in a ship, and if it is not adequately constrained and isolated, it will cause vibrations that are transmitted to the whole body of the ship and beyond. These transmitted vibrations can resonate with the natural frequencies of different components of the ship leading to unsatisfactory vibration conditions. The need to mitigate this is further increased in naval ships, which also require to avoid detection or identification by the enemy. [1]

2.2 An engine is subjected to various vibratory disturbances some external and others internal to it. Marine diesel engines are supported by anti-vibration mounts designed for the following [2]:-

(i) Isolation of all excitations caused due to rotation unbalances in the engine, transmission and engine mounted components.

(ii) Support the static weight of the engine and provide both structural rigidity of the engine to maintain alignment of various shafts and pipes connected to the engine and to minimise transmission of the vibrations generated from the engine to the vessel and beyond.

(iii) Resist strong dynamic force caused by wave slap, cornering loads and docking impact.

2.3 The usage of anti-vibration mounts to reduce the ship radiated noise and machinery vibration levels has been in vogue for many years; however, they have been found to be inadequate to achieve the desired stealth characteristics in case of naval ships and luxury watercraft. Hence, in the case of warships, where isolation of vibrations is of much greater importance to its operational capability engine foundations are usually designed as a double stage foundation.

**3. Double-Stage Foundation System**

3.1 In a double stage foundation system, the marine engine is placed on an upper stage of mounts which is supported by a single plate-like structure (raft) which in turn is connected to the hull girder of the ship using a lower set of mounts as seen in Fig. 1.

**Fig. 1: Double Stage Raft foundation for Marine Engine [3]**

3.2 The hull girder may be treated as the fixed support. Thus the engine mount foundation system can be modelled as a two-degree freedom system with certain assumptions. A two-stage mounting system (raft mounting) is employed where there is a demand for high structure-borne noise attenuation. The main objective of a two-stage mounting system is to reduce vibration levels from machinery to foundation, and thereby to radiate noise levels from ship hull.

**4. Features of a Double-Stage Engine Mount**

4.1 The features of a double stage engine mount can be listed as advantages and disadvantages [3].

***Advantages:-***

(a) Highly effective in the reduction of vibration transmission at very high frequencies.

(b) Improves broad frequency vibration isolation.

***Disadvantages:-***

(a) Low-frequency vibration and transmission attenuation are similar to single mounted isolation systems.

(b) Isolated machinery motion in response to perturbation forces is similar to one-degree mounting systems.

4.2 The challenge for the designer is the selection of vibration isolators and suitable raft size, to ensure the following:-

(a) Static deflection of isolators is within prescribed limits.

(b) Minimum transmission of structure-borne noise into water

(c) Shifting of the natural frequency of the system away from undesired frequencies.

(d) Dynamic amplitudes of engine and raft mounts are within prescribed limits.

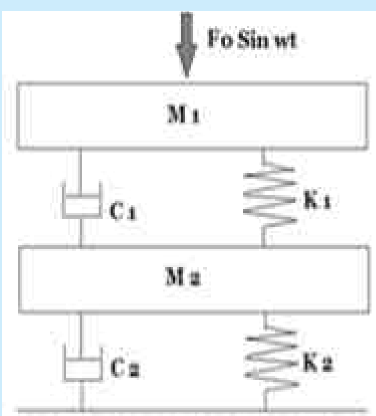
4.3 Thus, the different parameters which affect the dynamic response of an engine and its foundation system are the nature and magnitude of excitation forces, excitation frequency, mass of the engine and foundation, stiffness and damping properties of vibration isolators and so on. The aim of this paper is to enable the designer to predict the dynamic performance of a double stage foundation and then optimize its parameters if necessary.

## 5. Mathematical Modelling and Analysis

5.1 To generate the mathematical model of an engine positioned on a two-stage raft mount system, as the derivation of dynamic equations becomes difficult when the degrees of freedom are increased, it is assumed that all bodies are rigid, all vibration motion is small, and only isolators have damping. The vertical vibrations of the system are assumed to be most predominant. The other types of vibrations like rocking or transverse type of vibrations are assumed to negligible. The excitation force to analyse the forced vibrations was assumed to be harmonic in nature.

5.2 The modelling of a double-stage engine mount positioned on a hull girder system with the above-mentioned assumptions is as shown in Fig. 2. Upper and lower level mounts are considered to be made of a number of springs and dashpots in parallel and for the sake of analysis, their equivalent stiffness and damping coefficients are considered.

**Fig. 2: Mathematical Model for the System [2]**




| | | |
|---|---|---|
| Mass of engine | - | $M_1$ |
| Mass of raft | - | $M_2$ |
| Stiffness of upper-level mounts | - | $K_1$ |
| Stiffness of lower level mounts | - | $K_2$ |
| Damping coefficient of upper-level mount | - | $C_1$ |
| Damping coefficient of lower level mount | - | $C_2$ |
| Harmonic Excitation Force (Assumed) | - | $F_0 \sin \omega t$ |

Based on the mathematical model developed for the system, the 2D free body diagrams of the force and motion transmissibility are as shown in Fig. 3(a) and 3(b) respectively.

**Figure 3 (a) : Force Transmissibility**

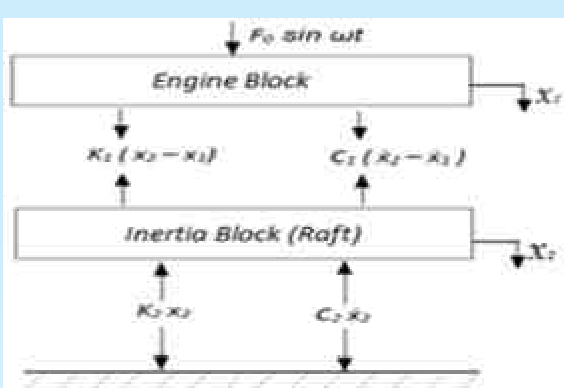
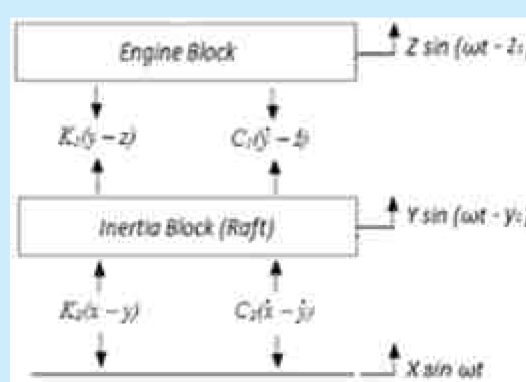



**Figure 3(b): Motion Transmissibility [3]**



## 6. Static Deflection

6.1 The static displacement amplitudes of the model can be calculated using:-

(a) Static Deflection of Raft - X s t ( r a ft )

$$Xst(raft) = (M1 + M2)\,g / K2 \quad ...(1)$$

(b) Additional static deflection for engine - X s t ( e n g i n e )

$$Xst(engine) = M1\,g / K \quad ...(2)$$

## 7. Free Damped Vibrations

7.1 The free damped vibrations of the system neglecting the excitation force are as follows:-

(a) $M_1 \quad _1 - C1\,( \quad _2 - \quad _1) - K_1\,(x_2 - x_1). = 0$ ...(3)

(b) $M_2 \quad _2 + C1\,( \quad _2 - \quad _1) + K_1\,(x_2 - x_1) + C_2 \quad _2 + K_2 x_2 = 0$ ...(4)

7.2 These equations are coupled second-order homogeneous equations of motions. The solution of the same can be generated as follows:-

$x_1 = e^{-rt}\{P_1 \sin(dt + \quad _1)\} + e^{-ut}\{Q_1 \sin(vt + \quad _2)\}$ ...(5)

$x_2 = e^{-rt}\{P_2 \sin(dt + \quad _1)\} + e^{-ut}\{Q2 \sin(vt + \quad _2)\}$ ...(6)

7.3 The values of constants P1, P2, Q1, Q2, 1, 2 are dependent on the initial conditions. These vibrations are a transient type of vibrations that die out in a very short time and hence can be neglected. They are neglected in the case of forced vibrations also, wherein the deflections are segregated as complementary function and particular integral.

## 8. Forced Damped Vibrations

8.1 The analysis is undertaken for forced vibration assuming a harmonic excitation force F0 sin ωt. This results in steady-state vibration. The dynamic amplitudes of engine bed and raft at various frequencies can be calculated using the following equations of motions:-

(a) $M_1 \quad _1 - C_1\,( \quad _2 - \quad _1) - K_1\,(x_2 - x_1) = Im\{F_0 e^{i\omega t}\}$ ...(7)

(b) $M_2 \quad _2 + C_1\,( \quad _2 - \quad _1) + K_1\,(x_2 - x_1) + C_2 \quad _2 + K_2 x_2 = 0$ ...(8)

8.2 Assuming damping is negligible and the solution to be represented by $x_1 = X_1 e^{i\omega t}$ and $x_2 = X_2 e^{i\omega t}$. The equations can be solved to obtain the final deflection in the form of:-

$x = x_{cf} + x_{pi}$ ... ( 9 )

here,

$x_{cf}$ = Complimentary function (Free vibration condition) which die out in a short time and can be neglected

$x_{pi}$ = Particular Integral

8.3 The steady-state motion of the two masses (Engine and Raft) are given by:-

$x_1 = X_1 \sin(\omega t - \Psi_1)$ ...(10)

$x_2 = X_2 \sin(\omega t - \Psi_2)$ ...(11)

where $X_1$ and $X_2$ are dynamic amplitudes of engine and raft. $\Psi_1$ and $\Psi_2$ depend on initial conditions.

## 9. Force Transmissibility

9.1 The force transmitted to the foundation in case of a double-stage foundation can be written as:-

$F_{tr2} = [ (K_2 X_2)^2 + (C_2 \omega X_2)^2]^{(1/2)}$ ...(12)

Force transmissibility for double stage foundation is $F_{tr2} / F_0$ ...(13)

## 10. Displacement Transmissibility

10.1 When the hull girder is excited by a sinusoidal displacement of x = Xsin(ωt) as shown in the free-body diagram of the system (Displacement Transmissibility) Fig 3(b)

Raft response is $y = Y \sin(\omega t - y_1)$ ...(14)

Engine response is $z = Z \sin(\omega t - z_1)$ ...(15)

where, Y and Z are amplitudes of bounce of raft and engine respectively

10.2 The motion of the engine bounce and raft bounce and their corresponding motion transmissibility are defined based on the equilibrium of forces at mass m1 (Engine Mass) and mass m2 (Raft Mass). The equilibrium of forces at m1 and m2 can be indicated by the force polygons indicated in Fig. 4(a) and Fig. 4(b) respectively [3].

**Fig. 4 (a): Equilibrium of forces at mass $m_1$**

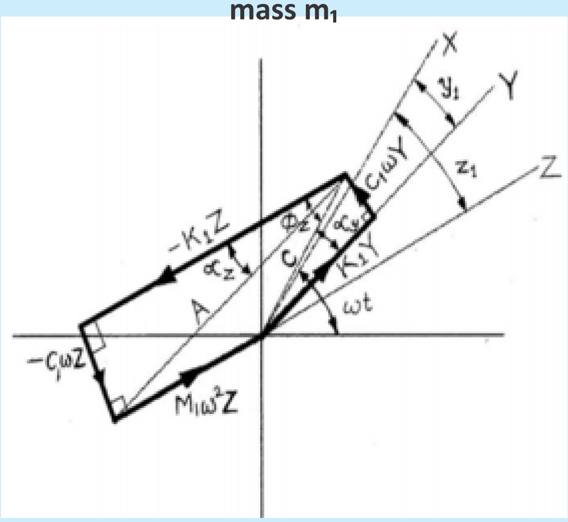
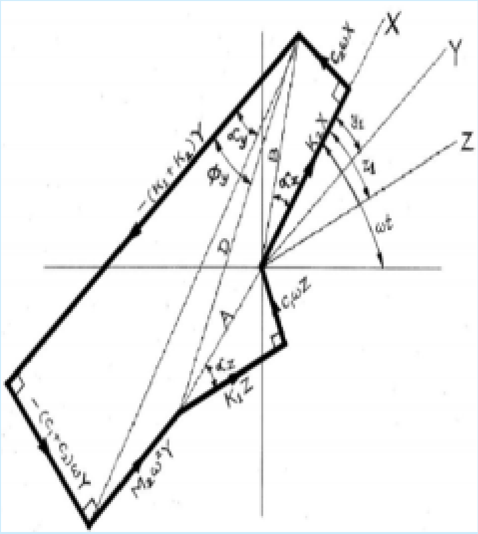



**Fig. 4 (b): Equilibrium of forces at mass $m_2$**




The following terms are defined regarding Fig. 4(a) and Fig. 4(b).

(a) Φz = tan-1(C1 ω / (K1 - M1 ω2))

(b) Φy = tan-1((C1 + C2) ω / (K1 + K2 - M2 ω2))

(c) αx = tan-1(C2 ω / K2)

(d) αy = αz = tan-1 (C1 ω / K1)

(e) A = {K12 + (C1 ω) 2}(1/2) Z

(f) B = {K22 + (C2ω) 2 }(1/2) X

(g) C = {(K1 - M1 ω2) 2+ (C1 ω) 2}(1/2) Z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(h) $D = \{(K1 + K2 - M2\,\omega 2)\,2 + [(C1 + C2)\,\omega]\,2\}(1/2)\ Y$

(k) $E = \mathrm{Cos}\,(\Phi y + \Phi z - 2\,\alpha y)$

10.3 Engine bounce, raft bounce and motion transmissibility of engine bounce and raft bounce can be shown as follows:-

Raft bounce $(Y/X) = BC/\{(CD)^2 + A^4 - 2A^2CDE\}^{1/2}$ ... (16)

where Y is Raft Bounce amplitude

Engine bounce $(Z/X) = AB/\{(CD)^2 + A^4 - 2A^2CDE\}^{1/2}$ ... (17)

where Z is Engine bounce amplitude

10.4 When the effect of damping is neglected as assumed in case of forced damped vibrations. The motion transmissibility for the engine and raft are as shown:-

Raft bounce $(Y/X) = K_2(K_1 - M_1\,\omega^2) / \{K_1 K_2 - (K_1 M_1 + M_1 [K_1 + K_2])\omega^2 + M_1M_2\omega^4\}$ ... (18)

Engine bounce $(Z/X) = K_1K_2 / \{K_1K_2 - (K_1M_1 + M_1[K_1 + K_2])\omega^2 + M_1M_2\omega^4\}$ ...(19)

**11. Sensitivity Analysis**

11.1 The parameters which affect the deflection of diesel engine and its foundation system are the mass of the engine and foundation, stiffness and damping coefficients of the mounts used and the nature and magnitude of excitation forces. Therefore, the selection of a suitable engine mount involves solving these equations for different possibilities. The process is laborious and repetitive in nature. Hence, the development of a MATLAB based algorithm for solving the equations for different possibilities of the raft mass, and different stiffness and damping coefficients for the upper and lower mounts to arrive at an optimum double stage engine mount combination for a given engine was considered to be an effective solution.

11.2 The vibration mounts suitable for an engine along with the raft can be determined by undertaking a parametric analysis using different combinations of damping and stiffness coefficients to minimize the transmitted vertical vibration to minimize deflection and transmitted noise.

**12. Problem Statement**

12.1 The algorithm was initially developed for an arbitrary case of selection of a double-stage mount for an engine of mass M1 = 5000 kg, constant rpm N = 500 rpm and excitation force $F_0 = 90000$ N.

12.2 The problem has 05 unknowns, which can be modified independently to optimize the solution. To simplify the situation the algorithm was developed sequentially in which 04 of the 05 unknowns are assumed arbitrarily and the best possible value of the fifth unknown is identified wherein a convergence is observed in values of the following:-

(a) Dynamic Amplitude of Engine ($X_1$)

(b) Dynamic Amplitude of Raft ($X_2$)

(c) Force Transmissibility ($F_{tr2}/F_0$)

(d) Raft Bounce (Y/X)

(e) Engine Bounce (Z/X)

**Step - 1**. Assume,

(a) Upper mount stiffness coefficient ($K_1$) = 3000 N/m

(b) Upper mount Damping Coefficient ($C_1$) = 300 N-sec/m

(c) Lower mount stiffness coefficient ($K_2$) = 2000 N/m

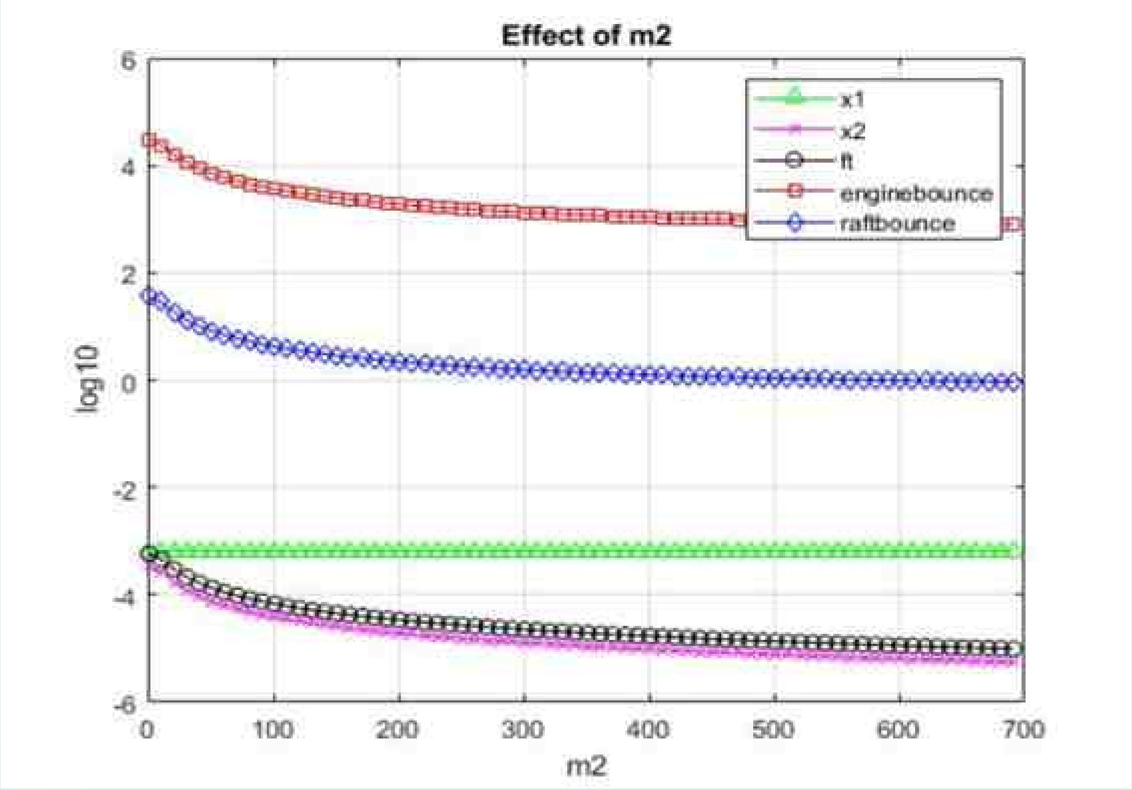
(d) Lower mount damping coefficient ($C_2$) = 300 N-sec/m

The values of $C_1$ and $C_2$ were assumed from values available for DMR VULKAN class dampers, while the values of $K_1$ and $K_2$ were assumed arbitrarily.

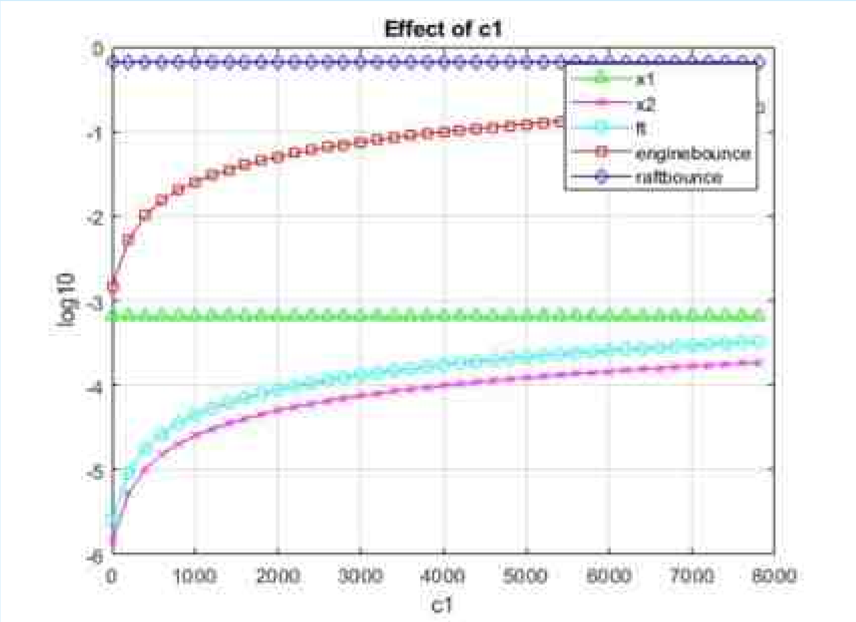
The equations of forced vibrations assuming a harmonic excitation force and neglecting damping effects were performed and the results are as shown in Fig 5. It was observed that the effect of raft mass on the amplitudes of vibrations and engine and raft bounce parameters is minimal after about 500kgs. Any further, increase in raft mass is not considered economical and hence the raft mass (M2) is optimized at 500kgs.

**Step - 2**. In the next step, the raft mass was assumed as the optimized value of $M_2$ = 500kgs and the remaining arbitrary values are kept unchanged except the upper mount damping coefficient ($C_1$). Thus the optimum value of the upper mount damping coefficient ($C_1$) was identified based on the convergence of dynamic amplitude of engine ($X_1$) and raft bounce which are a straight line, Fig 6. Hence, the upper mount damping coefficient ($C_1$) was optimized at 300 N-sec/m.

**Fig. 5: Effect of Raft Mass on the system response**

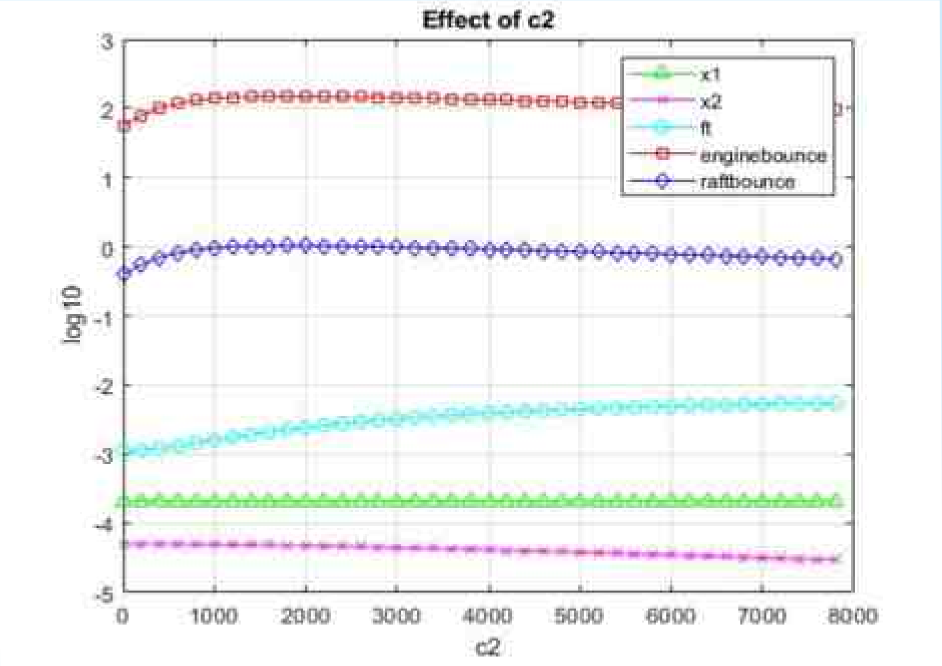


### Fig. 6: Effect of Upper Mount Damping on the system response




**Step - 3**. In this step the values of raft mass ($M_2$) is assumed as 500kgs, upper damping coefficient ($C_1$) is assumed as 300 N-sec/m and the values of $K_1$ and $K_2$ are kept at the same arbitrary constant and the optimum value of lower mount damping coefficient ($C_2$) is identified as 300 N-sec/m, since the dynamic amplitude of raft and engine bounce were found to be a straight line.

### Fig. 7: Effect of Lower Mount Damping on the system response




**Step - 4**. Thus the values of raft mass ($M_2$), upper damping coefficient ($C_1$) and lower damping coefficient ($C_2$) were optimized. In this step, the above-optimized values are considered and the lower stiffness coefficient ($K_2$) is optimized.

It was observed that the dynamic amplitude of the engine, the dynamic amplitude of raft, force transmissibility, and engine bounce and raft bounce tend to converge nearly when $K_2$ was approximately at 3.5 MN/m (Optimized value) Fig 8.

**Step - 5**. In this step, the value of the upper mount stiffness coefficient (K1) is optimized to be approximately 3.5 MN/m Fig 9.

**Fig. 8: Effect of Lower Mount Stiffness on the system response**

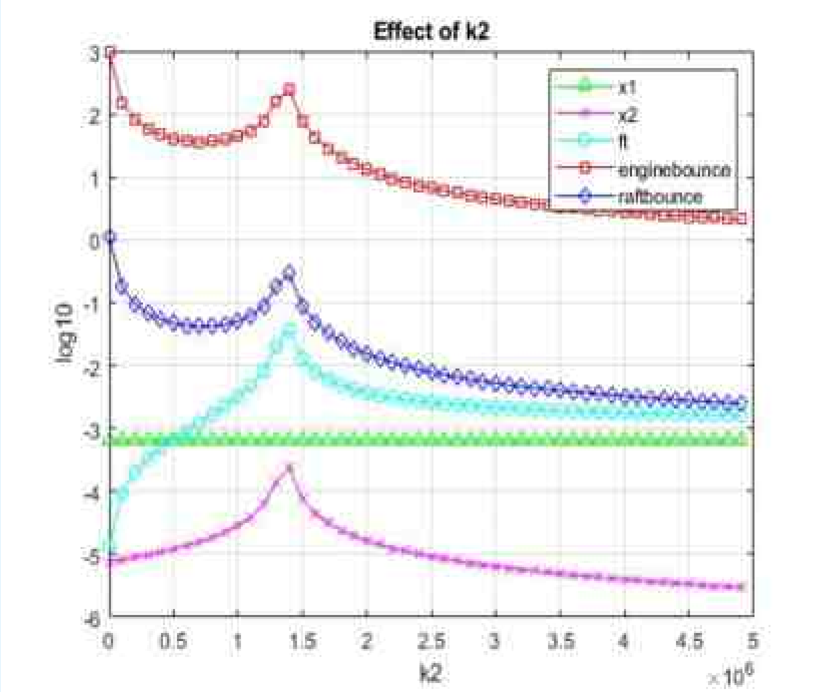
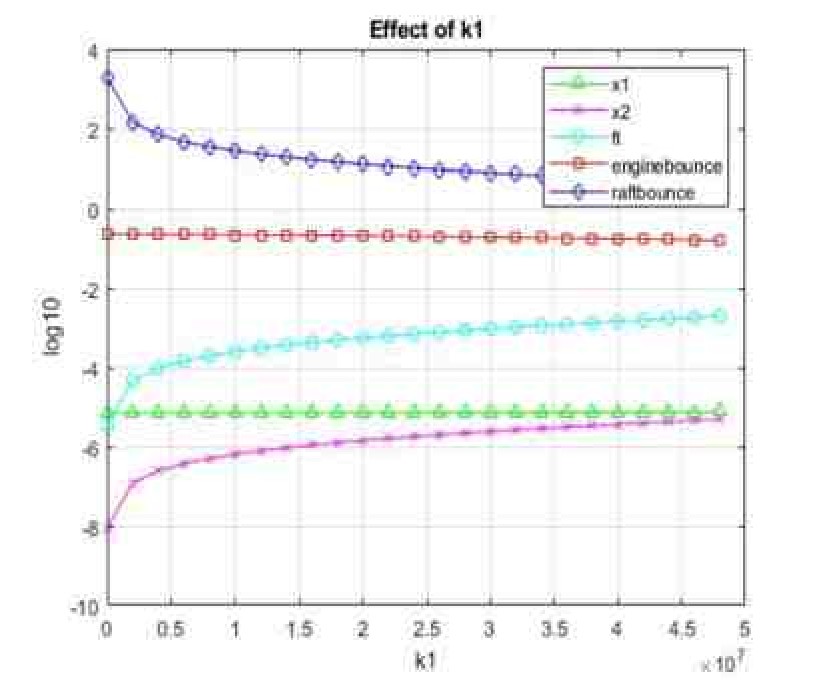



**Fig. 9: Effect of Upper Mount Stiffness on the system response**

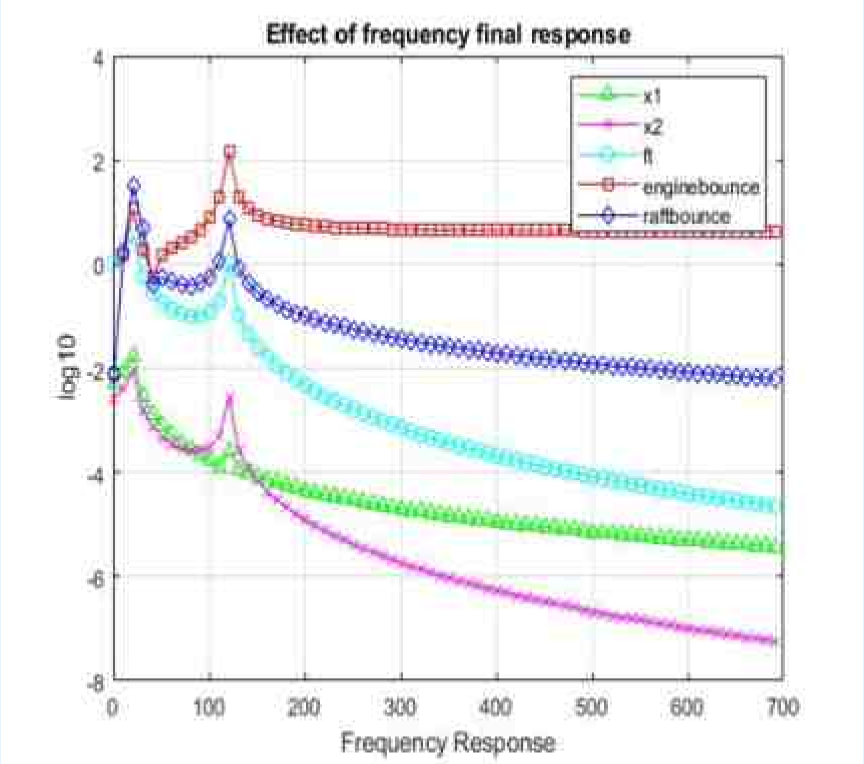


Step - 6. In the final step, the values of the system parameters have been optimized as follows:-

| | | | | | |
|---|---|---|---|---|---|
| (a) | Mass of engine | $M_1$ | - | 5000kgs | **Given** |
| (b) | RPM of engine | N | - | 500rpm | **Given** |
| (c) | Mass of raft | $M_2$ | - | 500kgs | **Optimized** |
| (d) | Upper mount damping coefficient | $C_1$ | - | 300 N-sec/m | **Optimized** |
| (e) | Lower mount damping coefficient | $C_2$ | - | 300 N-sec/m | **Optimized** |
| (f) | Upper mount stiffness coefficient | $K_1$ | - | 3.5 MN/m | **Optimized** |
| (g) | Lower mount stiffness coefficient | $K_2$ | - | 3.5 MN/m | **Optimized** |

The response of the system post-optimization of all the parameters was undertaken by varying the excitation frequency.

**Fig. 10: Response of optimized system with variation in frequency**




The final results obtained can be tabulated as follows:-

| | | | |
|---|---|---|---|
| (a) | Engine bounce (Z/X) | - | 0.307 |
| (b) | Raft bounce (Y/X) | - | 0.894 |
| (c) | Steady state amplitude of engine ($X_1$) | - | 0.07mm |
| (d) | Steady state amplitude of raft ($X_2$) | - | 0.046mm |
| (e) | Force transmissibility ($F_{tr2}/F_0$) | - | 0.176 |
| (f) | Static deflection of raft ($X_{str}$) | - | 14mm |

(g) Static deflection of engine ($X_{eng}$) - 15.4mm

(h) Total Static deflection of engine - 29.4mm

This value of total static deflection of engine achieved needs to be compared to available permissible limits of different types of engine mounts in the market (using Manuals of Shock effects in ships, VII) [4]. In the present case, though the system has been optimized and the final deflection has been obtained as 29.4 mm, it is observed that the deflection is beyond acceptable limits and hence necessitates the requirement of a change in the type of shock mount used for the system.

The final values of total engine deflection, force transmissibility need to be verified with acceptable limits to identify a suitable solution within the available and minimize structure-borne noise in a ship.

## 13. Conclusion

13.1 Based on the mathematical modeling undertaken, a MATLAB based algorithm was developed for the predictive design for a double stage engine foundation system. It can be used to instantly predict the suitability of any system to a given engine. It is further useful in parametric analysis to obtain the values of static deflection of engine, engine and raft bounce, etc. for various possible combinations to select appropriate mounts to conform to the norms set by classification societies.

## 14. Future Scope of Work

14.1 The present article has assumed that the dominant vibrations vertical vibrations and the lateral vibrations and rocking movements have been neglected. Further, both the engine and raft have been considered to be rigid bodies. In further analysis, the consideration of these lateral vibrations and flexibility of the raft can be considered. Further, the advantages of using a double stage engine mount in place of a single-stage mount need to be verified.

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# DEVELOPMENT OF MATLAB BASED CODE FOR DOCKING PLAN OF A SHIP

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**1. Summary**

1.1 Dry-docking is a procedure wherein a ship is moved to dry land for cleaning and inspection of the submerged portions of the ship's hull. The docking plan is used to obtain most of the information needed to plan the dry-docking of the vessel. This article aims to understand the basic methodology in the design of the docking plan of a ship and subsequently develop a MATLAB based tool that can enable the user in the development of a basic two version docking plan for any ship to for docking in a graving dock. The algorithm has catered for various conditions wherein complete details of the ship required to develop a detailed weight curve are not available.

**2. Introduction**

2.1 The drydock is a structured area for construction, repairs and maintenance of vessels. It is essential for maintenance and repair work of ship's hull submerged in seawater for a long time. Dry-docking is traditionally undertaken in two versions to enable access to all the underwater areas of the ship, including areas where the dock blocks will be supporting the ship structure.

2.2 Basin/ Graving docks are large, fixed basins built into the ground at water's edge, separated from the water by a dock gate. Graving docks have been predominantly used for docking of ships around the world due to long service life and ease of maintenance, as compared to other docks.

**Fig. 1: Basin Dock**

2.3 Dry-docking of a ship is a complex phenomenon; some of the important factors during the dry-docking operation are as shown below.

(a) Stability of vessel during dry-docking

(b) Block loading

(c) Position and dimensions of underwater appendages and openings

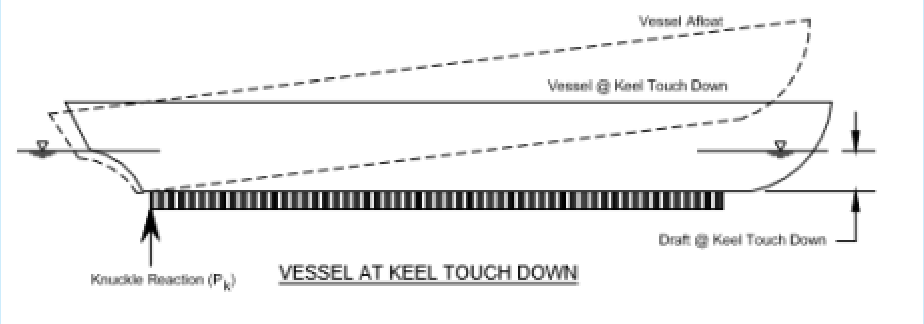
(d) Position and diameter of propeller(s)

## 3. Stability of Vessel During Drydocking (at the time of Keel touch down)

3.1 A vessel is usually in a stable condition when it arrives for dry-docking. Its stability characteristics will change as it sits down on the blocks. The vessel must be firmly cradled by the side blocks before it loses the stabilising effect of the water.

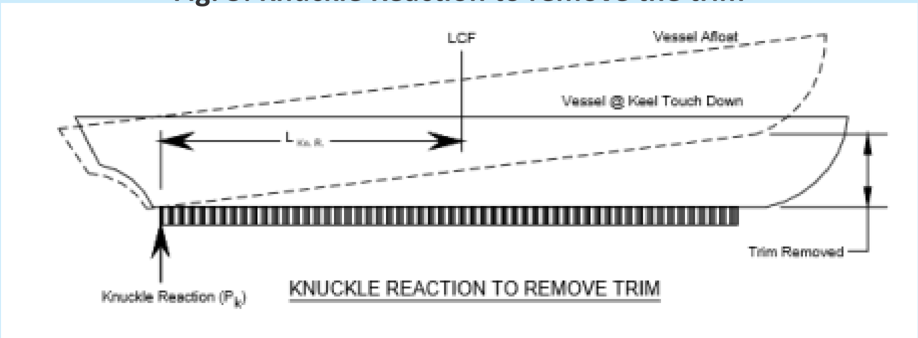
3.2 Generally, a ship enters dock with a trim by the stern relative to the dry dock's keel block line; hence the vessel's skeg/ aft makes the first contact with the blocks.

**Fig. 2: Vessel at keel touch down**




3.3 The first point to touch the blocks in a dry-docking is the skeg. When this happens, a force develops at the skeg (*knuckle reaction*) which rotates the ship until the vessel's keel has made contact with the keel blocks all along its full length, known as the *point of keel touch down* as seen in Fig. 3. The effect on the vessel's vertical centre of gravity (KG) would be the same as the removal of a corresponding weight on the vessel at its keel.

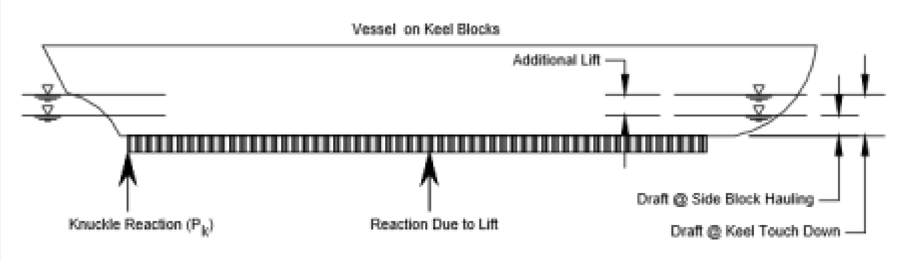
**Fig. 3: Knuckle Reaction to remove the trim**




## 4. Stability of Vessel During Drydocking (at Hauling of Side blocks)

4.1 A vessel when being docked on fixed blocks, is cradled by the side blocks until the keel touches down on the keel track. In a case where the ship is docked using hauling side blocks, the ship must be lifted an additional amount to ensure it is well seated on the keel blocks before side blocks are brought to bear as seen in Fig. 4.

Fig. 4: Lift due to hauling of side blocks




**5. Important Characteristics Required for Drydocking**

5.1 A docking plan of any ship is specific to the dock in which it is intended to be docked. Some important characteristics of the ship and the dock which are essential in the development of a docking plan of a ship are:-

(a) Main dimensions of the dock

(b) Main dimensions of the ship

(c) Strength of Ship's Hull

(d) Load bearing capacity of the dock

(e) Hydrostatic properties of the ship

(i) Displacement

(ii) Longitudinal Centre of Buoyancy (LCB)

(iii) Moment to Change Trim 1 cm

(iv) Tons Per Cm Immersion (TPC)

(v) KB and KM

(f) Zero tide level of the dock

(g) Maximum tide height in the region

(h) Appendage clearances required

**6. Assumptions**

6.1 This article aims to generalise the development procedure of a ship's drydocking plan for graving docks. Some of the assumptions taken in the process are as follows:-

(a) Centreline blocks are loading bearing blocks

(b) Side-blocks are only present for support; their position depends on the position of ship's transverse bulkheads

(c) Loading bearing capacity of the dock block is the main limiting criteria in the separation of the dock blocks.

(d) The size of the dock blocks has been assumed to be uniform.

(e) The height of dock blocks depends on the zero-tide of the dock, the draft of the ship, depth of appendages below the keel etc. It has however not been measured in this algorithm.

## 7. Dock Block Load Calculation

7.1 A dock block acts like a giant spring and will tend to compress under load, depending on the pressure on the block and its modulus of elasticity. Some of the factors affecting the load on a dock block are:-

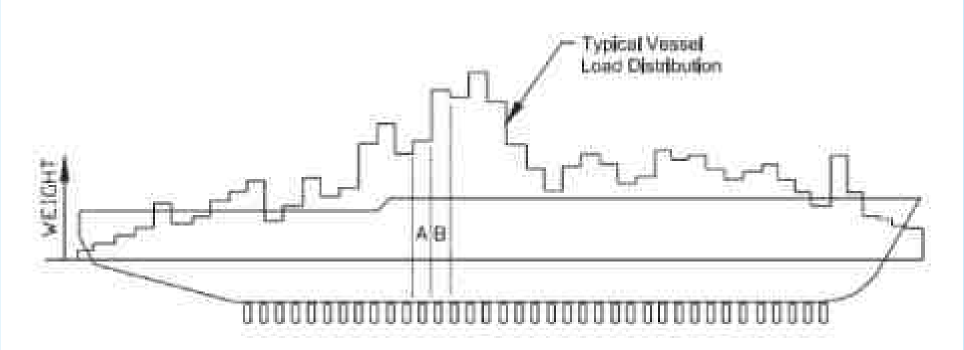
(a) Height of dock block as compared to other blocks

(b) Type of material of the block

(c) Weight and LCG of the ship

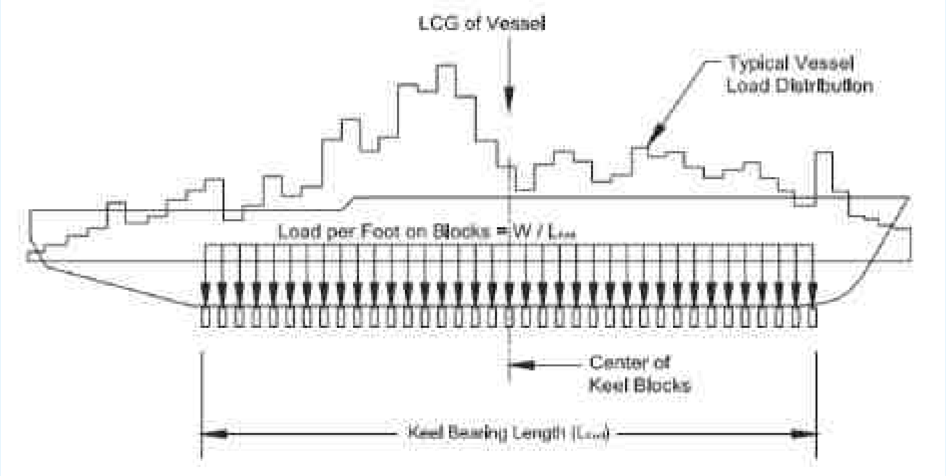
7.2 For this article, it was assumed that all the blocks are of constant height and same material. Thus load on any dock block can be attributed to the weight of the vessel and position of the block under the vessel. The weight distribution of a ship can be indicated as seen in Fig. 5.

**Fig. 5: Weight Distribution of a Ship**




7.3 However, the load on a block cannot be similar to that of the weight distribution as seen in Fig. 6 and needs to be a smooth straight line loading. If the longitudinal centre of gravity of a ship (LCG) is located directly over the centre of the keel line, the load on all the blocks is uniform.

**Fig. 6: Uniformly distributed load on keel blocks**




7.4 However, generally the longitudinal centre of gravity (LCG) of the vessel does not fall directly over the centre of clocks, it falls some distance forward or aft of the centre blocks. When this occurs, the load on the blocks is not uniform, but greater at one end than the other. When a ship is assumed to be a rigid body with a straight keel, the load on the dock blocks tends to be a sloping straight line, resulting in a trapezoidal shaped loading on the blocks. The further the vessel's LCG is from the centre of keel bearing length, the greater in the increase and decrease of the load per foot at each end of the block line. The load on any one block is equal to the portion of the trapezoidal load directly over that block

**Fig. 7: Trapezoidal loading on block**

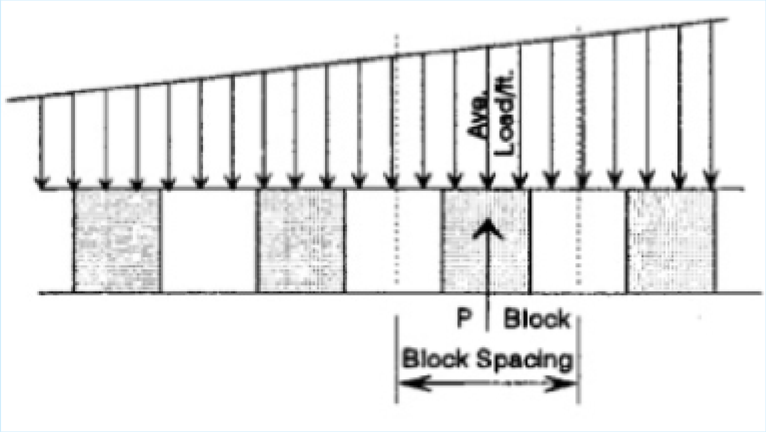
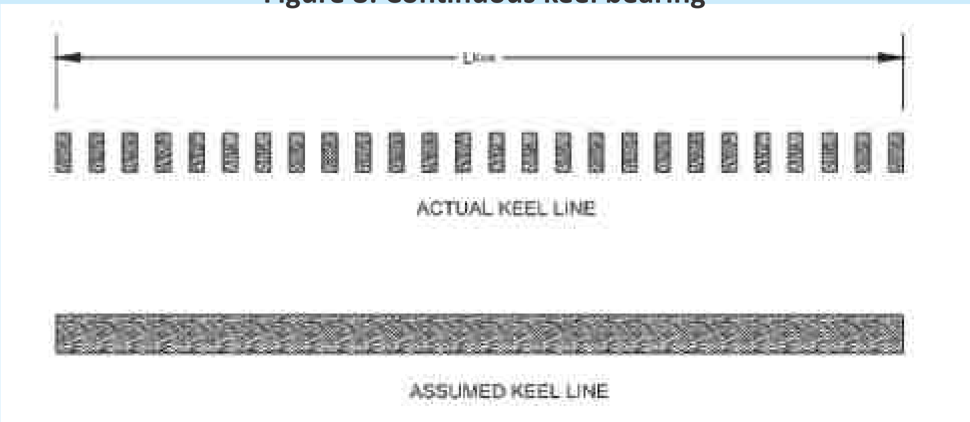
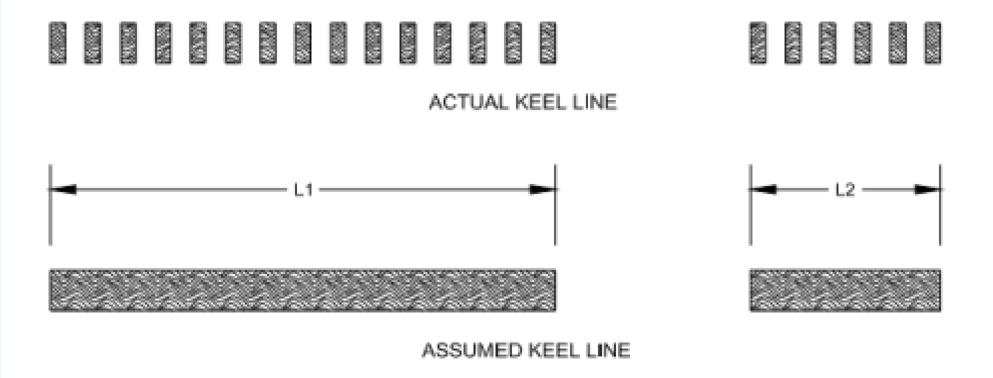



**Figure 8: Continuous keel bearing**



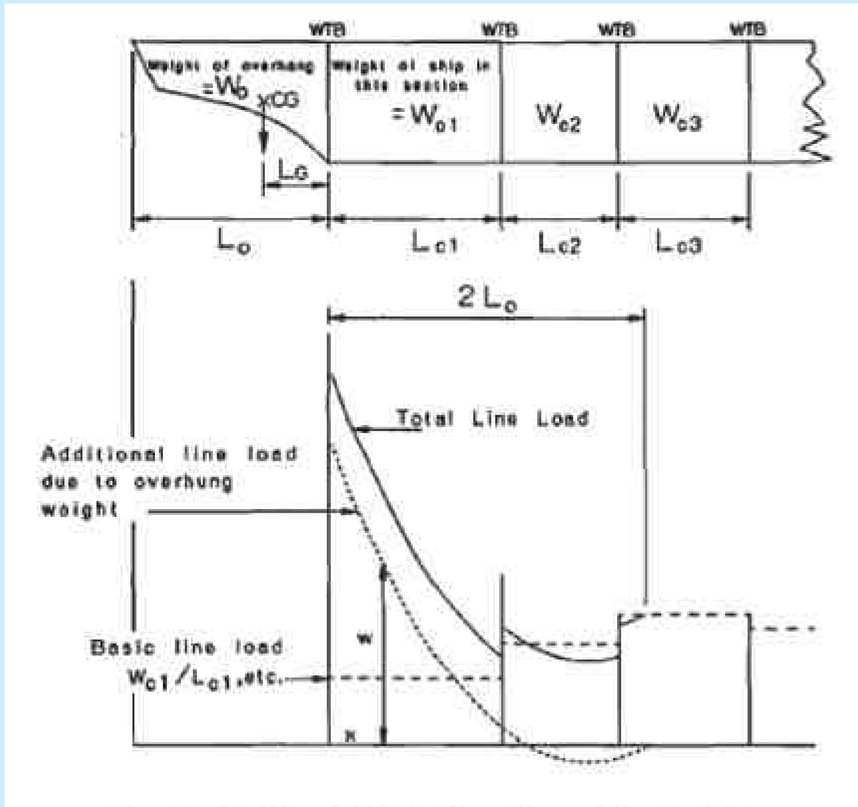

7.5 The above methodology is applicable in case of continuous keel bearing. It can, however, be modified for an interrupted keel bearing, in which case some keel blocks must be omitted to allow clearance for sonar domes or other appendages that hang below the hull.

**Fig. 9: Interrupted keel bearing**



7.6 In addition to the load on the keel line, the ship also has overhangs in the forward and aft. The load of the overhang is distributed parabolically over the blocks adjacent to the overhang.

**Fig. 10: Parabolic distribution of load on overhang**




## 8. Procedure for Dock Block Load Analysis

8.1 The procedure involved in undertaking the docking analysis of a vessel can be broadly sequenced as shown below:-

(a) Determine the weight curve of the ship

(i) Structural and electrical weights considered as distributed throughout vessels length with the help of the sectional area curve.

(ii) Other weights obtained from the GA, considered as point loads

(b) The weight curve obtained is in terms of load per unit length.

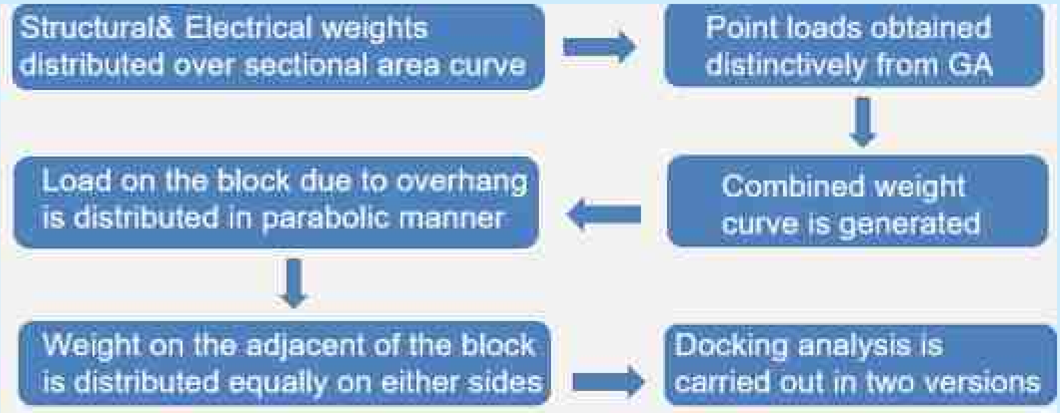
(c) Based on the width of the dock block used, the weight curve of a ship is obtained in terms of load per unit area.

(d) The weight and centre of gravity of the overhang structure are, distributed over the adjacent dock blocks in a parabolic manner.

(e) The total weight on self-weight over each dock block is calculated. The load adjacent to the blocks is distributed equally on either side.

(f) The net weight on each dock block is measured.

Fig. 11: Dock block loading




### 9. Matlab Based Program to Determine Position of Dock Blocks

9.1 Based on the assumptions mentioned above and the sequential procedure available, it was evident that the optimisation procedure for the development of a two version docking plan for a ship is iterative. Hence, a MATLAB based program to measure the load on each dock block considering a standard size dock block was considered appropriate.

9.2 This program was developed for multiple scenarios when the complete load distribution of a ship is available and not available. The keel line is continuous or interrupted etc. The procedure adopted for each case considered is as follows:-

**CASE I:** (Continuous keel bearing and weight curve not available).

*Available Parameters:-*

(a) Dimensions and displacement of the vessel

(b) LCG of vessel

(c) Length of keel and dimensions of keel block

*Parameters not available:-*

(a) Bonjean areas and point loads at each station

(b) Structural and electrical weights

(c) Overhang details(length, LCG and weight)

**CASE II:** (Interrupted keel bearing and weight curve not available).

*Available Parameters:-*

(a) Dimensions and displacement of the vessel

(b) LCG of vessel

(c) Length of keel and dimensions of keel block

(d) Dimensions of Openings and Appendages

*Parameters not available:-*

(a) Bonjean areas and point loads at each station

(b) Structural and electrical weights

(c) Overhang details(length, LCG and weight)

**CASE III:** (Weight curve available)

9.3 When sufficient data is available for the generation of the weight curve. The MATLAB based code developed requires some additional data. They are as follows:-

(a) No of stations and station spacing

(b) Structural and electrical weights

(c) Length, weight and LCG of the overhang aft and forward

(d) Length of the keel line

(e) Dimensions of the keel block

9.4 In Cases, I and II, the total weight of the ship is distributed by trapezoidal rule and a general weight curve of the ship is developed. In Case III, the bonjean areas are used to calculate the point loads at each station of the ship. These loads are used to develop a discretised load curve of the ship.

9.5 The total keel line available is divided into two to develop a two version docking plan. The number of keel blocks and their relative position to SRP is measured and indicated. Based on the position of the dock blocks and the distance between the blocks and the corresponding length of the overhang, the net load on each block is calculated.

9.6 In this dock plan developed, the blocks obstructing any underwater appendages and openings are eliminated and the final net load on the dock blocks is measured. If this load on the blocks is much lower than the permissible limits, the distance of separation between the dock blocks is increased gradually.

**10. Results**

The following data was obtained from the MATLAB code:-

a) Number of keel blocks in each version of the docking

b) Position of keel blocks for SRP

c) The number of keel blocks taking load due to overhang forward and aft.

d) The stress on each block and ratio with the maximum permissible stress

**11. Significance of the Project and Future Scope of Work**

11.1 The project is considered to be a time saver in development of a preliminary generic docking plan of a ship which needs to be customised further for every dry dock. It is applicable for both ships and submarines. The code is also suitable for the development of a docking plan for ships without much information, in case of emergency.

11.2 The future scope of this program is multi-fold. Some of the features which are considered to be achievable include:-

(a) Including the load-bearing capacity of ship and dock in finalising a docking arrangement.

(b) Inclusion of dock blocks of different sizes to enable the program to choose the best possible dock blocks for a given ship.

(c) Position of side blocks and shores

## 12. References


[1] Heger, Robert (Heger Dry Dock, "Dockmaster Training Manual," p. 278, 2005.

[2] https://www.marineinsight.com/naval-architecture/dry-docking-ships-understanding-stability-docking-plan/

[3] https://www.marineinsight.com/guidelines/dry-dock-types-of-dry-docks-requirements-for-dry-dock

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# DESIGNING EFFICIENT HIGH SPEED CRAFTS – DRAG REDUCTION OF PLANING HULL BY VARIATION OF GEOMETRY

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## 1. Summary

1.1 Ship resistance is defined as the force required to tow the ship in calm water at a constant velocity. It is numerically obtained using empirical methods, regression based analysis or model tests. Among the advanced marine vehicles, planning hulls have been widely employed for high speed applications. Planing hulls are characterised by a relatively large beam in comparison with that of displacement hulls, as well as a relatively flat bottom. They also differ in the range of operation, Froude number regime etc. from a conventional vessel. The aim of this study is to carry out a parametric investigation of drag characteristics of an existing model of High Speed Planing Hull (Hard chine) by variation of deadrise angle(β), L/B ratio and LCG and hence arrive at an optimum geometry for the particular hull chosen for study.

## 2. Introduction

2.1 High Speed Crafts. A high-speed craft (HSC) is a high-speed water vessel, also called a fast craft or fast ferry. In accordance with SOLAS Chapter X Reg. 1.3, High Speed Crafts are crafts capable of a maximum speed, in metres per second (m/s), equal to or exceeding:

$$V = 3.7 \times \nabla^{0.1667}$$

where: ∇ = volume of displacement in cubic meters corresponding to the design waterline, excluding craft of which the hull is supported clear above the water surface in non-displacement mode by aerodynamic forces generated by ground effect.

They differ in their structural features and in the way their body weight is supported. Vessel weight can be supported by:

(a) Submerged hulls

(b) Hydrofoils

(c) Air cushions

(d) Combination of the above

2.2 High-speed craft can be classed in two broad categories: **Air Supported and Displacement type.**

2.3 Air supported crafts include:

(a) Air Cushion Vehicles (ACV), Surface-Effect Ships (SES) and Foil Supported craft such as hydrofoils and jetfoils.

2.4 Displacement type vessels include:

(a) Conventional monohull, catamaran, trimaran, small waterplane-area twin-hull (SWATH), and air lubricated hulls (semi planning, planing). While each type of vessel has its own unique characteristics, they all suffer from the common problem of limited payload and a sensitivity to wind and sea state.

## 3 Planing Crafts

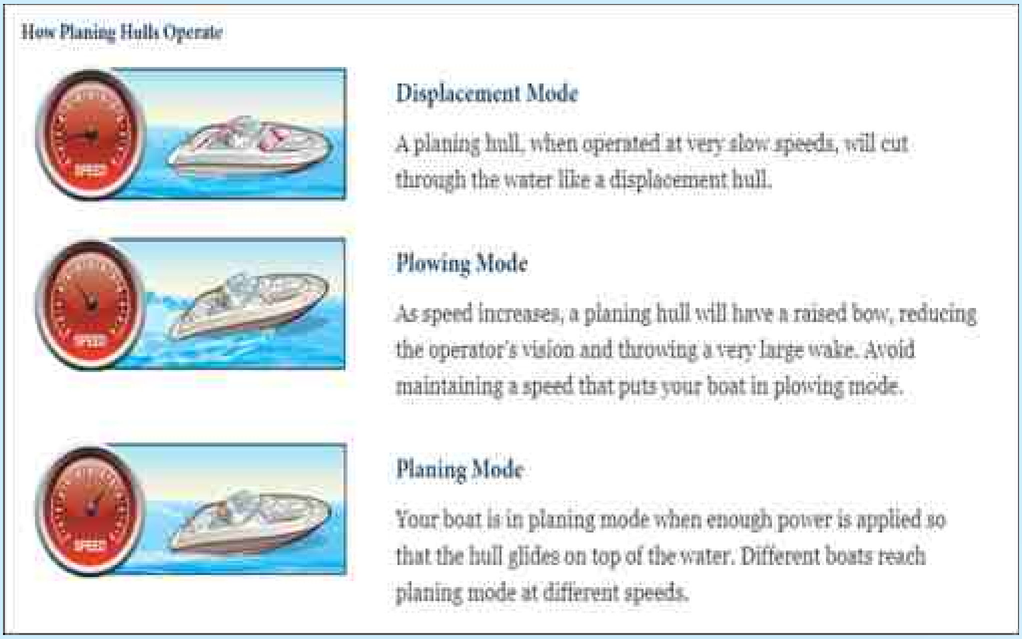
3.1 Planing hulls are characterised by possessing a relatively large beam in comparison with that of displacement hulls, as well as a relatively flat bottom. In this way the craft is intended to generate an upward hydrodynamic force which lifts it out of the water. Planing hulls are designed with a transom stern. This is done in order to encourage the required type of water flow under the hull, in which the water should separate cleanly off the transom of the craft.

3.2 **Mechanism of Planing.** Planing hulls are mostly supported by buoyancy at low speed. At high speed, they are raised by additional hydrodynamic lifts or aerodynamic forces in order to reduce their wetted surface area. The buoyant force decreases as the hull lifts out of the water, decreasing the displaced volume. At some speed the lift becomes predominant and planing starts. To plane, especially to initiate planing, the power-to-weight ratio must be high, since the planing mode of operation involves moving the hull at speeds higher than its natural hull speed.

3.3 **Types of Planing hull forms.** The round bilge and hard chines are the two forms widely used. Both the hulls possess a transom stern. The round bilge doesn't have distinct chines whereas the hard-chine type does have distinct chines. The chine is the line where the relatively horizontal planing surface meets the relatively vertical sides of the hull. The chine does not necessarily run along the entire length of the hull. The aft end of the chine is often at the transom stern and it may even fade out towards the bow.

3.4 The difference between the two hullforms is epitomized by the shape of the sections. A constant deadrise section and a constant force section are the two types of the sections that define the planing hull forms. While the constant deadrise section is likely to generate more lift under

**Fig. 1: Operation of Planing Hull [5]**

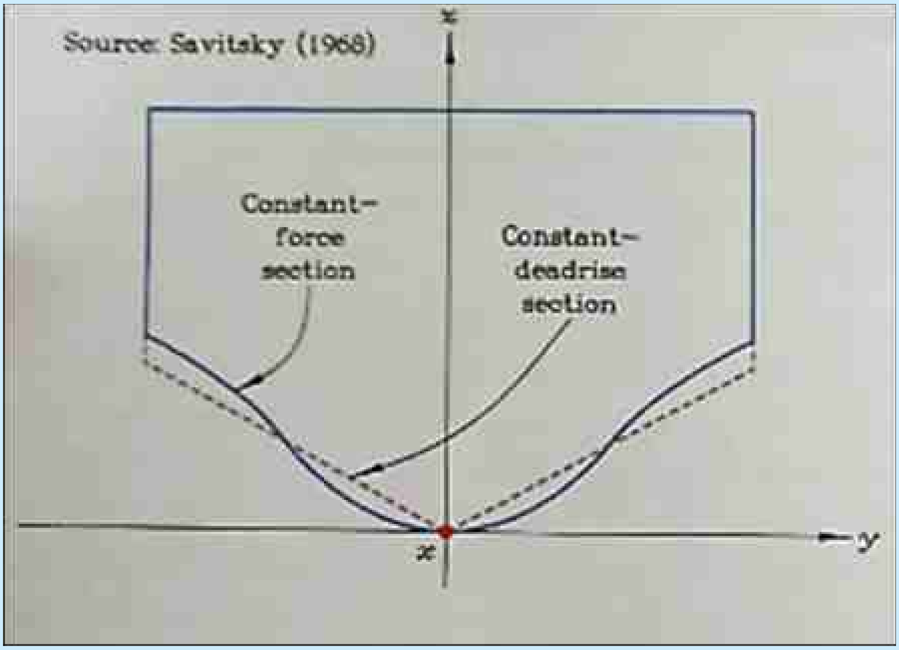


equivalent conditions, the constant force section has better seakeeping qualities.

3.5 Characteristics of Hard chine planing hull:

(a) **Deadrise angle(β):** The angle hull bottom makes with the horizontal plane. The correct

**Fig. 2: Section Shapes**



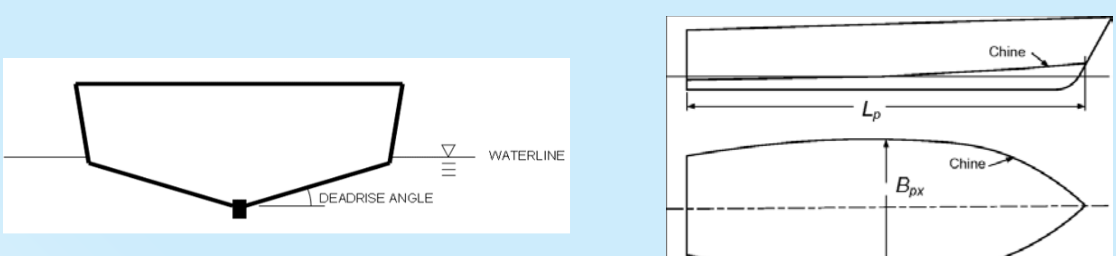

amount of deadrise gives the boat directional stability and reduces the wetted surface drag of the boat as it rises on a plane. Some designs have a constant deadrise while some have a variable deadrise. The variation of deadrise from aft to fore is called warping. Smaller the deadrise less power is required. The variation of deadrise angle is very important because angle of attack will depend on this variation and hence planing ability of the hull.

(b) **Chines:** A chine in boating refers to a sharp change in angle in the cross section of a hull. A chine in boating refers to a sharp change in angle in the cross section of a hull. Hard chines have a shallow "V" in the bottom and near vertical planes it approximates the shape of the traditional rounded hull boats. Shape of the chines in plan determines the projected chine area and the distribution of the area. Location of resultant hydro dynamic lift force would depend on the shape of the chines as well.

3.6 **Factors influencing performance of planing hulls:**

(a) Length to beam ratio, where the beam is the mean beam over chines

**Fig. 3: Deadrise angle (β) and Chines**



(b) Size to weight ratio

(c) Deadrise angle(β) and its variation along length.

(d) Longitudinal position of centre of gravity (LCG)

(e) Shape of chines

4. **Literature**

4.1 **Model Characteristics**. The model chosen for this study is VPS [1] i.e. V-shaped Planing and with straight sections.

4.2 **Test Conditions**

(a) Model is geometrically similar to ship (λ=1/6.5)

(b) Model is run at corresponding speed range from 1.01 to 9.08 m/s (Fn= 0.36 – 3.25), which corresponds to full scale ship speed of 5 to 45 knots.

| Table 1 | Model Type |
|---|---|
| Whole Section Shape | Deep V |
| Motion in Waves | Just Planing |
| Section Shape | Straight |

The model has the following particulars:

| Table 2 | Model Particulars | |
|---|---|---|
| **Dimensions** | **Unit** | **Values** |
| Length Overall (LOA) | m | 0.927 |
| Length of Waterline (LWL) | m | 0.796 |
| Breadth Overall | m | 0.308 |
| Draft | m | 0.08 |
| Weight | Kgf | 9.103 |
| L/B | - | 2.586 |
| Deadrise at AP | degree | 20 |
| Deadrise at midships | degree | 23 |
| Deadrise at FP | degree | 32 |

(c) Speeds are varied 5 to 45 knots at intervals of 5 knots in real ships.

(d) Corresponding towing speeds of model ships are 1.96 knots to 17.64 knots.

5. **Resistance Prediction Method**

5.1 Based on the literature survey, the most suitable method for estimation of resistance of planing crafts is Savitsky's method of resistance prediction.

Where Bch is defined as the breadth over chine

5.2 The numerical tool used for the present study to supplement manual calculation is NavCad.

5.3 **Overview of Methodology**

Step 1: Select candidate model planing hull from existing literature.

Step 2: Model the planing hull in 3D using CAD tools.

| Table 2 | Model Particulars | |
|---|---|---|
| **Parameter** | **Lower limit** | **Upper Limit** |
| Froude No (Bch) | 0.6 | 13 |
| Trim angle | 2° | 15° |
| Deadrise(β) at amidships | 0 | 40° |

Step 3: Estimate resistance of developed hull form using commercially available codes and manual methods.

| Table 4 | Limitations of Savitsky method in NavCad | |
|---|---|---|
| **Parameter** | **Lower limit** | **Upper Limit** |
| Froude No (Bch) | 0.968 | 13 |
| Froude No ($\nabla^{1/3}$) | 0.968 | 13 |
| LCG/ Bch | 0.6 | 3 |
| Deadrise(β) at amidships | 0 | 32 |

Step 4: Validate obtained results with published towing tank results.

Step 5: Modify geometrical parameters to narrow down desirable parameters window.

**6. Methodology**

6.1 **Offset Generation**. From the given plans of the model in the paper, offsets are obtained by introducing waterlines at the required change of curvature and interest. The model is divided in 12 stations. A 3D model is then developed in Paramarine which is used for the study.

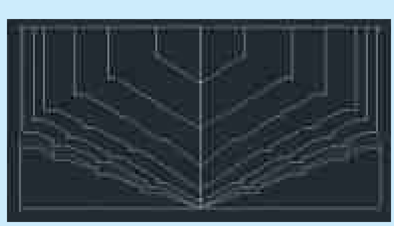
6.2 **Validation of Geometry**. The resistance is calculated for the developed model using manual method and NavCad software and the results are validated against the published results in the literature.

6.3 **Analysis of the geometry**. The parameters that influence the resistance in a planing hull are:

(a) The deadrise angle (β),

(b) Length to breadth ratio (L/B)

**Fig. 4: Body plan generated from measured offsets**

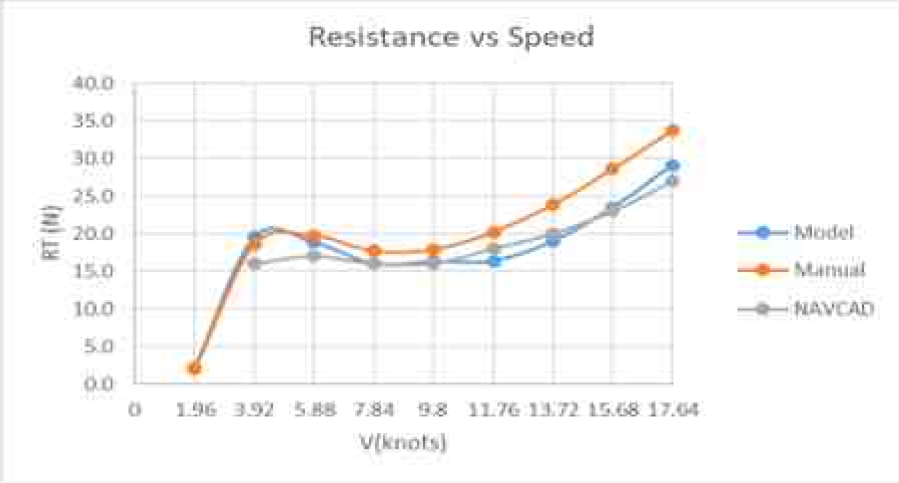


(c) Longitudinal center of gravity (LCG)

## 7. Work Flow

7.1 All the three parameters are varied over a range of values as decided by the literature, software and Savitsky method limitations.

**Fig. 5: Validation of the methods**

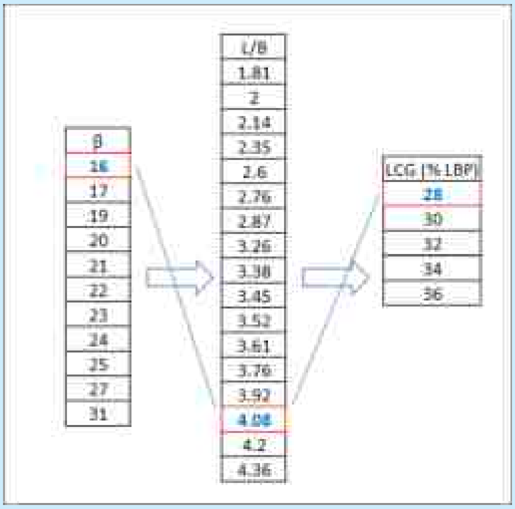



7.2 A best suitable geometry window is derived by varying all the parameters simultaneously i.e. varying the range of values of L/B, LCG for each value of β in the range specified. i.e. for each value of β, the L/B ratio is varied and for each value of L/B, the LCG range is varied

7.3 For each of the geometric combination, the resistance of the model is calculated using NavCad.

7.4 The combination which gives the least resistance is considered as the most optimum geometry for the candidate model considered for the study.

**Fig. 6: Work Flow**



## 8. Results and observations

8.1 The resistance of the candidate model selected is as shown below:

| Table 5 | Resistance of candidate model |
|---|---|
| Deadrise(β) at amidships | 23o |
| Length/ Breadth | 2.586 |
| LCG | 40% LBP |
| Resistance | 29 N |

8.2 Varying the parameters simultaneously and assessing all the possible combinations of the parameters, It is recommended that from a drag reduction perspective, the following is the best configuration. A reduction of 37.9% in the total resistance was observed between the two geometries for the same weight of the vessel.

| Table 6 | Final Optimised Geometry |
|---|---|
| Deadrise(β) at amidships | 16o |
| Length/ Breadth | 4.08 |
| LCG | 28% LBP |
| Resistance | 18 N |

8.3 The constraints of the Savitsky's method and the regime of planing are the important and critical considerations to be taken while varying the geometrical parameters of the planing hull.

8.4 As deadrise angle (β) increases the resistance at maximum speed increases.

8.5 For this particular model, the LCG if varied beyond 36%, the hull loses its planing ability and if varied below 28% the method of resistance estimation for the first 3 speeds becomes invalid due to the method constraints.

8.6 The resistance at maximum speed decreases with increase in the L/B ratio.

## 9. Conclusion

9.1 The study has demonstrated the method and procedure to be followed to optimize the geometry of planning crafts to achieve drag reduction. A candidate hull model (VPS) has been studied and the drag computation was carried out using Savitsky's Method. Deadrise angle was found to be the most influential parameter for planning hull drag. This work aims to serve as a building block for deriving more efficient designs of high speed crafts.

## 10. References

[1] D J Kim, S Y Kim, YJ You, KP Rhee, SH Kim and YG Kim, “Design of high-speed planing hulls for the improvement of resistance and seakeeping performance” JNAOE,2013.

[2] Daniel Savitsky, “Hydrodynamic Design of Planing Hulls", Marine Technology 1964

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## About Directorate of Naval Design (Surface Ship Group), Indian Navy

The early post-independence era saw the acquisition of ships from abroad to form the early composition of the Indian Navy. Our naval planners had the foresight and vision for the future growth of warship design and building in the country leading to the setting up of a Central Design Office in Sep 1964. This office later evolved into the Directorate of Naval Design (DND) in 1970, and in 1976, was upgraded to be headed by a Director General Naval Design (DGND). In the last five decades of indigenous design and warship building the Design Organisation has made several long strides to meet the growing aspirations of the Indian Navy for timely production of state-of-the-art warships embodying latest technologies. The Indian Navy's Design Directorate is possibly one of the few uniformed design organisation in the global scenario to possess self-sufficiency and self-reliance in warship design and construction capability to produce state of the art warships. Till date, 19 different types of designs ranging from small craft to destroyers have been designed by the Directorate of Naval Design, to which more than 90 warships have been built.

The Directorate has transformed over the years and it now holds a multi-disciplinary team of Naval Architects, Marine and Electrical Engineers working in tandem towards a singular goal of superior and challenging designs. DND has evolved into a unique organisational structure which is an amalgam of a project centric yet specialist groups based setup. The Specialists groups have developed expertise over the past many years and the experience in one project is seamlessly transferred onto the next. The Design Directorate has a vast specialist expertise in the fields of Forward Design & Stealth, Structural Design, Propulsion System Integration and Engineering System, Heating Ventilation and Air Conditioning, Ergonomics and Habitability and a well equipped Computer Aided Design Centre which has state of the art design tools such as Virtual Realty lab for design of Warships.

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A non-government, not-for-profit organization, FICCI is the voice of India's business and industry. From influencing policy to encouraging debate, engaging with policy makers and civil society, FICCI articulates the views and concerns of industry, reaching out to over 2,50,000 companies. FICCI serves its members from large (domestic and global companies) and MSME sectors as well as the public sector, drawing its strength from diverse regional chambers of commerce and industry.

The Chamber has presence in 14 states and 10 countries. It provides a platform for networking and consensus-building within and across sectors and is the first port of call for Indian industry, policy makers and the international business community.

National Maritime Foundation

## About the National Maritime Foundation

Inaugurated on 15 February 2005 by Mr Pranab Mukherjee, who was then the Defence Minister of India (and who later held the office of the President of the Republic of India), the National Maritime Foundation (NMF), New Delhi, is India's sole think tank that concentrates, with unwavering focus, upon the entire gamut of matters maritime. While it is an autonomous think-tank, its intellectual and organisational development is supported by the Ministry of Defence and the Indian Navy. In the 13 years that have elapsed since its inception, the NMF has grown into an established intellectual institution with robust academic linkages within the country and overseas.


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