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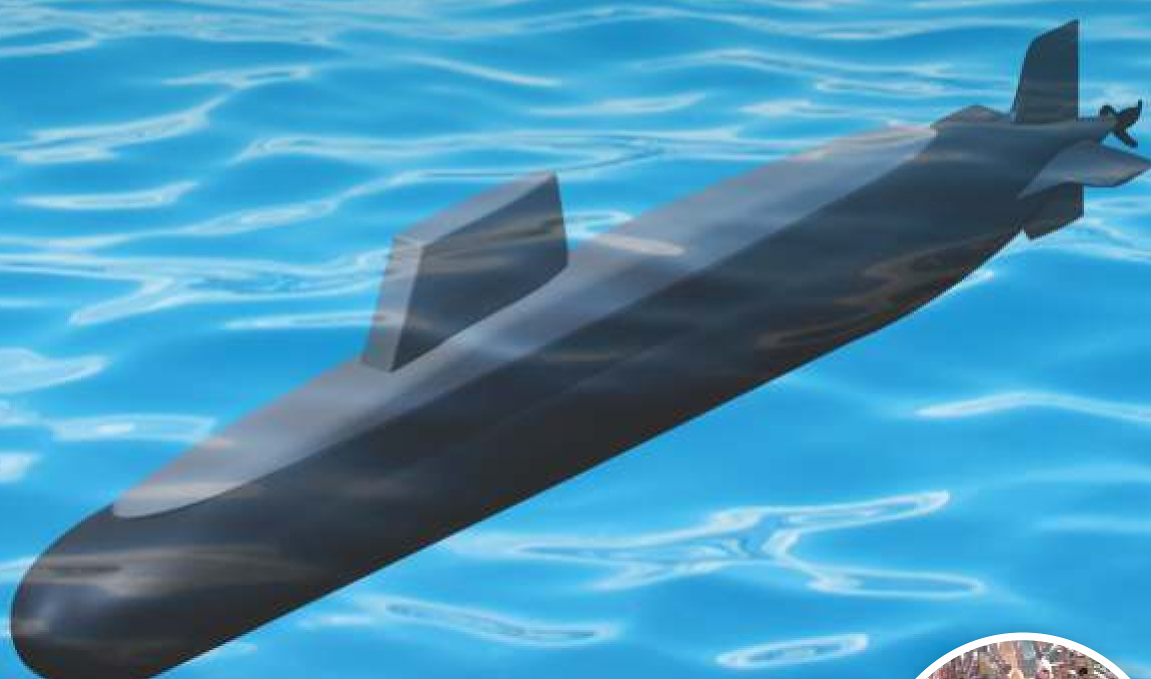

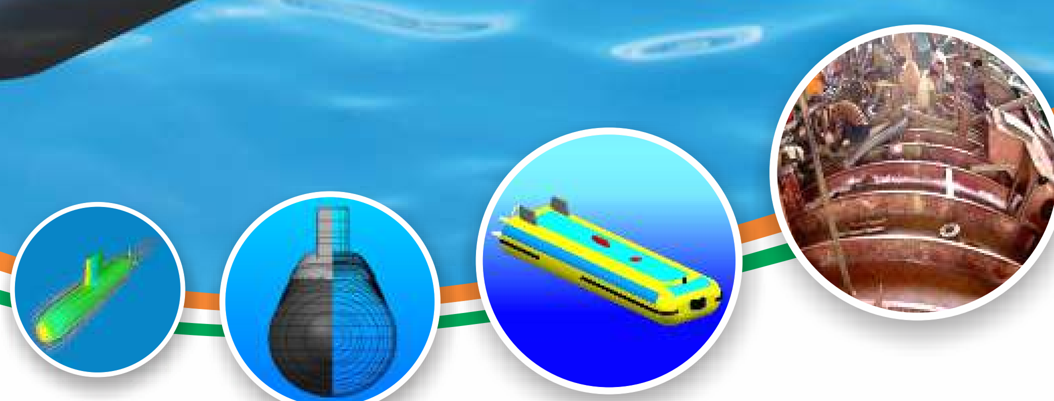

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TIMELY ADAPTATION OF CUTTING EDGE TECHNOLOGY FOR DIVERSE SUBMARINE SYSTEMS-A STRUCTURED MULTI-DISCIPLINARY GROUP APPROACH

(Cmde Shishir Shrotriya, ADG WESEE)

Introduction

1. The wide-ranging advances in the technology have been taking place far too rapidly and the revolution in technological areas has made a far-reaching impact on the Submarine Technologies and Systems. This technological revolution has also left a distinct influence on the system maintenance and long-term support. In the domain of submarine technologies, the pace of the technological shift, the complexities of the systems inducted requires a deeper appreciation of the technologies and the infrastructure support we need to develop to maintain and optimally exploit these systems over their life-cycle. Answering the challenges of evolving an adequate technology management methodology has triggered a debate of sorts, on the essential and immediate requirements of the supportability and reliability.

2. Self reliance and developing core-competence in the required fields by synergising our resources is the key question we need to address while we intend to succeed and sustain the technologies inducted optimally for coming few decades.

3. This paper aims to identify, analyse and predict the challenges of the inducting newer technologies and formulate a plan to tame these challenges ingeniously for a long-term reliable sustenance of the submarine systems with the appropriate interface of all other Stake-holders.

Key Requirements for Submarine Technology / System Induction and LCS

4. The environment today needs a constant in-depth study of the systems inducted from diverse sources and its suitability. **The Navy requires a detailed and documented analysis of the newer technology in order to advice its implementation.**

5. The long delay in induction of new technologies is generally attributed to the lack of awareness to the systems/technologies view limited information provided by the OEM or our inability to pursue complete know-how or transfer of technology or also our conservative attitude in experimenting with these systems. **Thus, we need to create a life long structured approach towards developing technical know-how, practices and maintenance paradigms to adapt and support the cutting-edge submarine technologies with our indigenous industry.**

6. The approach we follow for long-term exploitation of the systems inducted, suffers from the fact that while inducting we are unable to clearly define and standardise these systems for all new acquisitions. A newer generation of the equipment is developed every two to three years by any major defence sector OEMs. Usage of modular COTS (Commercial Of The Shelf) technology and OSA (Open System Architecture) in the Military systems is a reality. In order to adapt and sustain

the Naval systems **we need to arrive at research methods that only the matured and supportable technology is implemented.**

Technology support for Submarine Systems

7. In order to cope up with these challenges and identify suitable areas to adapt the emerging technology for Naval Submarines, there is a need to define the related technological areas. These can be sub-divided into the under-mentioned broad categories :-

(a) Technological Awareness. We need across the board awareness amongst all personnel related to the submarine (defence) industry about the advancements in technology and its usage in related fields. For this, we must have expertise to understand, realise the changing environment and keep a continuous technology watch. This could be achieved by developing a database or information bank where the evolution of appropriate new technology is prepared, stored, reported and retrieved. This information bank could serve as a basis to draw guidelines and procedures for embracing the technology for appropriate submarine systems. Thus we need to continuously research and develop an intelligent decision-support system to evaluate the technology/systems under consideration and draw comprehensive guidelines for adaptation of the same.

(b) Technology Management. There should be a mechanism to examine the process of identifying, development and induction of matured new technology for Naval applications. These comprehensive technology management guidelines are suggested to be drafted under the following broad concepts:-

(i) Reliability - of the technology under consideration.

(ii) Operability- in our operational environment.

(iii) Supportability - in terms of supplier, developing organisations, promoters and with future reference to spares etc.

(iv) Interoperability - of systems from diverse sources.

(v) Compatibility - with existing systems/technology.

(vi) Configurability - in terms of the architecture suited for submarine applications.

(vii) Usability - in terms of its adherence to the military or desired specifications.

(viii) Affordability - in comparison to other systems/technology and their associated advantages/disadvantages.

(c) Requirement Analysis. A detailed requirement analysis needs to be done up to the system level, clearly describing the pros and cons of the system/technology under consideration. **This analysis would further help the defence industry evolve the system specifications, its architecture and the configuration in keeping with the operational requirements.**

(d) Transition Readiness. Transition readiness guidelines promulgation and thereafter adherence to these guidelines is important task. The risk of migrating from one technology/system to another, keeping the older generation of equipment in operational condition whilst switching over to the newer generation needs utmost attention. **These systematic "process guidelines" are then mandatory to improve, support and accelerate the transition process.**

(e) Industry Co-operation for R&D. There is definite and most important requirement of promoting and grooming the vast indigenous resources of our industry to participate not only in design and development of submarine systems but also for long-term maintenance and upkeep of systems inducted. The Militarily advanced countries for past so many years have groomed their indigenous industry to reach to the present level of industry participation in defence applications. Further, all major business groups have a 'Vendor development cell'. While, there is a need for transparency in all Govt. contracts, the need for Vendor Development to groom our industry to develop core competencies in submarine sector cannot be overlooked for a self-reliance. Therefore we need to study and recommend measures for **establishing linkages with the industrial research systems and the industrial production base for long-term association which will establish and sustain the required ecosystem for this sector.**

(f) ToT of Submarine Technologies. Defining structured and consistent approach for ToTs is significant. The guidelines for these ToT contracts need to be carefully incorporated at each stage in consultation with the participating industry and our research agencies for the measurable and wider benefits. The guidelines should clearly specify the process for Technology Assessment, Valuation and Cost Estimation for ToT and required infrastructure for manufacturing and qualification. Documents and Processes for Software, Hardware and System Engineering transfer with measurable deliverables at each stage of design, prototyping, integration, qualification and acceptance form are significant.

(g) Technology Absorption. Internal R&D and Knowledge upgrade is a vital component of the "absorptive capacity", that is, our "capability to distinguish the value of new external information, its assimilation and application for submarine specific domain. Technology Absorption cannot be done by one time training or ToTs. This can only be done through creation of absorptive capacity with all concerned stake-holders in the ecosystem, which is a repeated effort required to be followed up and sustained in a structured way.

8. The areas requiring technological support and discussed in the preceding paragraphs warrant renewed/new management processes with closer linkages and co-ordination primarily between all identified stake-holders for adapting large scale, time-bound and tangible applications of the technology through its life cycle. These tasks need to be accomplished by creating renewed structures to integrate and synthesize our resources to bring together the grossly under utilised indigenous industry with DRDO, Academia, Public sector, Governmental agencies and most importantly the User(Indian Navy). The brief requirements for accomplishing the above tasks are enumerated below :-

(a) Channelise resources from within the Navy and industry to generate core teams for evaluation and implementation of technology/systems for the submarine projects.

(b) Draw structured approach to aid the Governmental and Non-Governmental agencies to evaluate & acquire the emerging technologies/products for usage in Submarines.

(c) Develop and maintain a database of emerging technologies for naval submarine systems, its vendor support, associated governing bodies and promoters to reliably determine the desired features of technology management.

(d) Evolve process guidelines for implementation of projects and transition guidelines after in-depth study and analysis with the help of experts in the industry.

(e) Promote and usher partnership with leaders in technology amongst indigenous industry, our premier academic institutions to formulate programmes for research and development and also long-term maintenance and upkeep of Submarine systems.

(g) Work on technological partnerships with advanced and developed nations like U.S, Singapore, Israel and France etc. to gain competitive advantage of consortium approach for mutual benefits.

Recommendations

9. The success of meeting the above proposals largely depends on the available infrastructure support. Thus, it is desirable to create nodal agency which could be christened as Submarine Technology Adaptation Centre (SubTAC) to closely and technologically interface the resources of our industry for meeting the requirements of Submarine Systems LCS.

10. The SubTAC will work to fulfil the above expectations to prepare & promote our industry for larger co-operation. To maintain the flexibility of working, funding and minimise the hierarchical bureaucracy, it is discernible to ideally set-up the Submarine Technology Adaptation Centre(SubTAC) with participation of all stake-holders. The organisation can be perceived and developed as an autonomous unit under the Design Directorates to promote direct research and development in developing indigenous technology or adaptation of imported technology for Submarine systems.

11. The creation of such a body shall also provision for an in-house consultant, who can provide the requisite expertise and have answers that are mandatory for a systematic, sustained and methodical growth of technology in the Naval Submarine systems.

Immediate Plans for SubTAC

12. Certain imperative and immediate project/tasks for SubTAC are enumerated below. A few of these projects(Appendix 'A') which are already underway, can be better accomplished by implementing the preceding recommendations:-

(a) Steer a sustainable growth by technologically interfacing and liaisoning to promote larger participation from Stake-holders in design, development and Life Cycle support of Submarine Technologies and Systems as per staff projections.

(b) Study and improve supportability of COTS technology/devices in naval Submarine systems where OEM support has diminished. Develop resources through directed research and initiatives for the in-house technological support within the dynamically changing requirements.

(c) Create the technological database as knowledge management for the life-long learning requirements in the field of submarines weapons and systems and disseminate information as consultants or through continuous QIPs/CEPs to the relevant stake-holders.

(d) Strengthen and contribute to existing technology initiatives by MoD/Shipyards/PSU/IHQ.

Conclusion

13. As long as we continue to depend on external sources for our Naval technologies/ systems and do not initiate concrete steps to develop our industry to imbibe technology, we will remain hostage to the ever-changing environment.

14. The knowledge of technological inter-dependence and self-reliance, can only lead us to strategic advantages. Thus renewed thrust and structured approach from the proposed Submarine Technology Adaptation Center towards a renewed Defence-Corporate-Academia Stake-holder partnership may help in achieving our vision & goals set for immediate and long term future requirements and contribute towards an advanced and self sustainable Submarine Sector.

Appendix 'A'

Key Focus Technology A

1. Optics and Optronics for Periscope
2. Si Based Smart Sensor Technology
3. Fiber Optics Acoustic Sensors
4. Homing Head Hardware and Software algorithms for Torpedoes
5. WFCS Hardware & Software Algorithms
6. Long Life Safety Critical Submarine Batteries
7. High Bandwidth and Secure Radios
8. Propulsion Motor Integration
9. Reduction and controlled radiated noise
10. Decoy Systems
11. Submarine Hull Design Technologies
12. Composite material for submarines systems

Author's Biodata

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article

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AIR INDEPENDENT PROPULSION THE ROLE OF FUEL CELLS IN SUPPLY OF SILENT POWER

(Cdr Ayush Khandelwal (51955-B)

Abstract- *Stealth is an important factor in littoral operations. Air Independent propulsion deals with powering a submarine without access to atmosphere or air. As we know that every diesel engine needs access to an air supply to work. So, the submarine has to resurface after every fixed interval in order to refill the air (oxygen) supply. This makes it difficult to have long stealthy operations under water in a submarine. It is true that a nuclear submarine can stay underwater for months. But, a nuclear powered submarine needs constant pumping of cooling water inside out, causing a lot of pumps to run which in turn causes a lot of vibration. Also the installation of an entire nuclear reactor makes the whole submarine a significantly large in size. So, it cannot be used for silent and stealthy operations. Stealthy power sources for underwater vehicles include air-independent propulsion technologies, such as fuel cells, perhaps hybridized with an energy store such as an advanced battery. The hybrid combination provides the most covert solution, with good underwater endurance. Of the fuel cell technologies examined, the proton exchange membrane fuel cell (PEMFC) currently offers the best performance, and we review relevant fuel and oxidant options.*

Introduction

While conventional submarines are far more effective in the littoral environment vis-à-vis their larger, more powerful and noisier nuclear counterparts, the limited dived endurance is also their greatest vulnerability

Perhaps the single greatest limitation in conventional submarine operations is the constraint on their dived endurance or the period they can remain dived without having to recharge their batteries. This duration is determined by the rate of discharge of the submarine's batteries which in turn depends upon the propulsion, speed, machinery and equipment running on board, and the tactical situation prevalent in the area. It is this limitation with its consequential effect on speed, stealth and concealment that makes conventional submarines vulnerable to detection, particularly in a geographically limited littoral environment. Herein lies the paradox; while conventional submarines are far more effective in the littoral environment vis-à-vis their larger, more powerful and noisier nuclear counterparts with concealment and stealth being their greatest assets, the limited dived endurance is also their greatest vulnerability as it exposes them to detection from the air and from surface platform in a relatively restricted oceanic space.

It is this limitation on dived endurance that has led the enthusiasts of nuclear powered submarines to contemptuously dismiss conventional submarines as "mere submersibles" to quote the legendary initiator of nuclear powered submarines, Admiral Hyman G. Rickover on a visit to an Indian Naval Submarine in December 1982.

Nuclear submarines are also of two types. There are the strategic ballistic missile submarines (SSBN) also called Boomers and the Attack submarines (SSN). The former are the ultimate instrument of nuclear deterrence as they combine concealment and speed with a weapon arsenal that can destroy the world several times over. During the Cold War, these submarines ensured that the war remained 'cold' and in the post-Cold War period have continued to deliver deterrence in an increasingly dangerous world. SSNs on the other hand are designed for speed, endurance and lethality; while their primary role was to tail the SSBNs, they have proved to be extremely effective in an expeditionary 21st century littoral environment with their cruise missile capability and long endurance limited only by the human factor on board. SSNs have repeatedly proved their versatility and reach from the Falklands in 1982 to Libya in more recent times.

Why Air Independent Propulsion?

The imperative for the development of the first AIP systems was the high loss rate of Kriegsmarine U-boats in the Battle of the Atlantic, when confronted by well-armed Allied maritime patrol aircraft. Diesel-electric U-boats had to run surfaced to recharge their battery systems, which made them susceptible to detection by the basic radar equipment carried by RAF Coastal Command and US Navy aircraft. Attempts to 'shoot it out' with aircraft using deck-mounted guns were mostly unsuccessful. Crash dives to evade the attacker would only succeed if the aircraft was sighted very early, or its radar emissions detected.

The inventive engineers of the Kriegsmarine developed the snorkel to permit the U-boat to run submerged and draw air in for the diesels, so the batteries could be recharged while the U-boat was submerged. Snorkels however produce a bow wave, a trough and wake, and these were also detectable by improving search radars, albeit at very much shorter ranges than a surfaced boat. By the early 1950s snorkels had become the technology of choice for submarine operators globally.

While snorkels are now clad in radar absorbent materials, and often shaped to minimise their bow wave and wake signature, they continue to provide a detectable signature, exposing the boat to any maritime aircraft with a good search radar system. This is because all submerged submarines produce a roughly conical disturbance in the water which expands outward behind the submarine, dissipating in intensity with time and distance. The strength of this disturbance increases with the speed of the submarine. As the disturbance expands behind the submarine, it eventually hits the surface, producing a roughly paraboloid surface disturbance, pointing in the same direction the submarine was travelling when it produced the wake. At snorkel depth even a ponderous 10 knots will produce a visible wake, which can be observed on numerous images of submarines at periscope or snorkel depth. Snorkelling will thus present a much greater risk than at any previous time, as the boat will produce a hull wake signature, a snorkel wake signature, a snorkel paint signature, and snorkel shadow signature.

The answer is of course to avoid snorkelling if possible, and spend as much time as possible as deep as possible and as slow as tactically feasible, all of which present major operational challenges for a diesel-electric boat design. As with the pressures that led to the first attempts at AIP more than half a century ago, it has been an unexpected advance in opposing sensor technology that has forced evolutionary change. AIP becomes not only a necessity for a submarine but also a mission critical and survival critical single point of failure for the boat. A non-nuclear-propelled, or conventional, oceangoing submarine will require a substantial alternative power generation capability. As well, to avoid detection, it will need to reduce the sound of noisy diesel generators to an absolute minimum. This leads to the topic of non-nuclear Air Independent Propulsion (AIP) systems. AIP is a power source that does not require access to the surface atmosphere to generate power.

Requirement for Non-Nuclear AIP

In response to the challenges of propulsion for submarines, in the late 1940s, the US government started the development of an AIP system to allow US submarines to become independent of the surface atmosphere. The United States expended massive resources to develop this technology. In 1954 the American submarine USS Nautilus became the world's first ship to be powered by a true AIP system, a nuclear reactor, which subsequently became the power source for all US submarines.

A nuclear power train is the ultimate AIP as it presents no restrictions on submerged time. However attractive this choice might be from a strategic, operational and tactical perspective, in many nations it is politically risky due to high levels of perceived and imagined risks in the public domains. It is unlikely therefore that nuclear propulsion will be studied and publicly assessed from an objective and rational perspective. The politics of perceptions rather than hard fact would dominate any attempt to pursue nuclear powered submarines. Nuclear submarines are very expensive, not only to build the boat (yes, submariners refer to their vessels as 'boats'), but the extensive infrastructure required to support them - a nuclear industry with all of the necessary safeguards, advanced training for all members of the crew, isolated high-security bases, etc. At the moment these boats are operated by just six states: USA, Russia, UK, France China and India. All six countries possess both ballistic missile submarines (SSBNs) and SSNs, indeed all but Russia and China now operate only nuclear-powered vessels.

That apart the limited utility of nuclear submarines in a littoral environment characterised by relatively shallower depths has led almost 40 nations to operate conventional submarines and this number is growing. Vietnam has recently ordered six Kilo class submarines from Russia. Bangladesh has also shown keenness in acquiring submarines, with China apparently willing to oblige. The entire Indo-Pacific region has in fact seen a proliferation of submarines as they provide the maximum bang for the buck in delivering the cutting edge of offensive firepower to any navy and are therefore the most effective instruments of sea denial, i.e. denying the use of the sea to the enemy and particularly if it is a more powerful one. While most submarine manufacturers offer different non-nuclear AIP systems, and several are currently in service, none can offer the range of benefits of nuclear propulsion. That said, the non-nuclear versions do allow a submarine to generate power without having to snort for limited periods of time.

Choosing an AIP system

One of the realities of this era is that any military Service about to decide on a new technology for a basic force structure component will have to contend with a deluge of glossy brochures, Power Point slides and briefings, all of which commend the virtues of a particular solution, and all of which profess to be without 'sin' of any kind. The situation is no different with AIP systems, whether they are offered as retrofits to legacy boats or as part of a new-construction boat. In assessing the merits of any AIP system several factors are important. Some of them are enumerated below:-

- Acoustic signature contribution produced by the AIP system in specific operating regimes, but especially at varying speeds and depths.
- Vulnerability of the AIP systems, especially oxidiser storage, to near miss explosive overpressure effects otherwise not lethal to the submarine or its systems.
- Various failure modes of the AIP system and its oxidiser/fuel storage, and to what extent are these repairable if a failure or battle damage arise in a contested patrol area.o Failover modes and internal redundancy in the AIP system, and what 'casualty' modes exist if a catastrophic failure arises to get the boat out of danger.
- Replenishment of oxidiser and fuel from a tender when operating at large distances from a friendly port.
- Lifecycle cost of operating and maintaining the AIP system.

In the final analysis, any AIP system will need to be subjected to some representative and tough testing before it even makes a shortlist, since AIP is becoming a mission critical single point of failure for the submarine in a combat environment. If the AIP system fails for whatever reason while the submarine is operating in a contested area, it may not have the option of snorkelling home.

Current Technologies in AIP

Although major naval powers like United States, United Kingdom, and Russia turned quickly to submarine nuclear propulsion as soon as it became technically feasible, smaller navies have remained committed to conventional diesel-electric submarines, largely for coastal defense. Many of these have incorporated innovations originally pioneered in the German Type XXI, but more recently, growing demand for longer underwater endurance has generated increasing interest in promising AIP technologies, both old and new. Currently, system developers are actively pursuing the following generic approaches for achieving "closed cycle" operation. These non-nuclear AIP systems can be broken down into four main types, all of which require liquid oxygen (LOX) to operate:

- Closed-cycle diesel engines, generally with stored liquid oxygen (LOX)
- Closed-cycle steam turbines
- Stirling-cycle heat engines with external combustion
- Hydrogen-oxygen fuel cells

Closed-cycle diesel engines

Closed cycle diesel or CCD AIP systems employ a stored supply of oxygen to operate a diesel engine when fully submerged. The technology was trialled initially by the Kriegsmarine and later adopted by the Soviet Voenno-Morskii Flot in 30 boats of the Quebec class, in which one of the three diesels could be used as an AIP system using stored liquid oxygen (LOX). In such designs the oxygen is mixed with exhaust gasses or inert gasses to protect engine components. The Soviet boats proved troublesome to operate, prone to fires, with limited endurance due to LOX boil-off, and were scrapped during the 1970s. While closed cycle diesel AIP is a simple technology, the principal challenge lies in storing the oxygen supply in a way that presents a low risk in operation. A stable liquid fuel that could be catalytically decomposed would present the best choice for such designs. The current CCD AIP systems offered by Thyssen Nordseewerke in Germany use diesel, LOX and Argon as the inert gas component.

Closed-cycle steam turbines

Closed cycle steam turbine AIP systems could be best compared to nuclear systems, in that heat is used to generate steam, which via a turbine or turbo generator package drives the propulsion system. In effect, the nuclear pile is replaced by a stored oxygen fuel burning heat source. The fuel and oxidiser mix used for the AIP system is then specific to the design in question. DCN in France offer the MESMA (Module d'Energie Sous-Marine Autonome) system in a lengthened Scorpene class boat, requiring the insertion of an 8.5 metre 305 tonne hull section. The MESMA system burns ethanol, using stored LOX as the oxidiser. The propellant mix is burned at 60 atm pressure. DCN claim up to three times the submerged endurance of the basic diesel-electric Scorpene class, or up to 18 days. Like LOX based CCD AIP systems, the MESMA will be primarily constrained by the need to store and handle LOX.

Stirling Engines

Stirling engine technology dates back to 1816, but had to wait until very recently to find a volume production application, which is AIP systems in submarines. Stirling engines are often compared to reciprocating steam engines, in that they employ a piston-cylinder assembly, but they differ fundamentally, in that the working fluid in the engine is sealed and separated from the heat source, in a closed cycle arrangement. Heat is provided to the Stirling engine by the external combustion of a fuel and oxidiser. The Swedish Kockums AIP system employs LOX as the oxidiser and diesel as the fuel, which are combusted at a pressure higher than that of the surrounding water mass permitting the exhaust to be directly vented to sea. The Stirling engine is coupled to a generator that feeds into the boats' primary electrical system. As with other AIP systems burning diesel and LOX, the LOX supply is the principal constraint to achievable endurance. Other than Sweden's Kockums, Stirling AIP is reported to be used by the PLA.

Hydrogen-oxygen fuel cells

Fuel cell based AIP systems typically employ a hydrogen oxygen fuel cell to generate electrical current, which then powers the boat's systems. Fuel cells have been employed successfully for decades in space vehicles that employ LOX and liquid hydrogen as main engine propellants. The principal issue in operating any fuel cell based system is the manner in which the oxygen and hydrogen are stored prior to introduction into the fuel cell. The fuel cell produces distilled water as a waste product. A key attraction in fuel cell systems is the virtual absence of moving parts in most key components, which makes them exceptionally quiet in terms of machinery noise, compared to closed cycle diesel and turbine systems.

Fuel Cell Systems

As discussed above, the AIP technologies like the Stirling engine, the closed-cycle diesel generator, and the French MESMA system are mechanical devices relying on moving parts, with a lower potential fuel and oxidant efficiency; this is illustrated by the oxygen consumption rates in Figure 1.

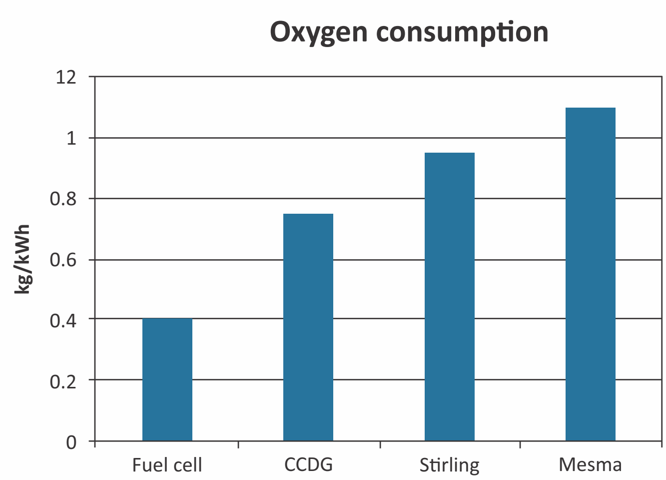

Figure 1: Oxygen Consumption for Four AIP Power Generation Technologies.

The fuel cell, which is an electrochemical energy converter, offers the greatest potential for stealthy, submerged operation, both for manned and unmanned platforms, and the rest of the paper will focus on this AIP technology. Fuel cells convert a fuel and an oxidant directly into electricity by an electrochemical process, which is, in theory, up to 100% efficient. However, practical limitations lower the fuel cell's efficiency, typically to between 40% and 65%. The basic fuel cell stack has no

moving parts, can generate electricity silently, and is potentially low maintenance with a long operational life, depending on design.

There are several types of fuel cell, operating in different temperature regimes, and typically named according to the type of electrolyte used. Solid oxide fuel cells operate at high temperatures (750-1000 ºC) using ceramic materials as electrolyte and electrodes. They hold promise for use in utility power and naval applications owing to the possibility of using a hydrocarbon fuel directly by either internal reformation to hydrogen and carbon dioxide, or by direct oxidation. Molten carbonate fuel cells operate at around 650 ºC and internal reformation is also possible with these systems.

Proton Exchange Membrane Fuel Cell (PEMFC)

There are several alternative configurations for fuel cells, but for submarine propulsion, so-called "Polymer Electrolyte Membrane" (PEM) fuel cells have attracted the most attention because of their low operating temperatures (80° Centigrade) and relatively little waste heat. In a PEM device, pressurized hydrogen gas (H2) enters the cell on the anode side, where a platinum catalyst decomposes each pair of molecules into four H+ ions and four free electrons. The electrons depart the anode into the external circuit - the load -as an electric current. Meanwhile, on the cathode side, each oxygen molecule (O2) is catalytically dissociated into separate atoms, using the electrons flowing back from the external circuit to complete their outer electron "shells." The polymer membrane that separates anode and cathode is impervious to electrons, but allows the positively-charged H+ ions to migrate through the cell toward the negatively charged cathode, where they combine with the oxygen atoms to form water. Thus, the overall reaction can be represented as **2H2 + O2 => 2H2O** (as shown in figure 2), and a major advantage of the fuel-cell approach is that the only "exhaust" product is pure water. Since a single fuel cell generates only about 0.7 volts DC (direct current), groups of cells are "stacked" together in series to produce a larger and more useful output. The stacks can also be arrayed in parallel to increase the amount of current available.

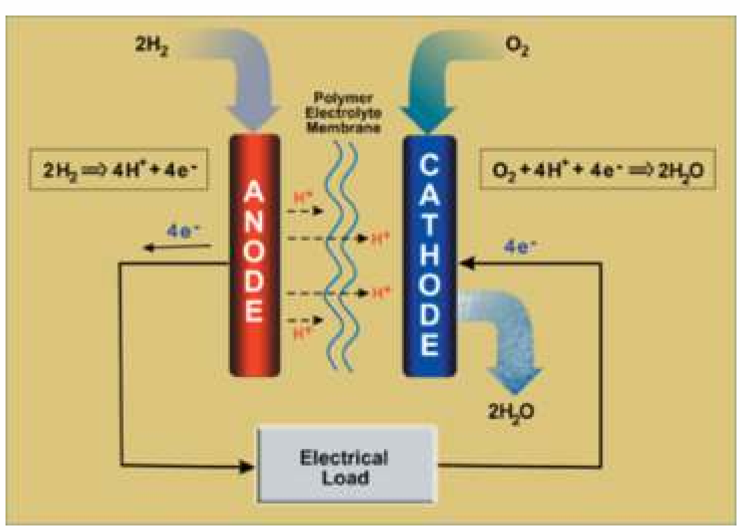

Figure 2: Basic Principle of fuel cell

In the last ten years, Siemens have developed a 34 kW PEM fuel cell for module for AIP (see figure 3) and a 300 kW assembly of these modules (see figure 4) is being used on the new Class 212 submarine, the first of which was launched early in 2002. The fuel cell alone will power the submarine to 8 kts; for greater speed, the fuel cell is supplemented by a lead-acid battery in a hybrid configuration. To replace the modules being used in the Class 212 submarine, Siemens are also developing a 120 kW PEMFC that will have higher volumetric and gravimetric power densities than the 34 kW modules.

Figure 3: A Siemens PEMFC Module as used on the German 212 AIP Submarine (Source: HDW).

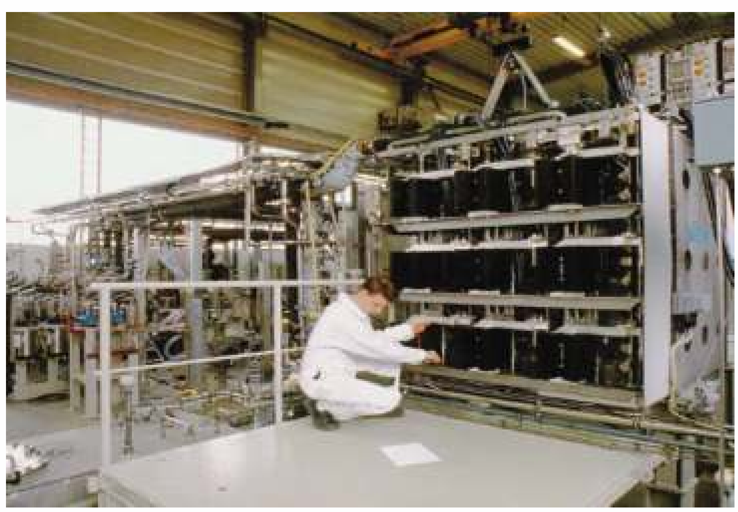

Figure 4: A Siemens 300 kW PEMFC Stack Assembly as used on the German 212 AIP Submarine (Copyright Jane's Information Group; Source: HDW)

One of the major advantages of the fuel cell over the traditional battery is that the power capability of the fuel cell stack can be varied independently of the energy storage capability. When a high energy storage density is required, it is the properties of the fuel and oxidant sub-systems that dominate the overall size of the complete fuel cell plant. The most energy-dense fuel in gravimetric terms is hydrogen, which has a theoretical energy storage density of 33 kWh/kg, compared with diesel and methanol at around 13.2 and 6.2 kWh/kg respectively. One of the greatest challenges is to package hydrogen effectively, particularly for minimum volume for submarine vehicles.

Hydrogen Storage and Generation Technologies

A fuel cell needs a fuel and an oxidant. The fuel of choice is hydrogen and the oxidant is usually oxygen. There are many methods by which hydrogen may be stored or generated but not all will be relevant to submarine applications, for which volume is usually a more important consideration than weight. Compressed gas storage technology has advanced considerably over the last decade Advanced, 700 bar, composite cylinders have been demonstrated with a storage capacity of 11 wt% hydrogen, which is roughly equivalent to 2.5 kWh/kg. This figure was recently raised to 13 wt%. The size of cylinders available is limited to automotive applications but would be eminently suitable for unmanned underwater vehicles and swimmer delivery vehicles. The same technology could also be used for oxygen storage.

The beauty of compressed gas storage is the simplicity of the hydrogen storage sub-system. Using the pure reactants - hydrogen and oxygen - also means that the only product is pure water. The disadvantage of compressed gas is the requirement for high performance, power hungry compressors. The volume taken up by the sub-system is also relatively high. Storing hydrogen as a cryogenic liquid is assumed to be impractical for underwater applications owing to the extremely low temperatures required. Hydrogen has a very low boiling point at 1 bar of 20 K (-253oC) and therefore special insulated containers are required, with attention being paid to the hydrogen lost due to boil off. Two further methods of hydrogen storage will be considered - reversible intermetallic metal hydrides and carbon nanofibres. In addition, hydrogen generation by reforming liquid fuels will also be discussed.

Reversible Metal Hydrides

Certain intermetallic alloys can store and release hydrogen reversibly [2]. These are referred to as reversible or secondary metal hydrides, to distinguish them from the primary metal hydrides, such as lithium hydride, that can only release hydrogen by decomposition, either at very high temperatures or by reaction with water. Many alloys are suitable for storing hydrogen; selecting the best depends on the precise conditions required.

Reversible metal hydrides are a heavy option but on a volume basis are very competitive, better than liquid hydrogen itself. Current ambient temperature alloys are capable of reversibly storing up to 1.8 wt % hydrogen and 0.1 tonne H2/m3 but, unfortunately, the hydride cannot be densely packed since hydrogen must be able to permeate through the medium. Additionally, the hydriding process is exothermic such that a heat exchanger is required to cool the alloy on charge and to heat it on discharge.

Metal hydrides are the safest method for storing hydrogen because the storage containers are filled with metal hydride and contain virtually no free gas. The pressure in the containers is low (10 to 15 bar) and, because the desorption of hydrogen is endothermic, a rupture of the storage container will only result in a controlled loss of hydrogen. As this leak continues, the alloy will get progressively cooler, which will reduce the leakage rate.

Howaldtswerke Deutsche Werft (HDW) has developed an air-independent-propulsion (AIP) system for the Class 212 submarine in which the hydrogen is stored as a metal hydride. The metal hydride is heated by the fuel cell cooling water system to provide the energy for endothermic dehydrogenation. The positioning of the hydride storage tanks around the outer hull means that their considerable mass can further contribute to reducing low-frequency radiated noise. The hydride storage system is completely maintenance free and can therefore be located outside the main pressure hull.

Carbon Nanofibres

Carbon nanofibre technology is still in its infancy but the hydrogen storage capability is claimed to be very high. The inventors, have claimed to have made a new form of carbon that can store up to three times its own weight in hydrogen, under pressure, at room temperature, but the claim has been met with some scepticism. Recent work by the inventors has revised the claims downward but they still report a very respectable 46-68 wt % hydrogen absorption and a release of between 43-58 wt % without heating. The estimated density of the charged fibres is 0.5 g cm-3, giving a volumetric storage density of 0.29 tonne H2/m3. The predicted specific energy and energy density for a system using fibres storing 50% hydrogen are 5.7 MWh/T and 4.2 MWh/l respectively, when the weight and volume of the container is included in the calculations. It should be noted that graphite nanofibre storage is at a very early stage of development and little is known.

Methanol Reformation

The nearest competitor to carbon nanofibre storage system in terms of energy density is methanol reformation. For most land-based applications, a fuel cell will use oxygen from the air as the oxidant as this saves the weight and volume of having to carry an oxygen source. However, for a submarine application, oxygen must be carried. A disadvantage of a fuel cell system that uses a reformate gas as opposed to pure hydrogen is that the reforming system will have a higher oxygen demand. This is because, in addition to operating the fuel cell, oxygen is also required to reform the liquid fuel into hydrogen, either for partial oxidation reforming or to burn a small proportion of the fuel or off-gas to provide the heat for steam reformation. This extra oxygen requirement must be factored into any calculations. A further complication of reforming systems is that carbon dioxide is also produced as a by-product of the reaction and this needs to be stored or disposed of safely and discretely.

Liquid fuels, such as methanol and diesel, have the advantages that they are readily available, may be stored in tanks and have a high energy density. Often, these advantages outweigh the complications introduced by a reformer. Carbon monoxide is a potential by-product of the reformation process. This is a reversible poison for the platinum catalyst used in PEM fuel cells and therefore purification of the gas is required before it is fed to the fuel cell.

A steam reforming system suitable for a submarine needs might comprise:

- a storage vessel for methanol,

- a storage vessel for oxygen,
- a steam reformer assembly,
- a gas purification stage,
- a CO2 handling system.

The CO2 produced during reforming must be stored on board the submarine or discharged into the sea with a minimum signature and energy loss. Carbon dioxide has a high solubility in water and, if necessary, could be discharged without producing bubbles by pre-dissolving the gas.

Methanol is a liquid at room temperature and could be stored in tanks. The methanol will be consumed as it is used by the fuel cell, and a hard conformal tank would require compensation to accommodate the changing volume to prevent it collapsing. Direct water contact with methanol is unacceptable because the two are miscible. External storage of methanol in soft conformal bags is a possibility. The bags would be fabricated from methanol-resistant material and, during operation, the seawater would naturally displace the consumed methanol without coming into contact with it.

Methanol is a toxic, flammable liquid that burns without a flame but is easily contained and therefore, if the system is correctly designed, it should not pose a safety hazard. A methanol reformer for submarine applications is being developed under HDW sponsorship. There is also considerable interest in methanol reformer systems for use in cars and buses.

Diesel Reformation

The most abundant fuels used in the world are derived from crude oil. Crude oils are complex mixtures consisting primarily of hydrocarbons and other compounds containing sulphur, nitrogen, oxygen and trace metals. The principal fuels are made by fractional distillation of the crude petroleum. Diesel fuel has very high volumetric and gravimetric energy densities (see Table 1).

Both diesel and kerosene have more than double the energy density of methanol. Unfortunately, the reformation of diesel is more technically difficult than reformation of methanol, and the overall chemical to electrical conversion efficiency of the fuel is only likely to be about 30%, compared with methanol at 55-60%. Diesel also contains appreciable quantities of sulphur compounds, which are poisonous to the conventional reformer and fuel cell catalysts. The much higher temperatures required for diesel reformation add to the complexity of a reformer system and reduce the conversion efficiency compared with methanol. The gas clean-up process is more complicated than for methanol since hydrogen sulphide, as well as carbon monoxide, must be removed. The main advantages of diesel fuel include:

- excellent volumetric and gravimetric energy densities,
- current military logistic fuel,
- extensive distribution network.

Table 1: Properties of Methanol, Kerosene and Diesel

	Methonol	Kerosene	Diesel
Formula	CH_3OH	$C_{9.3}H_{18.1}$	$C_{13.9}H_{22.6}$
Flash point	11	43	52
Wt percent H_2 produced	18.8	32.5	31.4
Vol. Density (kg H2/L)	0.071	0.266	0.267
Calorific energy density (kWh/L)	3.95	10.48	10.51
Calorific specific energy (kWh/kg)	4.97	12.8	12.37
Fuel Volume for 1MWH ($m^{3)}$	0.50	0.22	0.23
Fuel weight for 1MWH (T)	0.40	0.18	0.19

Its main disadvantages are:

- requires desulphurization,
- requires high pressure and temperature,
- reformer exhaust gas by-product must be managed (stored or discharged),
- higher oxygen demand than H2 storage systems.

Cleaner hydrocarbon fuels such as kerosene or gasoline could be reformed. Kerosene is a common commercial and strategic distillate used in a broad range of applications from lanterns to jet fuel. It is less volatile than gasoline and has a higher flash point to provide greater safety in handling. It has a much lower sulphur content than diesel fuel and can be reformed more easily.

Direct Oxidation of Liquid Fuels

Alcohols and hydrocarbons can, in theory, act as fuel for a fuel cell and be directly oxidized like hydrogen. One of the commonest fuels of this type is methanol, which is used in the Direct Methanol Fuel Cell (DMFC).

The direct oxidation of large hydrocarbons such as decane, petroleum and sulphur-free diesel has been demonstrated in high temperature (750-1,000 °C) solid oxide fuel cells, which would yield a high energy, liquid fuel. However, the high operating temperature, and the need to dispose of carbon dioxide and other detectable by-products, makes these systems unsuitable for covert operations.

Oxygen Storage

All AIP power generation options require the storage and consumption of oxygen. Primary systems store the O2 in either its gaseous or liquid form. Gaseous storage requires the use of large heavy tanks and, while the use of composite materials would reduce the weight penalty, the cost could be excessive for large platforms but acceptable for smaller ones. Composite cylinders would still suffer from a relatively low volumetric performance. LOX systems include the cryogenic storage of O2 in subcritical and supercritical form. Subcritical O2, which appears to be the most commonly used technique, is maintained in the liquid state at extremely low temperatures (< -118.6 oC) and at high pressures (3- 55 bar). It is also possible to store O2 as a supercritical fluid (> -118 oC, >50 bar), which removes the tendency to slosh. This could be advantageous in a submarine where trim may be affected by the changing distribution of liquid, although internal baffles could be used. Secondary systems provide O2 through chemical reaction. The alternatives are chlorate candles, superoxide and hydrogen peroxide. Primary storage in liquid form is the optimum choice.

Certainly AIP will significantly increase submerged endurance and reduce detectability. The longer underwater duration will ensure that conventional AIP vessels require new methods for supplying crew's oxygen; harnessing the boil-off of the oxidant supply for the AIP system would be a convenient and efficient method of achieving this. Each crew member requires about 1 kg of O2 per day for life support. Thus the mass of oxygen required for a 50-day patrol with a crew of 50 is about 2.5 tonnes. It is likely that LOX will remain the oxidant of choice for manned platforms, where oxygen is required for the crew. For unmanned systems, hydrogen peroxide is being evaluated as a serious alternative.

Technical Issues and Integration

Oxygen storage is a mature technology being accepted by several navies as the favoured option for storing the oxygen for AIP systems. In contrast, hydrogen storage technologies are at an early stage of development with new systems being proposed, so the system of choice is not yet identified. The major advantages and disadvantages of the four main hydrogen storage or generation systems are summarised in table 2.

Table 2: Comparison of Hydrogen Storage and Generation Technologies

Technology	Advantage	Disadvantage
Metal hydride	Good volumetric density Pure hydrogen liberated Ambient temperature operation Proven technology of suitable scale	Poor gravimetric density
Carbon nanofibres	Excellent gravimetric and volumetric energy densities claimed Pure hydrogen liberated Ambient temperature operation	Technology not proven Cycling ability unknown
Methanol reformation	Good gravimetric and volumetric energy densities No sulphur produced Liquid fuel	Requires reforming High oxygen demand CO2 disposal
Diesel reformation	Very good gravimetric and volumetric energy densities Logistic fuel Inexpensive	Requires reforming Sulphur impurities Higher oxygen demand High temperatures required CO2 and other emissions Technically difficult/not proven

CONCLUSIONS

For covert littoral operations, submerged platforms have a key role, and stealthy propulsive and surveillance power is required. This is best provided by an integrated, hybrid, air-independent propulsion system in a full electric architecture. AIP will be valuable primarily as a low-speed, long-endurance adjunct to the under- water performance of conventional submarines. Their tactical flexibility, their small size, their inherent stealth - and the novel operational paradigms AIP submarines introduce to undersea warfare - will make these new boats a dangerous threat to submariners accustomed to nuclear- or conventionally diesel-powered adversaries.

Of the current AIP power generator options, the proton exchange membrane fuel cell (PEMFC) is the stealthiest, fuel efficient, option for all sizes of platform. The ideal fuel option would be hydrogen stored in a reversible metal hydride, or in compressed form using an advanced, high performance, composite cylinder. If it really works, carbon nanofibre hydrogen storage could revolutionize fuel cell exploitation. The ideal oxidant, particularly for large platforms, is oxygen, stored as a liquid. For smaller platforms, hydrogen peroxide looks a more attractive oxidant, and a metal anode, such as aluminium, magnesium or lithium, might be a more attractive fuel than hydrogen.

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[8] www.chinfo.navy.mil/navpalib/cno/n87/usw/issue_13/propulsion

[9] www.ijert.org

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LESSONS FROM SUBMARINE DESIGN AND CONSTRUCTION PROGRAMMES WORLDWIDE

Capt Amit Ray, PhD.

Abstract

Design and construction of submarines are among the most challenging engineering projects by any standards. With increasing sophistication of technology and cost, coupled with reducing scale of submarine construction programmes in most countries, there is increasing emphasis on improving processes and practices. This paper reviews the various approaches adopted by submarine building nations in recent design and construction projects. Approaches adopted in contemporary construction programmes of the US, UK, Russia, France and Australia have been assessed. Aspects of programme management, technology induction, design process, and equipment development are discussed. Lessons learnt from construction practices and timelines achieved have been compiled and analysed.

Introduction

Submarines, particularly nuclear-powered strategic platforms, are among the most complex engineering creations in the world. While the number of countries operating submarines worldwide has been steadily increasing, the capability of submarine design and construction is limited to a handful of nations. Even for nations with established capabilities, the number of submarines being built has reduced over the last three decades. While the focus on new technology has been steady, there has been increasing emphasis on costing and efficient programme management. Consequently, there have been several studies and reports on recent submarine construction programmes in the USA, UK, France, Australia and China. The approaches adopted and evolved by different nations for various aspects of their submarine programmes offer valuable insights into the options available and lessons learnt.

Programme Management

The world's first strategic submarine construction project was the Polaris programme of the UK, which set several new benchmarks in project management. The nuclear propulsion system had already been proven, for the first time in the world, by the attack submarine programme starting with Nautilus, commissioned in 1954. In the wake of the Soviet Union's achievements in space, the US accorded the topmost national priority to its sea-based strategic deterrence programme, which was given extraordinary authority in order to ensure very stringent timelines[1]. In spite of the numerous first-time technologies involved, the programme took just four years, exactly as per schedule from inception (in Nov 1955) till delivery of the first SSBN (USS George Washington commissioned in 1959). The programme management of the 'Special Projects Office' though manned by naval personnel, was characterised by independence from the existing hierarchy, autonomy in financial powers and direct lines of communication with all stakeholders.

The Polaris programme of the UK was also formed on similar lines, with the 'Chief Polaris Executive' heading an independent organisation with its own design team, procurement team and weapons team. The UK Polaris programme benefited immensely from a unique and close working relationship with the USA. The nuclear reactor of the first SSN, the HMS Dreadnought had been obtained from the USA[2]. The Polaris missile system installed in the SSBNs, starting with Resolution (commissioned 1967) was also from the USA. Access to these technologies enabled early readiness of the first UK SSBN, just four years after the programme was initiated[3].

While detailed information of the first Soviet, French or Chinese SSBN programmes are not available to the same extent (as the US and UK programmes), it is certain that similar focused efforts would have resulted in their first boats being delivered in 1960, 1971 and 1983, respectively.

Over the next few decades, the SSBN programme management has gradually merged with the acquisition organisations of respective navies. However, the national importance of the strategic submarine programmes is now well established. The design and construction programmes in the USA have strived to not only ensure timely and cost-effective replacement of obsolescent platforms, but also enable retention of national submarine design and construction capability, for both SSNs and SSBNs[4]. This concern for keeping alive design capabilities has been observed in the UK as well, in spite of depletion in options for submarine construction yards.

People are the key. Both the Astute and the Collins class submarine construction programmes that were faced with several issues, recognised the lack of continuity of personnel in technical and management roles as a key problem. On the contrary, part of the success of the Virginia program was due to the strong leadership and management in both the Navy and at the shipbuilders, particularly due to identifying and grooming of future leaders[5].

Further, it is essential to utilise and closely involve the entire gamut of expertise available for technology induction, acquisition, maintenance, operations, construction and design at all stages of the programme. Co-location of appropriate organisations was found to be an essential factor in ensuring such participation.

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[1]Spinardi, G., From Polaris to Trident: the Development of US Fleet Ballistic Missile Technology, Cambridge, 1994, p. 38

[2]Hennessy, P. and Jinks, J., The Silent Deep: The Royal Navy Submarine Service since 1945, Penguin, 2016.

[3]Moore, J.E., The Impact of Polaris: The origins of Britain's seaborne nuclear deterrent, Richard Netherwood, 1999.

[4]Schank, J., et al., Sustaining U.S. Nuclear Submarine Design Capabilities, RAND, 2007.

[5]Schank, J.F., et al., Learning from Experience, Volume II – Lessons from the US Navy's Ohio, Seawolf and Virginia Submarine Programs, RAND, 2011, p.91.

Technology Induction

Induction of cutting-edge technology has been the primary objective in evolving from one design to the next. Technology has been driven by operational imperatives such as greater payload, longer range and endurance, greater operational flexibility in terms of speed and depth, and better stealth capabilities. The years of the Cold War saw tremendous advances in submarine technology[6]. Aspects such as hull form, propulsion, silencing, sonars and navigation saw radical improvements.

Many of these technologies could be tried out on prototype submarines because of the funding available in those years of heightened tension and maximum priority. In the US, these included nuclear propulsion (as well as various types and configurations of reactors) tried out in the USS Nautilus, the Glenard P. Lipscomb, the Narwhal and the Triton. Successive innovations in drag reduction and manoeuvrability were tried out on various generations of the Albacore (1960-1970)[7] by the US and on the Beluga (1983-1990) by the USSR.

An example of technology induction is pumpjets, the current generation of low-noise propulsors. The pumpjet was first tested on the UK SSN HMS Churchill in 1970 and implemented on the Trafalgar class SSNs, which entered service from 1978. The US evaluated a pumpjet first on the USS Cheyenne (SSN 673- Los Angeles class) and adopted it thereafter for the Seawolf class (entered service in 1997)[8]. The Soviet/ Russian Navy first undertook trials on a Project 877 (Kilo) submarine, B-871, from 2004[9]. Pumpjets have now been implemented on all modern SSBNs (as well as most SSNs) of the US, UK, French and Russian navies.

The multiplicity of submarine classes designed and produced in the USSR offered much greater scope for new technology induction. The path-breaking automation, liquid metal reactors and Titanium hull of the Alfa class (Project 705) that served during 1977-1981 shook up US submarine design. Similarly, the silencing levels achieved by the Akula (Project 971) that entered service in 1984 drove US and UK submarine designs towards even lower noise levels.

With the end of the Cold War, the high expenditure and cost of programmes such as the Seawolf class SSN of the US could no longer be sustained. In hindsight, the Seawolf class suffered from too great a proportion of new, unproven technologies[10]. The ideal mix of proven and new technologies in a design appears to be somewhat near 80:20 ratio, but this is neither sacrosanct nor easily amenable to quantification.

Governmental Defence R&D organisations were at the core of technology development for submarine applications. Iconic organisations such as the David Taylor Research Center in the USA, the Admiralty Marine Technology Establishment in UK and the Krylov Ship Research Institute in

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[6] Polmar, N. and Moore, K., Cold War Submarines: The Design and Construction of US and Soviet Submarines, Potomac Books, 2003.

[7] Jackson, H.A., 'The Influence of the USS Albacore on Submarine Design', RINA Symposium on Naval Submarines 4, May 1993.

[8] Polmar and Moore, p.309.

[9] Apalkov, Yu.V., Podvodniye Lodki VMF SSSR - Spravochnik (Submarines of the Soviet Navy - Handbook), Galea Print, St. Petersburg, 2006.

[10] Schank, J.F., et al., Learning from Experience, Volume II, p.53.

Russia were the path blazers in marine hydrodynamics and a variety of other technologies for propulsion, acoustics and stealth that were specifically developed for submarines. Many of the test facilities created were conceived and developed to unique proportions in these laboratories, such as cavitation tunnels, signature measurement chambers, hyperbaric chambers, large-scale unmanned models and acoustic ranging basins. In the West, responsibility for new technology development gradually shifted from captive government R&D facilities to academia and industry.

The Chinese nuclear submarine programme, which originated in 1959, was nowhere as smooth as those of the Western powers. A series of challenges were faced in technological aspects of submarine construction, nuclear power plant and development of the various sub-systems of the missile complex, which took decades to overcome, culminating in the first Chinese SSN being commissioned in 1974[11].

For the replacement to the Ohio class SSBN, of which the lead boat is planned to be inducted in 2031, technology development work started as early as 2012. The technology development phase includes research and investment in certain key areas such as electric drive, X-shaped stern and propulsion shaft research[12].

Design Process

The traditional submarine design process has been sequential, with successive stages of design involving greater level of definition, and greater time and effort. The process has also been described as cyclic, with every iteration leading to better definition (reduction in assumptions), leading to refinement in characteristics.

Till the 1960s, submarine design capability was the responsibility of the Navy or specialised governmental design bureaus. Gradually, detailed design capability was built up in the shipyards building the submarines. Further, since the 1970s, the in-house design capability of the US and UK navies were gradually diluted. Correspondingly, the design capability of shipyards (such as BAE Systems-Barrow in UK, Electric Boat in USA) and private firms (such as IKL in Germany, QinetiQ in UK) were gradually consolidated. Some firms such as Kockums in Sweden and RDM in the Netherlands suffered mergers or dissolution due to dwindling business volumes.

The dilution of Navy design capability, such as pausing inductions to the Royal Corps of Naval Constructors in the UK[13], had negative impact on the viability and progress of subsequent projects. The initial delay in the Astute SSN programme was partly attributed to this loss of in-house design expertise.

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[11]Lewis, J.W. and Litai, X., China's Strategic Seapower: The Politics of Force Modernization in the Nuclear Age, Stanford University Press, 1994.

[12]Osborne, K., 'Navy Ohio Replacement Submarine Starts Early Construction', http://www.defensetech.org/2013/10/24/ohio-replacement-submarine-starts-early-construction/ , Accessed Sep 16.

[13]Schank, J.F., et al., Learning from Experience, Volume III – Lessons from the United Kingdom's Astute Submarine Program, RAND, 2011, p.14.

Splitting the design responsibility between agencies, particularly between competitors, is fraught with risks. This happened in case of the Seawolf class SSN, where the initial design responsibility was with Electric Boat. Detailed design was split between Electric Boat as well as Newport News, for construction in parallel at both the yards[14]. Similar disconnect between the design team of GEC Marconi for Astute and the Barrow shipyard resulted in delays and difficulties[15].

After the expensive and short-lived Seawolf class, as part of efforts to reduce time and cost of construction, the concept of 'Integrated Product and Process Development' (IPPD) was adopted for the Virginia class SSN[16]. This involved multi-disciplinary teams, responsible for each zone of the submarine, across all stages of design. Each team was composed of specialists from the Navy as well as the shipyard (Electric Boat). This included not only naval architects (designers) but also operators, equipment suppliers, those in the production trades, cost engineers, purchasers, engineering analysts, testers and quality assurers.

Apart from the composition of these teams, another new feature of the IPPD approach was the compression of design stages into a seamless process, unlike the traditional process of design stages with gaps in-between. The teams progressively developed the design from the definition of requirements till issue of construction drawings in the following stages:-

(a) Platform characteristics are defined.

(b) 2-D and 3-D drawings of each area are prepared and systems modelled to evaluate arrangements.

(c) Mock-up drawings are created for limited areas and after finalising design configuration, 'intelligent models' created incorporating materials and parts details.

(d) Drawings are produced and manufacturing support data is generated

(e) Build strategy finalised and drawings are issued for construction

Along with each "Major Area Team" responsible in the IPPD for each physical area (such as Engine Room, Sail, Accommodation, etc.), there was a set of "System Integration Teams" responsible for systems (such as electrical network, ventilation, hydraulics) distributed across the submarine.

It is a common lesson from many programmes that design changes must be minimised once construction has commenced. Delays in construction may suggest opportunities to make improvements, but these temptations should be determinedly resisted. Three years into the Virginia programme, the initial requirements remained unchanged despite challenges. In each case, the Navy programme manager cited cost control as the dominant program requirement in denying all proposed changes.

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[14] Schank, J.F., et al., Learning from Experience, Volume II, p.47, 49.

[15] Schank, J.F., et al., Learning from Experience, Volume III, p.34, 40, 65.

[16] Schank, J., et al., Sustaining U.S. Nuclear Submarine Design Capabilities, p.15.

Physical mock-ups that were once standard during the detailed design process, appear redundant with implementation of 3D-CAD models. However, it is noteworthy that even in the Virginia class, which was largely designed using CAD, partial physical models were still necessary and did prove useful[17].

Submarines are intricate designs and the fine margins available in weight, stability, power, heat load and other design margins need to be carefully managed and monitored. The detailed design, construction and operations of a new submarine may begin to consume its initial design margins[18]. These need to be closely examined, since without adequate margins, it may be difficult or impossible to modernize the equipment or undertake missions over the entire operational life of a submarine class.

Roles of Agencies

The reduction in government funding after the Cold War led to scaling down of Defence R&D laboratories and facilities in not only Russia but also in USA and UK. Various R&D labs in UK were brought under a single Defence Research Agency in 1991, further integrated into the Defence Evaluation Research Agency (DERA) in 1995. In 2001, the DERA was split into two separate organisations: the Defence Science and Technology Laboratory ("Dstl") and Qinetiq. The government remained a part-owner in newly created organisations such as Qinetiq in UK and DCNS in France.

An offshoot of the scaling down of captive Defence R&D was the increasing reliance on private engineering firms for consultancy in specific areas such as propulsion, signature management, or various systems integration. There was also a consolidation of private firms within larger conglomerates. Examples are the incorporation of Electric Boat Yard within General Dynamics and the acquisition of Barrow shipyard (after many changes in its name and ownership) within BAE Systems.

At the beginning of the UK's Astute programme, in a quest to lower costs, the significant MoD presence in design and on-site overseeing was cut down assuming that the private sector would assume technical as well as management responsibility. The MoD advocated an "eyes on, hands off" approach. The 'prime contractor' was supposed to be the design authority, right from concept design, based on extraordinarily detailed performance specifications prepared by the MoD. However, due to issues faced in the first three boats of the Astute class, the MoD reclaimed its role of design authority for boats 4 to 7 in the series[19].

The number of shipyards capable of building submarines has steadily reduced in the US, UK and Russia. Maintaining even two shipyards capable of nuclear submarine construction was a challenge for the USA in the post-Cold War years, while for the UK there was no choice but to rely only on one yard.

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[17]Schank, J.F., et al., Learning from Experience, Volume II, p.85.

[18]Schank, J.F., et al., Learning from Experience, Volume I – Lessons from the Submarine Programs of the United States, United Kingdom and Australia, RAND, 2011, p.41.

[19]Schank, J.F., et al., Learning from Experience, Volume III, p.15, 23. Schank, J.F., et al., Learning from Experience, Volume III, p.15, 23.

Equipment Development

The design and development of customised equipment is an essential pre-requisite for the construction and indeed, for finalisation of the design itself. The process is closely linked to technology induction and as mentioned earlier, the balance between proven and unproven technologies is hard to strike. Other than in the Soviet Union, most equipment development for submarines has been in the private sector, relying upon a plethora of vendors ranging from large corporations to small enterprises.

The Navy or the shipbuilder's role is to specify the performance requirements, the limiting characteristics and the quality parameters. Sustained efforts are required to promote developmental efforts by private firms, and prototype testing is generally essential. The long-lead developmental and production time for complex and major equipment are often defining parameters in the construction programme. These include the propulsion plant, the combat systems and the weapons complex.

About 58 unique suppliers were identified by US yards engaged in Virginia class construction[20]. The key suppliers of equipment are those significantly involved in design as well as production of components. For example, such capability for nuclear reactors was built up in the UK by Rolls Royce in association with a few other firms that formed 'Rolls Royce and Associates' in 1959. This conglomerate was the recipient of submarine nuclear reactor technology from Westinghouse of the USA, facilitated by close governmental and naval links between UK and USA[21].

Bulk orders and the assurance of repeat orders are an essential incentive for engaging capable firms in equipment development. Series production enables long-term partnerships, but submarine production runs have reduced worldwide. A number of vendors suffered losses in the USA when the planned production run of the Seawolf SSN was curtailed from the initially planned 29 boats to just three actually built.

Another example of the effect of long gap between successive designs was seen in the Astute. In the design of the Astute, it was assumed that many equipment of the earlier Vanguard SSBNs and Trafalgar SSNs would be used. However, most of this legacy equipment was no longer available since many approved vendors had left the industry when orders stopped. Re-establishing suitable vendors caused further delays in the readiness of Astute.

The proportion of “Buyer Furnished Equipment” (BFE) or “Government Furnished Equipment” (GFE) was also sought to be reduced in the Astute programme to cut costs, in the belief that the prime contractor could reduce costs through competition for various equipment. Consolidation of vendor base is considered to be helpful in improving supply chain management. For the Astute programme, ten key vendors supply 70 per cent of the material value of the submarines. Quarterly meetings are held to assess the health of these key suppliers and the MoD and prime contractor work with them to provide an overview of future programmes and challenges faced[22].

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[20] Schank, J., et al., Sustaining U.S. Nuclear Submarine Design Capabilities, p.101.

[21] Hennessy and Jinks, p. 182.

[22] Schank, J.F., et al., Learning from Experience, Volume III, p.48.

While the thrust on indigenisation must remain the top priority, the need to source certain key equipment from foreign suppliers may remain. Assurance of the reliability and economic viability of such suppliers during the operational life of the submarine is essential. The Collins class faced serious problems in equipment such as diesel engines and its combat systems due to foreign suppliers providing inadequate support[23].

Construction Approach

The classical approach of submarine construction involves complete joining of structural sections before commencing piping or cabling across the boat. With submarine construction inevitably occurring in cylindrical / conical blocks, there has been progressive increase in the quantum of cabling, piping and equipment installation before these blocks are joined. A major step forward has been off-boat system integration and testing, and rolling-in of systems rather than equipment into the structural blocks.

This 'modular construction' concept was first implemented at a large scale in the US on the Ohio class SSBNs by Electric Boat. Interior systems were built as modules and slid into place in cylindrical sections. A similar approach had been adopted earlier for construction of SSKs in Sweden and was subsequently adopted for the Astute class construction in the UK. Even for the Collins class of Australia, large modules of the submarines came from multiple shipyards, including the Kockums yard in Sweden.

In the Virginia class (and later, the Astute class) all major systems and equipment were tested off the submarine before their installation and integration. Separate test facilities created for machinery systems and even combat systems enabled discovery and correction of problems in conducive environment off the boat.

The advances in modular construction are reflected in the level of outfitting completed before joining structural sections. The first Virginia-class boat was 81 percent complete when the shipyard closed the pressure hull, compared with 57 percent for the Seawolf and 33 percent for the Los Angeles[24]. As the Virginia program progressed, the size of the modules was increased and the number of separate modules was reduced from ten to four.

In the gap of just eight years between start of construction of the last / first boat of successive classes of submarines at Barrow shipyard in the UK, crucial knowledge about managing the build process and ensuring quality of construction significantly depleted. This gap also resulted in production practices lagging behind advances made in the corresponding period in Electric Boat in the US.

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[23]Schank, J.F., et al., Learning from Experience, Volume IV – Lessons from the Australia's Collins Submarine Program, RAND, 2011, p.49.

[24]Schank, J.F., et al., Learning from Experience, Volume II, p.80.

Use of 3D CAD environment for construction was introduced in the US for the Ohio class and in the UK for the Astute class. There were many teething troubles experienced due to this transition. There was conflict between the details in the drawings and the previous practices of shipyards. Learning how to develop CAD models was a challenge for the designers and learning how to read and implement them was a challenge for the shipyards. It took several years for the production drawings to be optimised to suit production requirements.

The term 'concurrent design' is often used to refer to the process of design overlapping with the construction of the lead boat of the class. The Seawolf class construction started when only about 5 percent of the construction drawings were completed. For Virginia, this figure was improved by ten times to 50 percent[25]. In the case of the Australian Collins class, construction of the hull began in 1989, when only about 10 percent of the construction drawings were complete[26]. In case of the Astute as well, construction started before the detailed drawings were completed, which resulted subsequently in significant rework, cost and delay. Based on these experiences, it is recommended that the electronic product model should be approximately 80 percent or more complete when construction begins[27].

An essential feature enabling timely delivery of successive Virgina class boats generally within 8 to 12 months of each other was the comprehensive Integrated Master Schedule (IMS), with a very high level of detail. This schedule was linked to imposition of discipline in procurement and delivery of equipment for installation, both contractor-furnished and buyer-furnished.

For better performance in schedule adherence as well as cost accounting, the Virginia programme adopted an Earned Value Management System (EVMS) for programme performance measurement. Earlier methods compared planned results with actual results, whereas EVMS integrated cost, schedule and scope to help the programme manager to identify and control problems through a series of metrics reviewed in weekly meetings[28]. Construction metrics covered the complete range of ship construction activities down to the ship system level.

Oversight of construction by the MoD/ Navy prior to the Astute consisted of about 50 personnel, which was drastically cut down to only 3. Based on lessons learnt mid-way through the programme, increased involvement of MoD was reflected in the oversight presence being increased to more than 30 personnel in the Barrow shipyard. The role of overseers is not limited to quality control or providing feedback on status of the programme, but also to interact with designers and builders and help to arrive at decisions on changes to contract requirements.

Testing prior commissioning is a crucial part of the construction process. Prior to Astute, the UK Royal Navy/ MoD had been responsible for testing and commissioning a new submarine. For the first time in Astute, this responsibility was transferred to the prime contractor, which was not prepared for the same. Rectification required a new organisation with cooperation between key submarine suppliers and the Navy[29].

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[25]Schank, J.F., et al., Learning from Experience, Volume II, p.82.

[26]Schank, J.F., et al., Learning from Experience, Volume IV, p.23.

[27]Schank, J.F., et al., Learning from Experience, Volume III, p.72.

[28]Schank, J.F., et al., Learning from Experience, Volume II, p.82.

[29]Schank, J.F., et al., Learning from Experience, Volume III, p.46.

Project Timelines

Design and construction timelines for SSNs and SSBNs span decades. The duration of the submarine design process (from concept design to completion of workshop design) is about 12 to 13 years. However, this duration may vary in the range of 10 to 15 years depending on factors such as governmental approvals, shipyard loading and naval requirements.

The first Chinese SSBN, boat 406 of the Type 092 (Xia class), was laid down in 1978 at Huludao shipyard; she was completed in 1981. After fitting out and trials, she finally became active in 1987. The current Chinese SSBN class is the Type 094 (Jin class). The first boat became operational in 2010, three were operational in 2013, and four in 2015[30].

Timelines for construction of recent classes of SSNs and SSBNs worldwide are shown in Figure 1. The construction process, from laying down till acceptance by the navy, takes about 7 to 10 years. However, examples of projects that have taken longer are the Yuri Dolgorukiy (Borei class SSBN) and the Severodvinsk (Yasen class SSN). Their first-of-class boats took more than 16 / 20 years (respectively), with durations expected to reduce to about 6-10 years for subsequent boats. Since the processes of design and construction usually overlap to varying extents, the total period of design and construction from beginning of concept design till induction into service (commissioning) is about 12 years for Virginia and 16 years for Astute first-of-class boats.

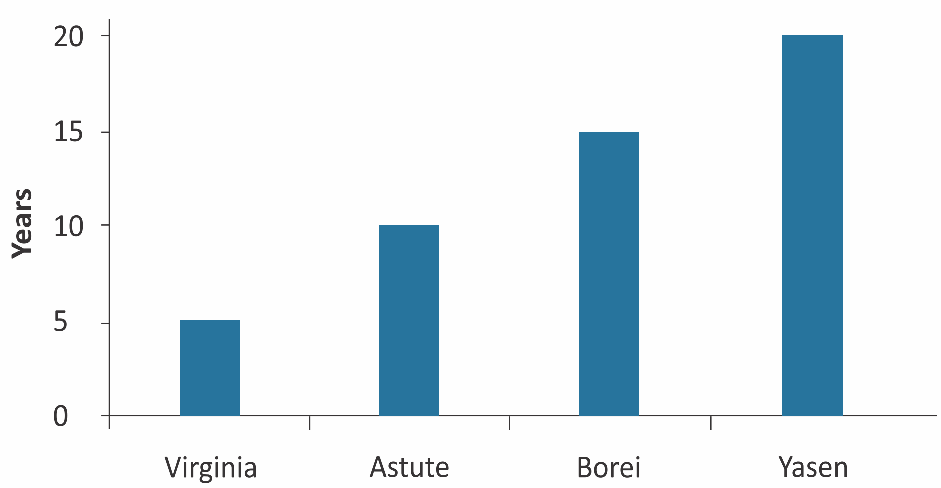

Figure : Duration for construction of first-of-class: Recent nuclear submarines

[30]Fisher, Richard D, Jr., 'US upgrades assessment of China's Type 094 SSBN fleet'. IHS Jane's 360. Accessed October 2015.

The construction duration for successive boats of the same class ideally should show the positive effects of a 'learning curve'. However, this is not always seen. For the first eight boats of the US Ohio class in the 1980s, the delivery interval was 8 to 10 months. For the current UK SSBN (Vanguard) class of four boats delivered in the 1990s, gap between commissioning of successive boats actually increased from 17 months to 23 months, to 36 months. For the Virginia class, the gap has been varying from 4 to 23 months, with an average periodicity of about 12 months.

As the existing Ohio submarines reach the end of their extended service life of 43 years, the first Ohio replacement submarine was planned to enter service in 2029[31]. It was announced in July 2016 that the lead boat will be named Columbia. With a delay of about two years as on date, the scheduled developmental, design and construction timelines for the next generation US SSBN, spanning 19 years, are as follows[32]:-

- 2012: Commenced research, development, test, and evaluation
- 2017: Start detailed design and advanced procurement of critical components
- 2021: Commence construction of lead boat (build period: 7 years)
- 2028: Commence three-year strategic certification period for lead boat
- 2031: Lead boat commences active strategic sea-service.

Recommendations

Salient lessons for attention that may be highlighted for indigenous submarine design and construction programmes are as follows:-

- It is essential for the MoD and the Navy to be an intelligent and informed customer, and not delegate design or oversight authority.
- Contract structures need to include appropriate provisions to absorb or tackle the technical risks inherent in such long-duration complex endeavours. Incentives for improvements need to be built-in and risks need to be shared between both parties.
- A single agency for detailed design, closely integrated and familiar with the production yard, is essential for an effective design and efficient resolution of issues during construction.
- The design process must include and take inputs from builders, maintainers, operators and major equipment developers. The goal of design and construction should be not only achievement of specifications but also cost-effectiveness after its delivery, with balanced emphasis on ease of maintenance and operation.

[31] O'Rourke, R., 'Navy SSBN(X) Ballistic Missile Submarine Program: Background and Issues for Congress', Congressional Research Service Report for Congress, April 22, 2011.

[32] Osborne, K., 'Navy Finishes Specs for Future Nuclear Sub', http://www.dodbuzz.com/2014/04/08/navy-finishes-blueprints-for-future-nuclear-sub/, Accessed Sep 16.

- Successive designs should aim towards enhancing operational availability and avoiding mid-life refuelling.
- The majority of design drawings (ideally at least 80 percent of the 3D CAD model) must be completed before construction begins.
- Responsibilities of supply chain management need to be adequately staffed and given due importance since they greatly affect the progress of the programme.
- Selection of government-furnished and contractor-supplied equipment need to be judiciously done based on the strengths and capabilities of each.
- Development of strategic capabilities in the industrial base as well the MoD and Navy is a long term effort that needs to be nurtured to ensure retention of skills and institutional experience. Undue gaps between design / construction programmes or switching industrial partners can lead to serious attrition in specialised capabilities.
- Changes during construction need to be minimised and discouraged.
- Quality and adequate numbers of key personnel are essential for the success of every complex programme. Grooming future programme managers and technical experts within the Navy and the industrial base are essential. Continuity of personnel in ongoing programmes is also essential for ploughing in lessons over decades-long programmes.

Author's Biodata

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His academic qualifications are B.Tech. (Hons.) from CUSAT, PG DIIT from IIT Delhi, M.Tech. (Ocean Engineering & Naval Arch.) from IIT Kharagpur and Ph.D. (Submarine Hydrodynamics) from IIT Delhi. His awards include the Director's Gold Medal from IIT Kharagpur (2006) and Medal of Distinction from Royal Institution of Naval Architects, UK (2010).

He has served twice in Naval Dockyard Visakhapatnam as AMFAB, MFAB and DGM(Hull). He has served at IIT Delhi as faculty, and at IHQ MoD(Navy) in Directorate of Naval Architecture and Directorate of Naval Design (SDG). He is presently serving in Ship Building Centre, Visakhapatnam.

article

4

AIR REGENERATION PROCESSES ONBOARD UNDERWATER PLATFORM

BY – Devinder Singh Pannu Sc 'É' DND(SDG)
Lt Cdr H M Pradeep DDND(SDG)

Introduction

1. Keeping air quality and atmosphere composition into appropriate ranges is one of the most critical problems of a submarine. Oxygen consumption and Carbon Dioxide generation represent the main threats, that all subs in the world have to manage and monitor carefully. Since the advent of nuclear-powered submarines with their ability to travel long periods submerged without surfacing, while generating vast amounts of electricity for shipboard use, replenishment of oxygen in the closed atmosphere and removal of air impurities has been a critical requirement and a complex technological and engineering task. Air Regeneration in Submarines was introduced towards the end of World War II and was limited to the use of soda lime for removal of carbon dioxide and oxygen candles for regeneration of oxygen. The next major advances came with the advent of nuclear-powered submarines. These included the development of regenerative and, sometimes, energy-intensive processes for comprehensive atmosphere revitalization. With the present development of conventional submarines using air-independent propulsion there is a requirement for air purification/revitalization similar to that of the nuclear-powered submarines but it is constrained by limited power and space. Some progress has been made in the adoption of air purification equipment used in the nuclear-powered submarines for this application.

Background:

2. The air we breathe is made up of significant quantities of four gases such as Nitrogen (78%), Oxygen (21%), Argon (0.94%) & Carbon dioxide (0.04). When we breathe in air, our bodies consume its oxygen and convert it to carbon di oxide. Exhaled air contains about 4.5% carbon dioxide. Our bodies do not do anything with nitrogen or argon.

3. A Submarine is a closed eco system that contains people and a limited supply of air. There are three things that must happen in order to keep air in submarine breathable:

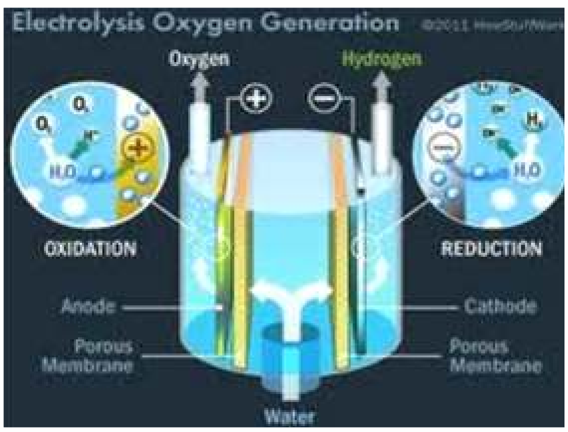
   - Oxygen has to be replenished as it is consumed. If the percentage of oxygen in the air falls too low, a person suffocates.
   - Carbon dioxide must be removed from the air. As the concentration of carbon dioxide rises, it becomes toxic.
   - The moisture that we exhale in our breath must be removed.

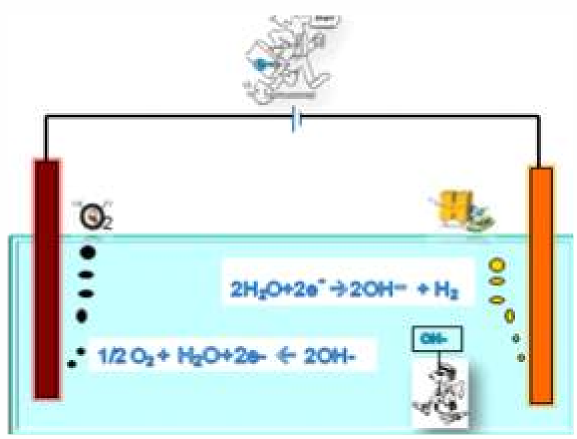
Closed Atmosphere Control Equipment:-

- Electrolytic Oxygen Generators, Oxygen Candles
- CO2 Scrubbers, CO2 Adsorber/Absorber

Oxygen Generation

Electrolytic Oxygen Generators





Electrolysis Process Diagram

4. Using pure water, a mixture of potassium hydroxide, and electricity, a grouping of electrolytic cells shown in the above drawing provide more than sufficient breathable oxygen for a submarine crew. The electrolytic cells are enclosed within the electrolytic oxygen generator cabinet shown above. The hydrogen produced is safely disposed-of. A newer unit, the Low Pressure Electrolyzer, using state-of-the-art proton exchange membrane electrolysis cells is now being used in newer submarines.

Solid Polymer Oxygen Generator

5. A new generation oxygen generator has been developed to advance the technology of safe and reliable oxygen production. The Oxygen Generating Plant (OGP) produces breathing oxygen through water electrolysis using a Solid Polymer Electrolyte (SPE) cell. This method of producing

oxygen requires no free acids or caustic liquids. The OGP offers the following advantages over current units.

a) Eliminates caustic electrolyte (KOH) and asbestos which is used as an insulator. The catalyst impregnated plastic diaphragm serves as both the electrolyte and separator.

b) Microprocessor controlled. The OGP requires only 15 minutes to go through a shutdown, purge, and restart to full operation compared to the 6 hours required by the Electrolytic operated O2 generators (EOGs).

c) Operates at low pressure. Although capable of operating at pressures between 300 and 3000 psi, the normal mode of operation will be at low pressure (500-600 psi) once the oxygen banks are charged.

d) Reduced inventory of combustible gases. At equal pressure the hydrogen side contents of the OGP are one-tenth of the EOG. Lower normal operating temperatures bring further H2 reductions.

e) A 50% increase over EOG capacity, which permits providing the entire crew O2 needs with only one OGP.

f) Discharges pure oxygen products. Provides essentially pure O2 compared to EOG contamination of 0.5 to 1.0 % H2 contamination.

Oxygen Candles

6. A chlorate candle, or an oxygen candle, is a cylindrical chemical oxygen generator that contains a mix of sodium chlorate and iron powder, which when ignited smolders at about 600 °C (1,112 °F), producing sodium chloride, iron oxide, and at a fixed rate about 6.5 man-hours of oxygen per kilogram of the mixture. The mixture has an indefinite shelf life if stored properly: candles have been stored for 20 years without decreased oxygen output. Thermal decomposition releases the oxygen. The burning iron supplies the heat. The candle must be wrapped in thermal insulation to maintain the reaction temperature and to protect surrounding equipment.

Potassium and lithium chlorate, and sodium, potassium and lithium perchlorates can also be used in oxygen candles.

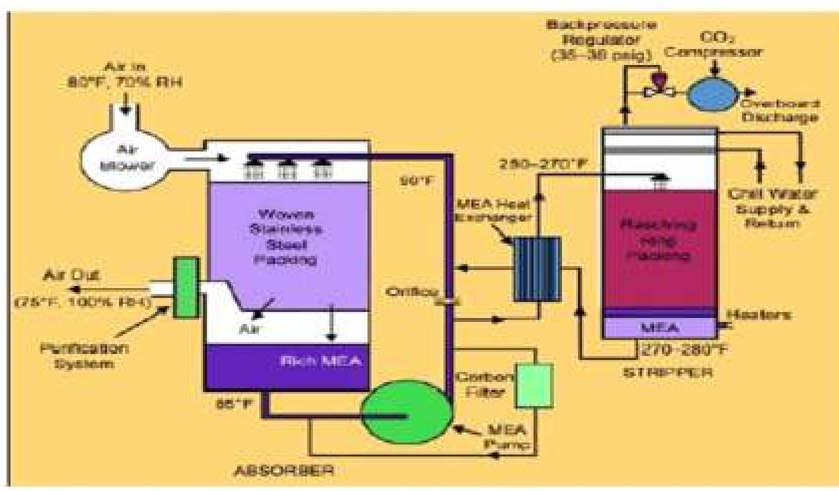
Cryogenic Process

7. Cryogenic air regeneration/revitalization is a new promising method to purify air in AIP submarines carrying liquid oxygen (LOX) at approximately –180oC for their propulsion system. Here the heat sink in the LOX is utilized to cool the contaminated air to approximately -150oC, thus separating pollutants from the air stream by condensing or freezing them. Cryogenic air purification is efficient for a large number of air pollutants, e.g. CO2, VOCs (except methane), particles, ozone, etc. It is therefore a highly attractive technique to develop further. The use of energy that is otherwise wasted is another feature making cryogenic air purification to a suitable method for the future.

Co2 Gas Elimination Processes

CO2 Scrubbers/Absorbers (Chemical Based)

8. A Scrubber / Absorber is used to remove CO2 gas continuously on a submarine using chemical based process. Chemical generally used to remove CO2 is mono-ethanol amine. MEA is the acronym for mono-ethanol amine. MEA has the formula NH2 C2 H4 OH. The air to be treated enters the exchange tower at 80oF and 75% relative humidity. Between 70 to 90% of the CO2 is removed by this one pass through. The air is passed through a filter to entrap droplets of the MEA solution and the air returns to the Submarine at about 75oC and 100% RH. The MEA solution is recycled over the stainless steel screens with a portion of it withdrawn on each pass. This material is passed through a column packed with glass rings and heated to drive off the CO2 under pressure. The 'cleaned' MEA is returned to the absorption cycle. The CO2 is cooled, compressed and discharged overboard.



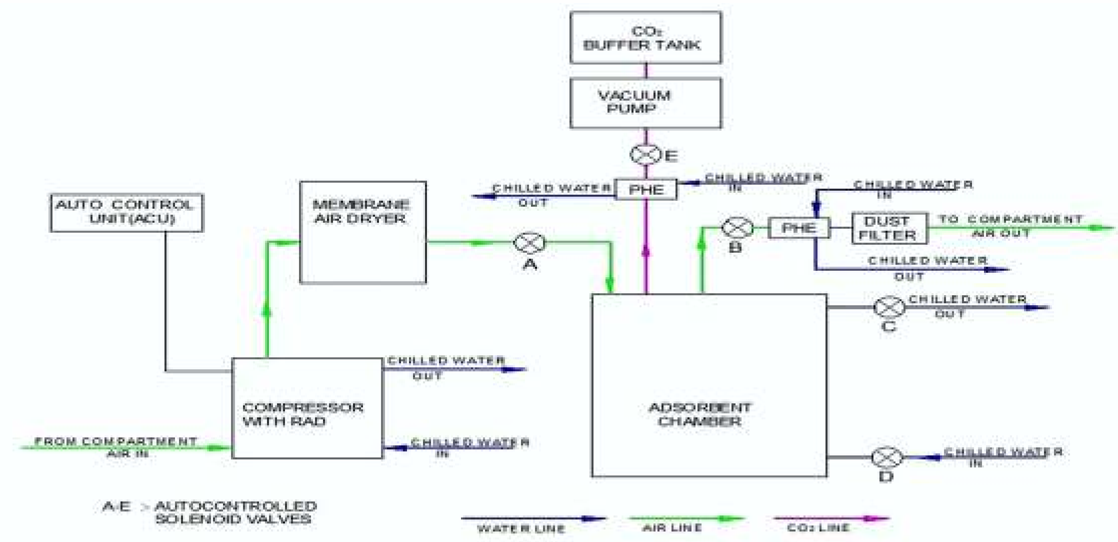
Chemical Based Scrubber / Adsorber Process Diagram

CO2 Adsorbers (Molecular Sieve Based)

9. In the molecular sieves based CO2 absorbers, the adsorption of CO2 takes place when the air coming from compartments is passed over the molecular sieves placed in each adsorption bed of the unit. A molecular sieve (grade 5A) is an industrially produced zeolite material with an extremely large internal surface. Each pore is of uniform size and is slightly larger than a CO2 molecule. As CO2 contaminated air is passed through the zeolite bed the CO2 molecules are adsorbed to the bed pores. When the majority of the pores are occupied, the bed is heated, releasing the CO2, which can be discharged overboard.

   These beds are generally placed parallel in the adsorbent chamber and connected in series using top bed connectors and bottom bed connectors.

10. A water jacket is maintained around the beds. A flow of chilled water is maintained in the jacket to take away the heat during the exothermic adsorption reaction. Adsorbent chambers can be of rectangular or circular shape based on the requirements.



Flow Diagram of Adsorption Process

Soda Lime Process

11. In diesel-electric submarines carbon dioxide is usually purified with either soda lime or lithium hydroxide. As air is fed through a soda lime/lithium hydroxide canister, the carbon dioxide is chemically attached to the purification agent. This process is not easily reversed, making it necessary to store a full mission load onboard, occupying valuable space. Even though soda lime/lithium hydroxide is not the optimum solution.

Cryogenic Process

12. Cryogenic air purification is a new promising method to purify air in AIP submarines carrying liquid oxygen (LOX) at approximately –180oC for their propulsion system. Here the heat sink in the LOX is utilized to cool the contaminated air to approximately -150oC, thus separating pollutants from the air stream by condensing or freezing them. Cryogenic air purification is efficient for a large number of air pollutants, e.g. CO2, VOCs (except methane), particles, ozone, etc. It is therefore a highly attractive technique to develop further. The use of energy that is otherwise wasted is another feature making cryogenic air purification to a suitable method for the future.

Under Development Process

Biological Method

13. Biological air purification, mainly with green plants, has been used and tested in ordinary buildings (Darlington, Chan, Malloch et al 2000). However on submarines is still on an experimental stage. Biological purification uses either photosynthesis or enzymes to purify the submarine air. The photosynthesis approach, a photo bioreactor, is based on marine green algae that are kept onboard the submarine. The algae are fed with CO2-rich air and a nutrient

while being exposed to fluorescent light, thus converting the CO_2 to O_2 in a natural way. A possible problem with this method is to keep the algae alive. The Defence Science and Technology Organization (DSTO) in Australia has performed studies on this air purification method. It is not known if this system can also remove other air contaminants other than CO_2.

Overboard Disposal/Discharge Process of CO2

14. The CO_2 gases eliminated/absorbed/adsorbed through various process are required to be discharged out from the underwater platform safely. Accumulation/collection of CO_2 gases onboard is also harmful/hazardous. This overboard discharge of CO_2 gas can be carried out by compact compressors, which compress the CO_2 gas to the required pressure and the same will be discharged overboard through valves.

Author's Biodata

Capt DS Pannu (Retd) Sc 'E' is presently posted as a Director Naval Design (Submarine Design group). He is heading the group responsible for design of systems required for maintaining habitable micro climate onboard underwater platforms. He has been closely associated with indigenization of equipment related to Air Regeneration systems and improving the air flow pattern and temperature contures using CFD analysis in Habitable compartments.

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Lt Cdr HM Pradeep is posted as a Deputy Director Naval Design (Submarine Design Group). He has been involved in design of various systems of underwater platforms. He has shouldered various responsibilities at Naval Dockyards and Ships during earlier appointments. He is an aluminous of IIT Delhi Presently, the Officer is undergoing Management Course from IIM, Ahmedabad.

article 5

SHOCK RESISTANCE ESTIMATION USING TRANSIENT ANALYSIS OF FINITE ELEMENT MODEL OF SUBMARINE EQUIPMENT

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Abstract:

The shock mount plays a crucial role in shock attenuation in case of shock due to underwater explosion. This paper presents modeling and simulation of the dynamic behavior of shock mounting scheme of equipments installed inside submarine. The Finite Element Analysis software (ANSYS- APDL) was used to obtain the transient behavior of a DG set model and it was demonstrated that effect of shock can be effectively modeled by transient analysis of equipment FE model to estimate the shock resistance of the equipments.

1. Introduction

Shock resistance is an important design consideration during equipment and Platform design. Every equipment has specific shock strength [1] and it is platform designer's responsibility to make sure that the equipment should not receive the shock more than its shock resistance value for which it has been designed during its service life onboard. Finite element analysis plays a significant role in estimating the shock attenuation. In this paper emphasis is laid on use of transient analysis [2][3]of model to obtain shock attenuation and shock mount deflection.

2. Transient Analysis

Transient analysis is a module of ANSYS software which is employed for time varying dynamic analysis and is based on the transient dynamic equilibrium equation[4][5].

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F^a\}$$

Where:

$[M]$ = structural mass matrix

$[C]$ = structural damping matrix

$[K]$ = structural stiffness matrix

$\{\ddot{u}\}$ = nodal acceleration vector

$\{\dot{u}\}$ = nodal velocity vector

$\{u\}$ = nodal displacement vector

$\{F^a\}$ = applied load vector

In this Analysis structural Mass matrix, structural damping matrix, structural stiffness matrix and applied load vectors are used to calculate nodal acceleration, velocity and displacement. Transient analysis basically simulates the shock excitation wherein the time varying load is applied at the base of equipment and residual shock is measured at the equipment. In this paper Dynamic simulation was carried out for shock resistance estimation of Diesel generator. Transient analysis in ANSYS contains three principal steps, i.e., Pre-processing, solution and post-processing.

3. Finite Element modeling in ANSYS

ANSYS is general purpose finite element analysis (FEA) software package. Finite Element analysis is numerical method of deconstructing a complex system into very small pieces (of user designated size) called elements. The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for design and optimization of system far too complex to analyze by hand. Systems that may fit into this category are too complex due to geometry, scale or governing equations. The three principal steps in FEA are given below 6 .

3.1 Preprocessing

The user construct a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions , or elements, “connected at discrete points called nodes”. Certain of these nodes will have fixed displacements and others will have prescribed loads. Some of these preprocessors can overlay a mesh on a preexisting CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting and design process. In our finite element model elements were modeled using mass element MASS21, spring element COMBIN39 and beam element BEAM 188. Mass element was modeled to simulate the mass of equipment and lump mass of submarine. Spring element was modeled to simulate the shock mounts; the spring element here used is COMBIN39 which is a non linear spring element where one can define non linear force-deflection relation for spring as shown in Fig 1, which was very essential requirement to simulate the actual properties of rubber [2][9]. Beam element was modeled to simulate the connecting members which link the DG set with shock mount.

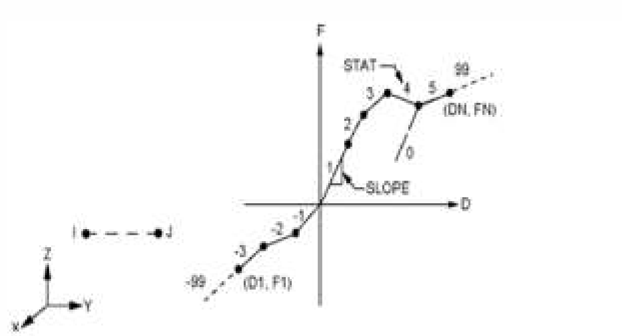

Fig. 1. Force-deflection relation of COMBIN39 Element.

After modeling the equipment in preprocessing, next step is applying load and boundary condition. In this case time varying load was applied based on the shock pulse as per naval standards as shown in Fig. 2, from the shock pulse equivalent g load is calculated and applied on the equipment base. Boundary conditions were applied on equipment such that only one degree of freedom was kept free i.e., the shock loading direction [7][8].

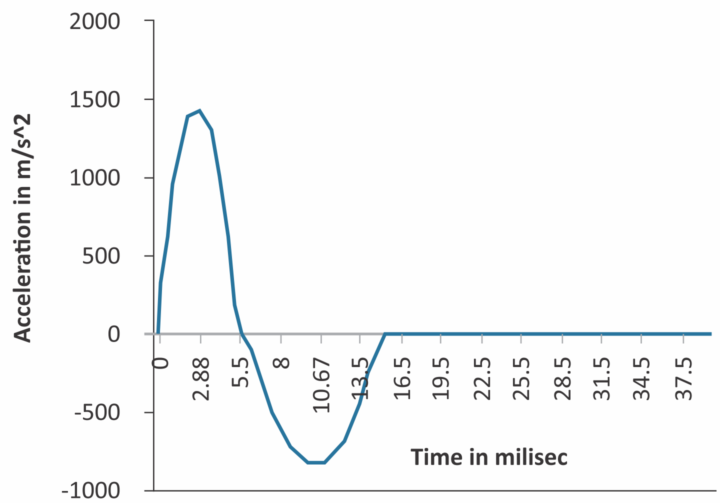

Fig. 2. Acceleration vs. time graph based on naval standard.

3.2 Solution

The data prepared by the preprocessor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations. After applying load and boundary condition next step is solving the finite element model, there are three solvers available in ANSYS Transient analysis i.e., Full solution method, Reduced solution method and Mode superposition method. For our application "Full solution method" was used. . Finite element model formed in ANSYS APDL for Diesel Generator shown in
Figure 3.

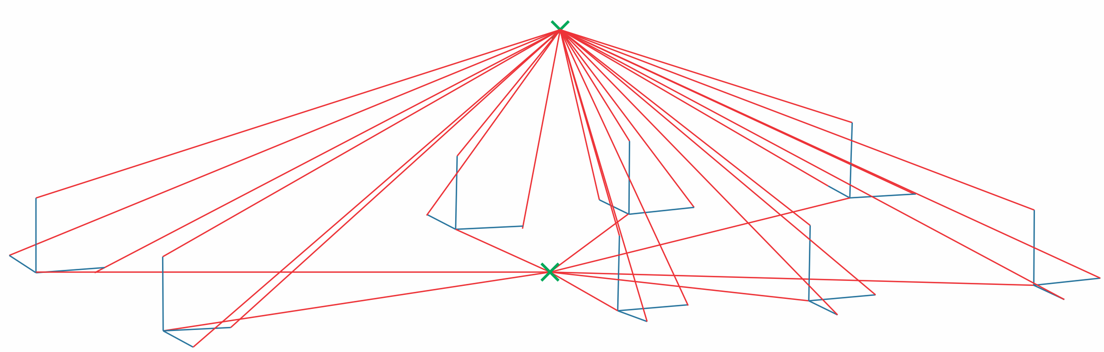

Fig. 3. Finite element model for Diesel Generator

Blue Lines represent spring Element COMBIN39, Red lines represent beam Element BEAM188 and Green Dots represents Mass Element MASS21.

3.3 Post Processing

In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hotspots this way, and modern codes use graphical display to assist in visualizing the results. Typical postprocessor display overlays colored contours representing stress and displacements on the models. The results for shock and deflection of DG set are shown in Fig. 4 and Fig 5 respectively.

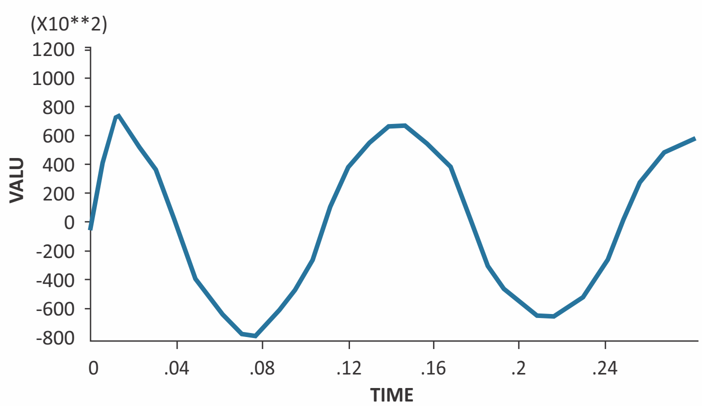

Fig. 4. Residual Acceleration in Z direction.

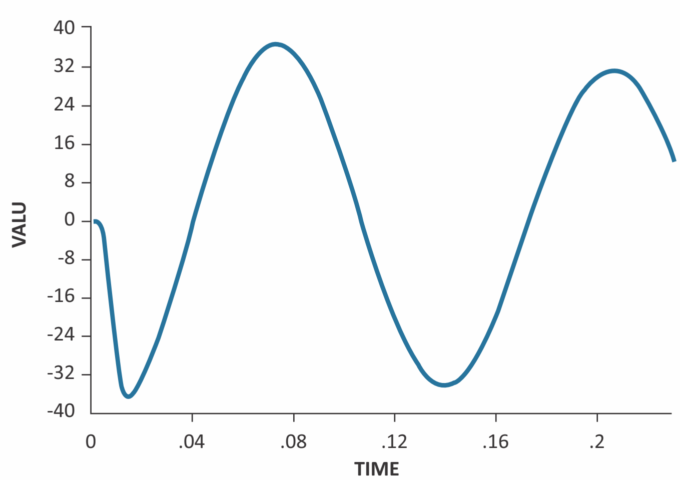

Fig. 5. Mount Deflection in Z direction.

4. Results

In Post processing the Time varying results were visualized, the important parameters were residual shock on equipment and deflection of shock mount are mentioned in table 1.

Table 1: Properties of Methanol, Kerosene and Diesel

Direction	'g' Value	Shock Pulse (ms) Full sine wave	Displacement (mm)
X	5	30	12
Y	5.6	25	15
Z	8	12	37

4. Conclusion

Finite element analysis plays a significant role in estimating the shock attenuation which is important design consideration while designing shock resistance of equipment and selection of shock mount. Practical testing for shock is a cumbersome task for submarines; hence finite element method seems most viable and simplistic approach for shock resistance estimation.

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Author's Biodata

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article 6

STUDY ON MULTI EFFECT DESALINATON SYSTEM FOR NAVAL APPLICATIONS

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Introduction

1. Water is one of the most abundant elements on the earth. However, only 3% of the earth's water is fresh, non-saline, held in lakes, rivers, and reservoirs while the remaining 97% is salt water in oceans. Meeting shortage of freshwater resources onboard naval platforms has been a major factor of consideration for naval designers. Need is felt to review a better, efficient and thermodynamically superior alternative in order to overcome this challenging task.

2. The development of desalination technology is an important way to resolve shortage of feed and fresh water availability onboard naval platforms. There are other desalination technologies such as membrane based Reverse Osmosis (RO) and thermal desalination based Multiple Stage Flash (MSF) being largely used onboard Naval Platforms. However, these have peculiar limitations governing their exploitation patterns and limiting distillate output. LT-MED (Low Temperature - Multi Effect Desalination) technology is one promising alternative technology for these. This technology can be coupled with power plants, propulsion systems or any other auxiliary systems powered with energy sources like nuclear, thermal or solar, but also have features of high thermal efficiency, high purity water production and sustained stable operation.

3. Naval platforms operate on different propulsion cycles and thus have abundance of high and low quality fluidic energy available. All platforms operating on steam propulsion (Rankine cycle) have an essential requirement of installation of Distilling Plants (DPs) onboard in order to ensure sustained availability of high quality feed water. Depending upon the output required from the DP (Distilling Plant) in terms of quantity and quality, the temperature of pilot steam into the desalination system can be selected.

4. MED technology is a thermal energy desalination based technology which has been developed and exploited on a large scale in Middle East and arid regions of African continent for production of potable and high purity water production. This technology has been used in paper, pulp and food processing industries since early twentieth century. With increased fresh water demand all around the world, the technology gained a substantiated growth in sea water desalination. Presently, MED technology has shown an increasing market demand overcoming conventional MSF (Multi Stage Flash) technology due to its inherent advantages and better results.

5.This paper aims at understanding prospects of utilizing MED technology for Naval Military platforms where stealth, space and complexity of equipment are the major challenges. Whilst the industry has already been utilizing this technology at a large scale, it is opined that, it has a vast scope of implementation as an alternative to the existing thermal and membrane based desalination systems which demand increased electrical loads, noise and vibration signatures and intense maintenance schedules. Aspects related to advantages, disadvantages and challenges associated with implementation of MED systems onboard naval platforms have been brought out in this paper.

Multi Effect Desalination for Naval Platforms

6. **Advantages of MED for Naval Platforms**. Following are the advantages of a MED plant for a Naval platform:-

(a) **Operation at Low Temperatures.** MED systems operate at comparatively much lower temperatures compared to conventional MSF plants due to utilization of low pressures for vaporization over tubes stacks under vacuumized conditions. This makes MED more suitable for even low grade primary heat sources wherein heat from engines exhaust, exhaust steam ranges, residual heat of flue gases or heat rejected overboard may also be efficiently utilized.

(b) **Absence of Tubes Scaling.** Unlike conventional MSF systems wherein scaling of tubes is a major cause of reduced heat transfer and sub-optimal performance, MED by virtue of its low operating temperatures operates much below the tubes scale inducing temperature range. This results in a reduced downtime of plant for maintenance and thus a longer operational cycle. ***Fig. 1*** indicates the calcium sulphate ($CaSO_4$) solubility curves for MED and MSF desalination systems. It can be observed that, salt based scale deposition is much lesser for MED systems due to low operating temperature ranges.

(c) **High Performance Ratios**. MED process has the potential of offering performance ratios in excess of 20. The maximum ratio will depend upon the top temperature of operation and the number of effects used. Depending upon the required distillate output rate the steam quantity and its temperature required at the first stage varies.

(d) **Low Initial Cost**. MED systems are comparable to MSF systems for initial cost of installation. Improvisation in materials and production facilities may result in further reduction of initial capital costs of plant installation.

(e) **High Stealth Characteristics**. Due to its ability of optimally operating at low temperatures, absence of dynamic components and low range of sea water flow Reynolds No, the MED plants result in having excellent stealth characteristics.

(f) **Improved Performance with Increasing First Stage Steam Temperature**. MED system performance improves with increasing performance ratio due to increase in the inlet temperature of first stage pilot steam. Onboard naval platforms, the availability of a suitable temperature source fluid, therefore can suffice for the improved performance of distilling plants by utilizing the MED system with increased output rate and quality of distillate.

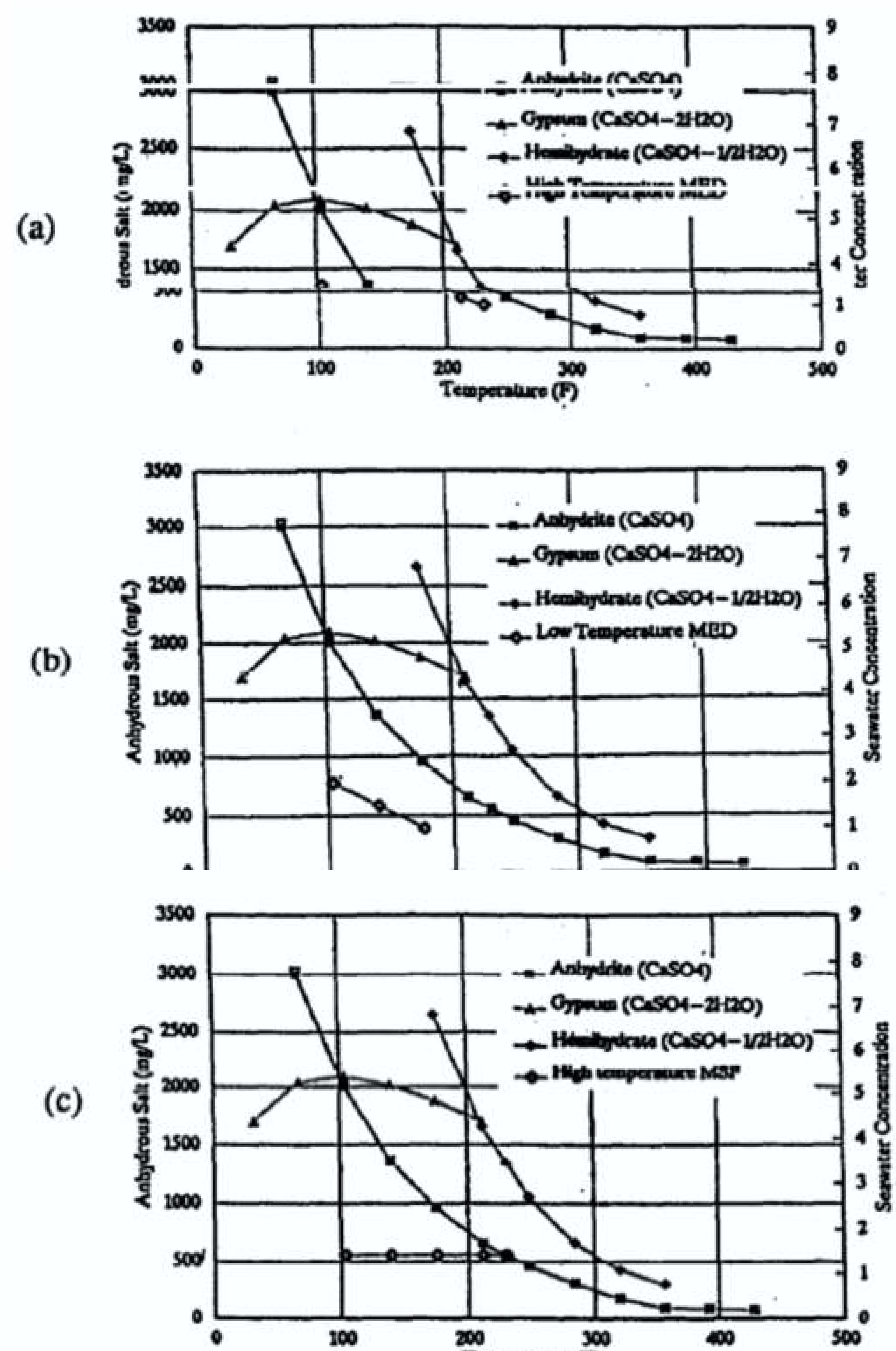


Figure 1. Calcium Sulphate Solubility Curves

(g) **Low Maintenance**. MED systems require low maintenance due to longer operational cycle periods avoiding requirements of undertaking de-scaling and frequent inspections of internal components. Additionally, absence of moving components further reduces the wear and tear factors experienced during exploitation of plants.

(h) **Absence of Low Tube Leak Contamination Risk**. MED systems may be considered free from sea water tube leak contamination free. Since the pressure inside of tubes stacks is always higher than the sea water flow pressure outside. Thus, in case of a tube leak, only steam leaks out and desalination remains contamination free with a little high rate of steam consumption.

7. **Typical MED Plant**. The schematic of a typical horizontal tube Multi-Effect Desalination (MED) unit is placed at ***Fig. 2.*** The steam enters the plant and is used to evaporate injected seawater into the respective effect stages. The secondary vapor produced is used to generate tertiary steam at a lower pressure. This operation is repeated along the plant from stage to stage in a cascaded pattern.

8. The MED technique is based on falling film evaporation and heat transfer phenomenon. The latent steam heat is transferred at each stage between the steam condensing inside of the evaporator tubes through the heat transfer surfaces to the sea water falling over the horizontal or vertical tubes stacks as thin film. Heat transfer on both sides of the heat transfer area is considered highly efficient due to the low resistance of the thin falling films, which allows efficient operation with a low temperature difference across the tube walls. The low temperature difference is limited by the increasing boiling point elevation (BEP) due to the increase in salt concentration while evaporating part of the water. It is also limited since at too high fluxes, the film starts to boil, nucleating bubbles, causing dry spots that may lead to salt precipitation. This mode of operation needs to be avoided. The low temperature difference across the heat transfer surfaces allows designing a large number of effects between the steam temperature at the first stage and the temperature of the cooling seawater at the other side.

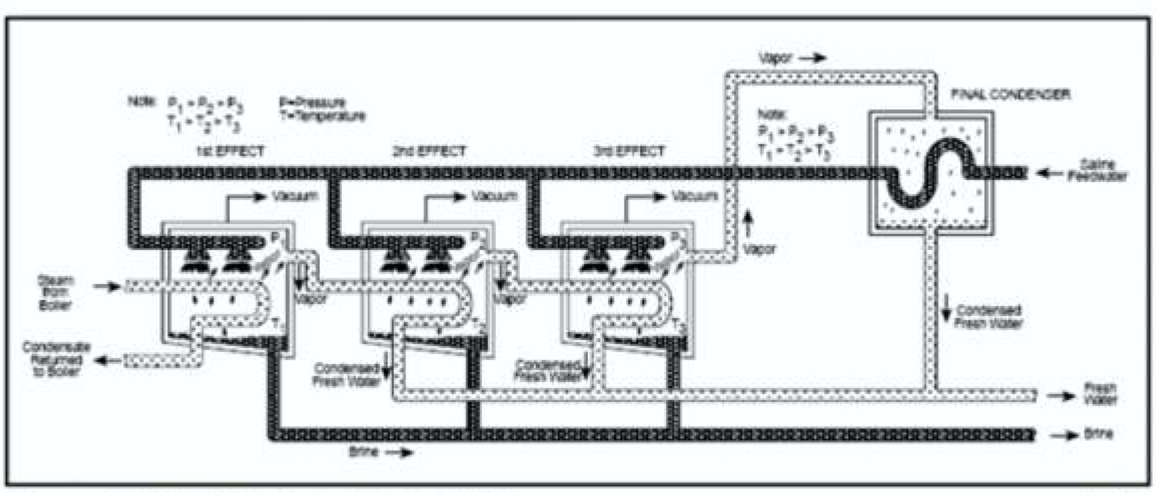


Diagram of a Multi-Effect plant with horizontal tubes. *USAID*

Figure 2. A Typical Horizontal Tubes MED Plant Layout.

9. This cascaded process has been repeated up to 16 times and even more in the existing plants used for large scale desalination processes. The efficacy of a MED plant depends upon the temperature difference between the upper possible temperature of inlet steam to the first stage and the lower possible inlet seawater temperature. The product water is the condensate that accumulates from stage to stage post condensation in each stage evaporators. A vacuum pump is used to maintain the gradual pressure gradient inside the vessel by removing the accumulated non-condensable gases together with the remaining water vapor after the final condensation stage. The pressure gradient along the MED effects is dictated by the saturation pressure of the feed stream and the saturation pressure of the condensing steam exiting the last stage and is condensed by the seawater. Pressure gradients of 5-50 kPa across the system and less than 5 kPa/stage are typical.

10. More stages increase the performance ratio or the **GOR - Gain Output Ratio**, which is actually the quantity of tons of water produced per ton of initial steam while reducing energy consumption of the process. The number of effects required for a given

desired output thus can be estimated using the following relation:-

$$\mathbf{GOR = 0.8 \times n}$$

Where,

GOR = Gain Output Ratio

n = No of effects

The GOR typically depends upon the initial steam temperature and can reach up to a value of 15, which is higher than the maximum value of 10 for MSF. Therefore, thermal efficiency of MED may be considered better than MSF.

11. The economy of design and operation is dictated mainly by the availability of a source of low-cost energy. In this case, operational conditions may lead to the choice of low cost materials and heat transfer surfaces when corrosion problems are minimized, while maintaining low probability of $CaSO_4$ precipitation on the tubes. A MED plant can be operated below 70 deg C using Aluminum or Titanium tubes, involving up to 50% recovery of energy. Corrosion rates are very low below this temperature and thus there is no need to remove oxygen, and cleaning of internal components and tubes is less frequent. An efficiently designed MED plant thus can easily meet the required water demands for a naval platform. Twin trains of MED stages may be built up to enable larger overall plant capacity in a compatible arrangement.

12. Many possible MED system designs are available as horizontal or vertical tubes or flat sheet heat exchangers during a stage. The stages may be arranged horizontally or vertically, and the seawater flow can be co-current, counter-current or parallel feed with the flow direction of the steam produced. These design variations affect water pumping in the system, which is related to part of the energy losses, and they affect the occasional cleaning of the heat exchangers. Specific process designs are sometimes developed for specific site conditions. **Fig. 3** illustrates a schematic view of a vertical tube evaporator design. Fig. **4, Fig. 5, Fig. 6 and Fig. 7** show installations of forward feed, backward feed, mixed feed and parallel feed MED system arrangements respectively. Research has indicated that **a parallel feed MED system has the highest and most optimal performance characteristics.**

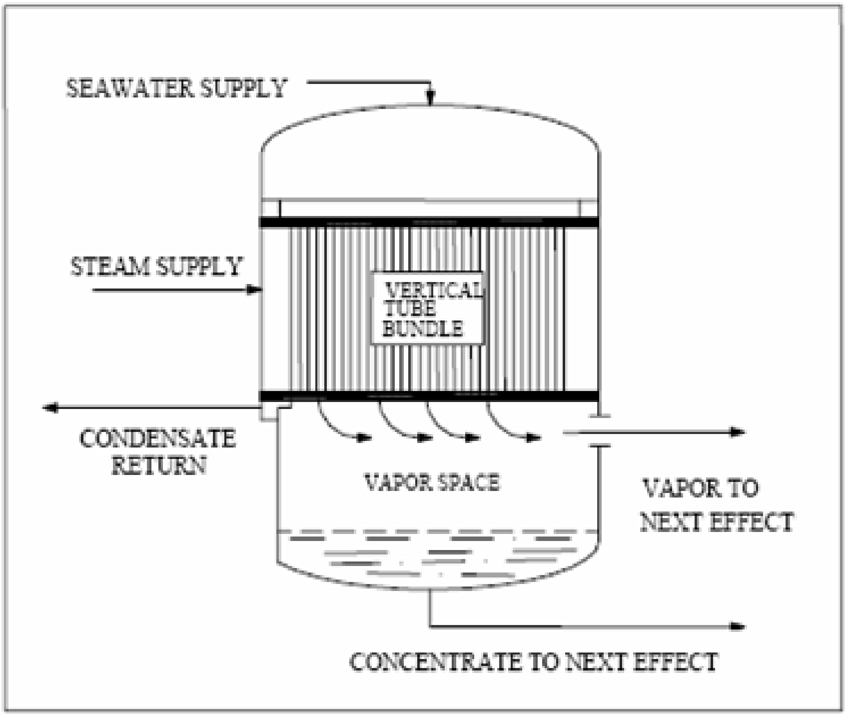


Figure 3. A Typical Vertical Arrangement MED plant Layout

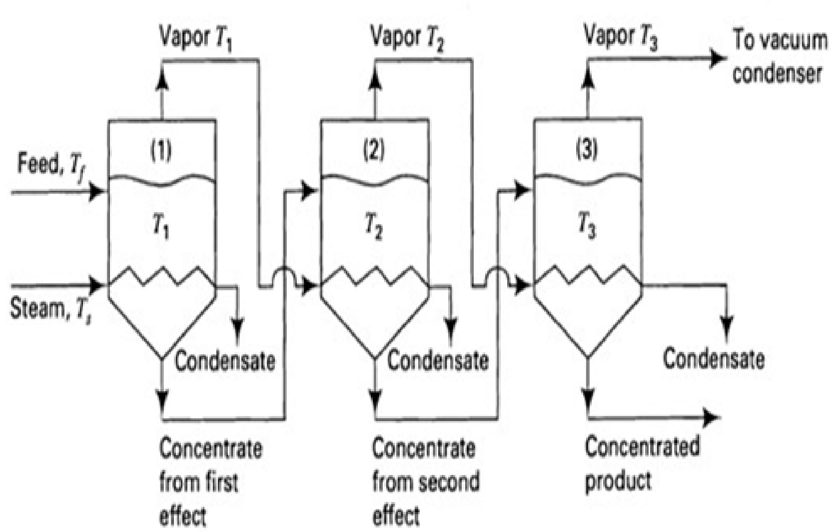


Figure 4. Schematic of a Forward Feed MED system

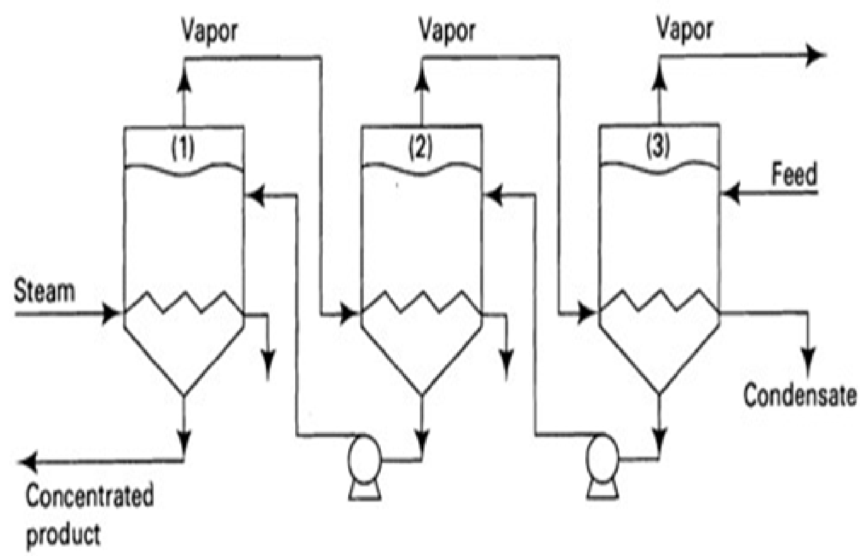


Figure 5. Schematic of a Backward Feed MED System

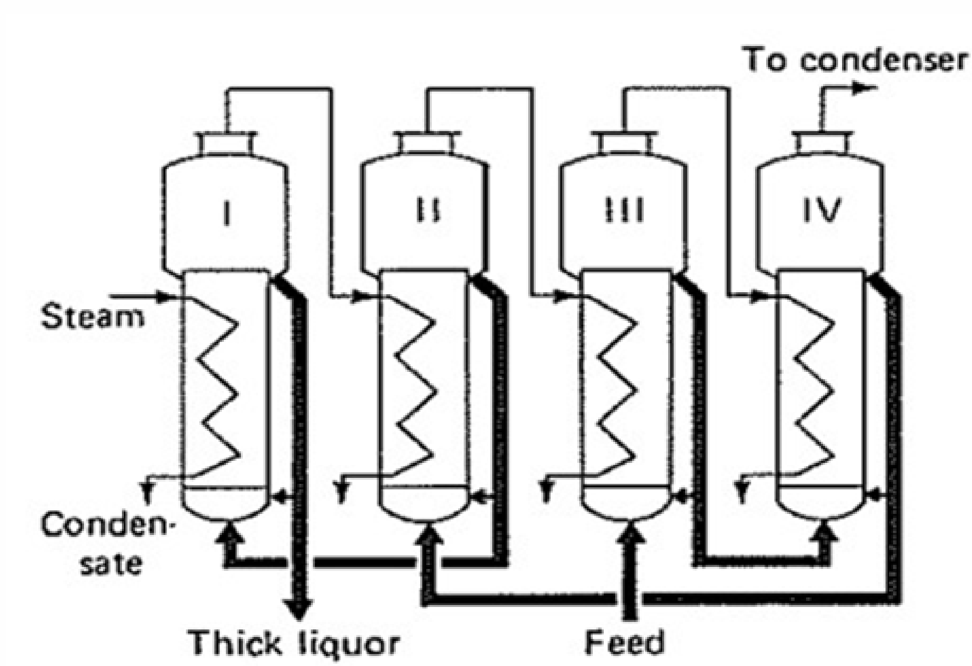


Figure 6. Schematic of a Mixed Feed MED System

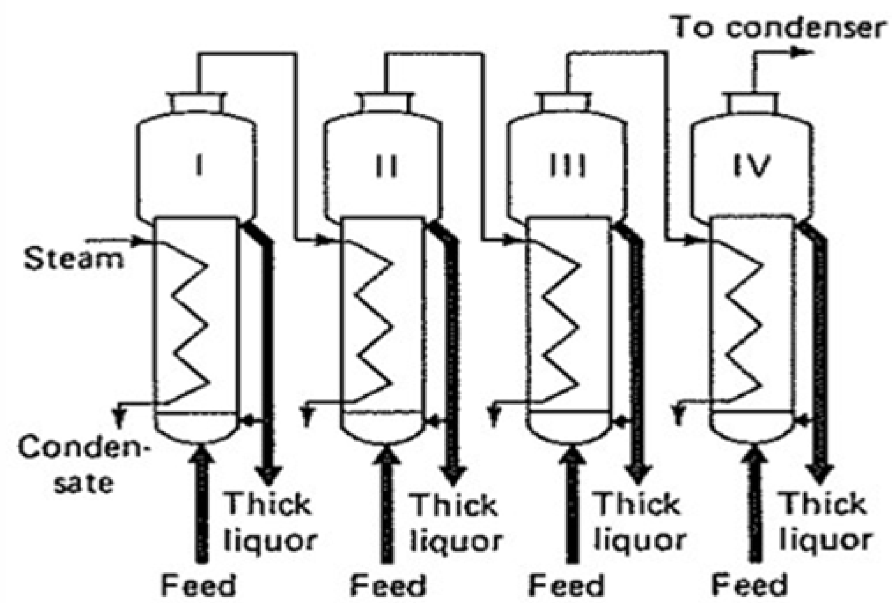


Figure 7. Schematic of a Parallel Feed MED System

13. Main components of a typical marine MED plant are as follows:-

(a) **MED Evaporator**. Usually a horizontal or vertically arranged stacks of tubes over which sea water flow takes place and exchanges latent heat of condensation with steam flowing within the tubes. This exchange of heat depends upon the heat transfer coefficient over the tubes. Tubes are either made up Ti or Al alloys for better heat transfer characteristics. However, for naval platforms requirements usage of Ti tubes is recommended. Evaporator is maintained under vacuum to achieve vaporization of sea water at low saturated temperatures.

(b) **Auxiliary Pumps**. System requires typically four pumps. These are as follows:-

(i) Sea water feed pump

(ii) Brine pump

(iii) Distillate pump

(iv) Vacuum pump or Steam ejector or Seawater educator

(c) **Associated Controls**. Controls are required to monitor system performance and remote control it's functioning. It also includes integration of salinity sensors and remote auto operation of valves, provisioning of alarms and suitable indicators etc.

(d) **Heat Source for First Effect**. First stage heat is required from an external heat source. The source could be a steam generator, flue gases or engine exhaust. Typically, steam is preferred as it makes system more compact by incorporating an additional condensate effect.

(e) **Final Stage Condenser**. A final stage condenser is required for condensing final effect produced vapour, cooling of cumulative distillate produced in all stages and ensuring pre heating of sea water prior injection in stages of MED evaporators. It is generally a shell and tube type heat exchanger maintained below the lowest vacuum of final stage.

Technical Challenges

14. Even though the MED systems have large number of advantages over other thermal desalination systems, its naval application has to be realized considering typical specifications and operational constraints of space, reliability and longer operational cycles. The challenges associated with the design, development and integration of a naval platform with MED system are highlighted in the succeeding paragraphs.

15. **Design Challenges**. Unlike land based large scale desalination plants, marine based MED plants have peculiar requirements of assured performance, safety, reduced maintenance and compact design which would be subjected to heavy sea states, marine environment and demanding prolonged operational conditions. Another important aspect is the marine environment induced corrosion, shock and vibration considerations. Further, stringent standards of feed water quality also need to be achieved under all operational conditions. The machinery compartments of naval platforms are highly congested and some internal sections remain inaccessible for inspection or replacement throughout for a long period. Thus, the required design must be able to sustain longer operational periods without failures.

16. The manufacturing of naval version MED would include piping designing and pressure vessel designing as per the stringent norms of ASME PV Codes/NES. These codes give criteria for selection of materials, fabrication, examination, testing and norms for safety of equipment and operator. These standards also include stringent standards for special production procedures and rigorous quality assurance conditions. The factor of military application makes them even more stringent vis-à-vis the conventional plants.

17. The major design challenge for naval platform MED plant is to sustain operational marine environment, achievement of optimal compact configurations and high reliability in operation. A naval MED plant therefore must meet the following:-

(a) A reliable performance under all sea states.

(b) Compact design for ensuring occupancy of minimum space in machinery compartment.

(c) Ability to withstand variations in sea water temperatures.

(d) Ability to withstand shock loads.

(e) Reach sustained desired operational state in minimum duration of time.

(f) To achieve stringent Naval Engineering Standards (NES) for various aspects like shock, EMI/EMC and habitability factors.

18. **Material Challenges**. With the advent of better metallurgy and active research in the field of optimizing materials for thermal applications, new opportunities have emerged with high

probability to meet the performance requirements of a marine MED system. Making a component compact with enhanced performance inadvertently demands usage of materials with better heat transfer, anti-corrosive and ease of machinability characteristics. Usage of tubes made of Ti alloys can result in an efficient marine MED evaporator. Similarly, most suited materials for various MED components are as listed below in ***Table 1:-***

Table 1: List of Suited Materials for a Naval MED plant

Sl	Component	Material Used
(a)	MED Evaporator tubes	Ti or SS tubes
(b)	Final Condenser	Ti and SS tubes and Carbon steel structure
(c)	MED Shell	SS/Carbon Steel alloy
(d)	Secondary system piping	Carbon Steel/SS
(e)	Pumps	Cu alloy impellers and body
(f)	First stage steam pipeline	439 Ferritic steel

Challenges for Integration of MED on Naval Platforms

19. A highly sophisticated and congested network of system layouts exist onboard naval platforms due to limited space availability. One of the major challenges is to accommodate an efficient but much compactly designed MED unit for naval application. Additionally, distillate produced has to meet a stringent quality standard which is of prime importance. This demands a highly efficient designing of critical components for MED system. Authors have undertaken formulation of sample design algorithms for final condenser and MED evaporators in order to optimize the design procedure. These are placed at ***Algorithm 1 & Algorithm 2*** respectively.

Developments in Designing & Manufacturing of Marine MED Plants in Country

20. With the advent of new technologies, better understanding of materials and increasing industrial experience a considerable competence has been gained in design and development of MED technology for marine applications. National Institute of Ocean Technology (NIOT), MoES, Chennai in consultation with industry R&D sectors has been actively involved in realizing the potential of this innovative technology at commercial level for mass production of fresh water from sea water desalination. The industry has shown a considerable understanding and growing interest in this technology and can play an instrument role in realizing its naval platform variants. Many naval and commercial ship yards across the country can be tasked to undertake the production of customized systems on turnkey basis in close consultation of industrial expertise in this field. Following is recommended:-

(a) Application of advance metallurgy in fabrication of equipment and components in order to withstand variations in temperatures, salinity and vacuum pressure condition.

(b) Development of new and better metals based alloy for fabrication of tubes and shell structures of MED evaporators and condensers.

(c) Development of superior performance hydraulic pumps with high efficiency and low noise characteristics.

(d) Development of test facilities for controls and performance analysis of model based plants.

(e) Development of Ti welding and fabrication expertise.

(f) Development of suitable control equipment in terms of hardware and software.

(g) Development of compact systems with high reliability in consultation with academia and industrial experts.

(h) Development of improvised designs for achieving better heat transfer and compact configurations. Fig. 8 indicates a possible tube surface design for improvised heat transfer rates.

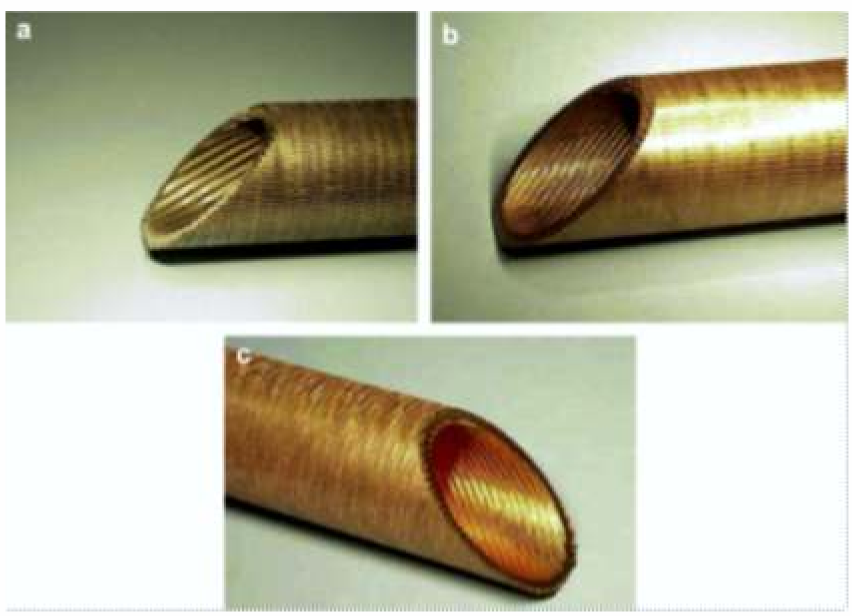
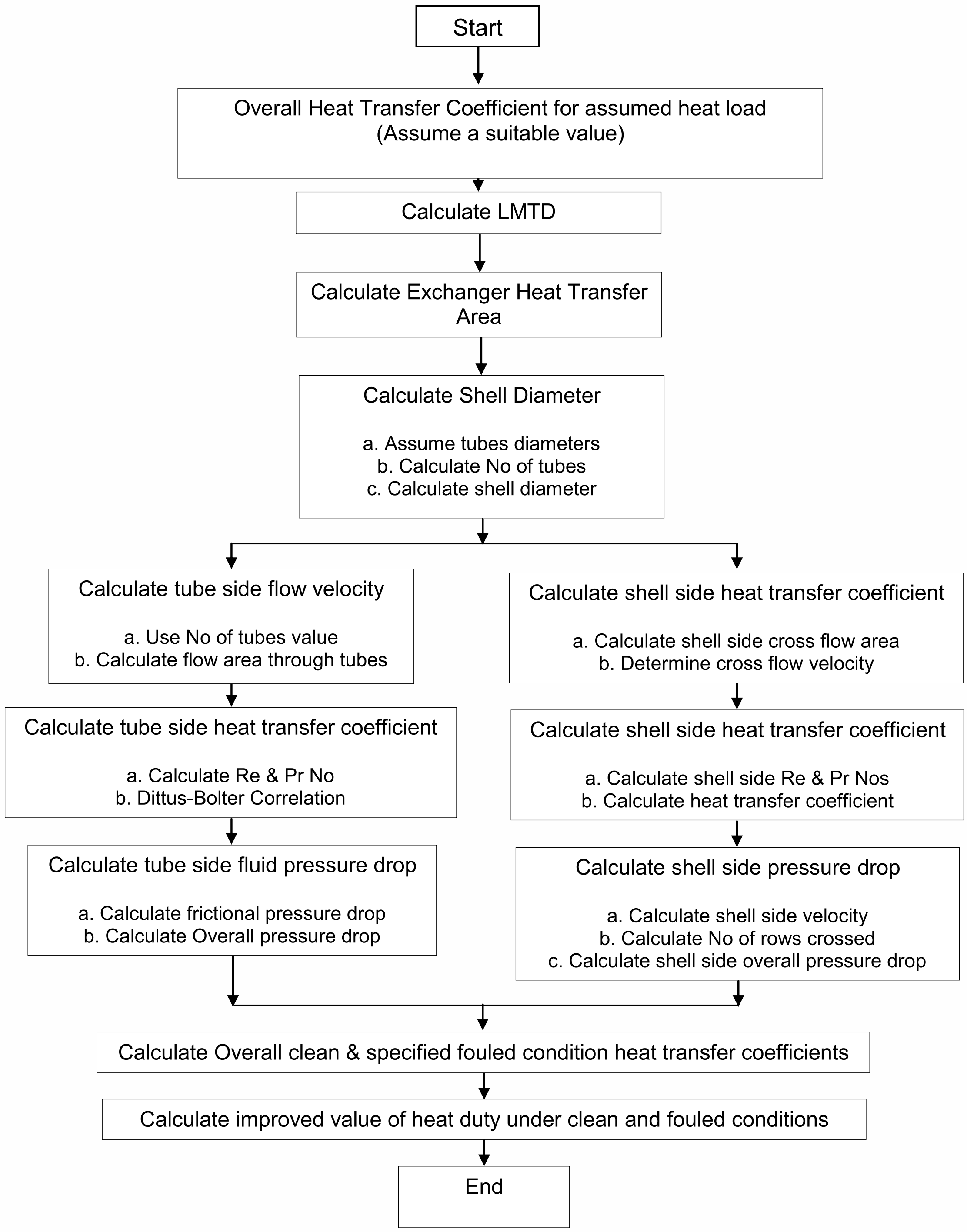


Figure 8. Improved Tube Designs for Enhanced Heat Transfer

Way Ahead

21. MED technology has a large scope of implementation on naval platforms due to its inherent superior performance characteristics with high thermal efficiency compared to other conventional thermal energy based sea water desalination systems. Though, the technology has been tested and proven for commercial applications, its usage for naval platforms needs to be established in which Indian industry can play a pivotal role. It is therefore recommended that the applicability and specific requirements of customizing an MED system for Naval applications be taken up for a detailed study and subsequent design and development through indigenous sources.



Algorithm 1. Estimation of Design Parameters of Condenser

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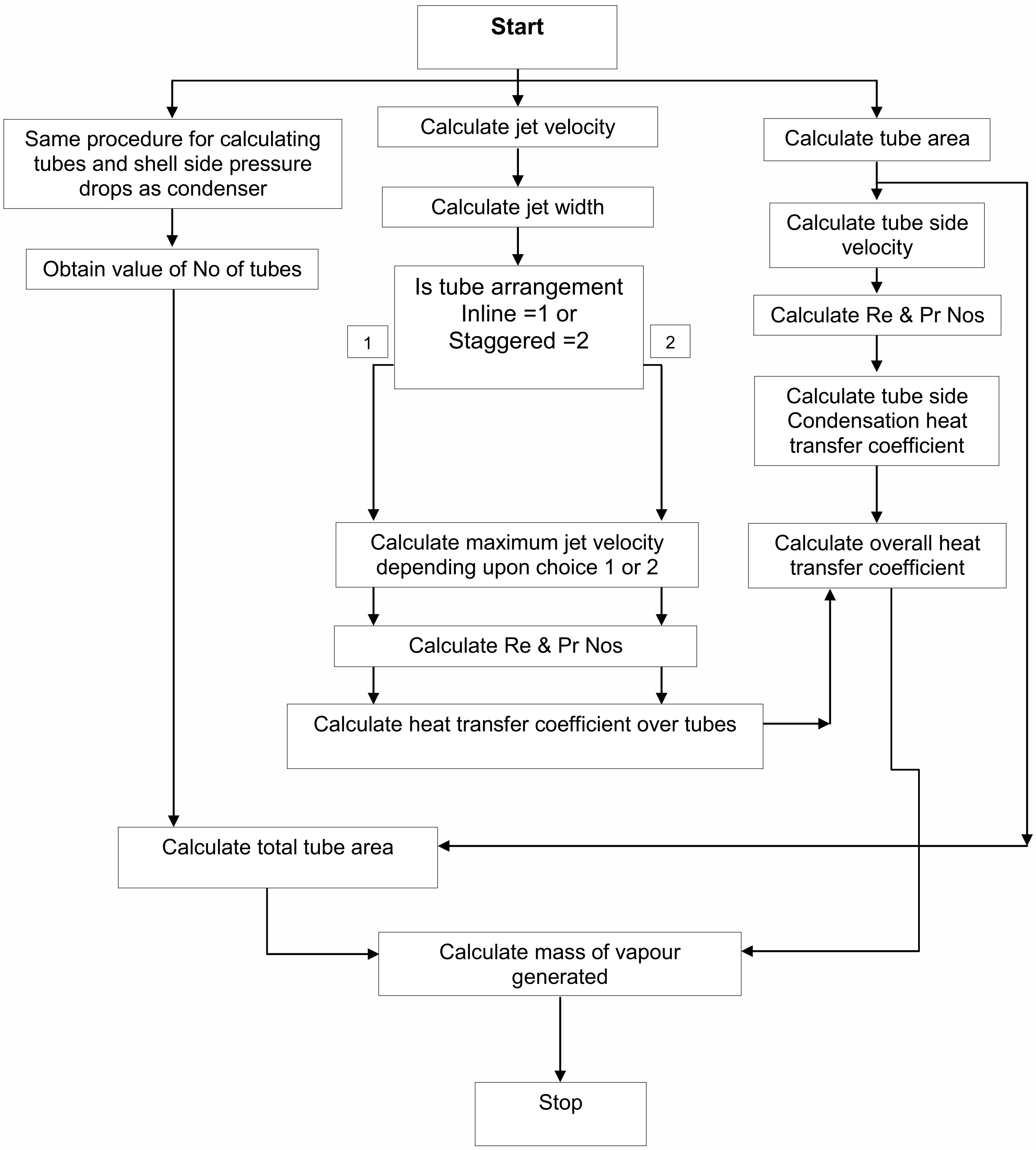

Algorithm 2. Estimation of Design Parameters of MED Evaporator

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article 7

EFFECTIVE DESIGN OF SUBMARINE EQUIPMENT MOUNTING SCHEME

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Abstract: *- The design of mounting scheme is a very important evolution which is carried out to isolate the vibration and noise of the equipment which helps in the reduced acoustic signature of the platform. This paper contains the various design procedures that are used for optimization of the mounting scheme for equipment.*

I. Introduction

Stealth capability is the most important characteristic of a submarine to carry out its missions undetected. To achieve this ability one of the primary step to be taken is the isolation of vibration and noise generated by equipment with the hull. The designer has to select the most optimal mount and its orientation to achieve this isolation for each of the vibro-active equipment onboard.

Equipment are mounted with Shock and Vibration mounts for the following reasons:

(a) Protect equipments from shock due to underwater explosion.

(b) Reduce transmission of equipment vibration to the hull which in turn reduces Under Water Radiated Noise

II. Natural Frequency and Transmissibility

Natural Frequency. SV mounted equipment effectively acts as a spring mass damper system (Fig.1). Here the equipment is the mass and the mounts act as springs in parallel. The natural frequency of the system can be calculated using the following:

$$f_x = \frac{1}{2\pi}\sqrt{\left(\frac{kx * n}{m}\right)} \qquad (1)$$

Where f_x - Natural frequency in x direction
k_x – Stiffness of the mount in x direction
n - Number of mounts
m – Mass of the equipment

This equation can be used accurately when the Center of Gravity of the equipment lies in the plane of mounts. When the Centre of Gravity is away from the plane of the mounts, softwares are used to determine the natural frequency.

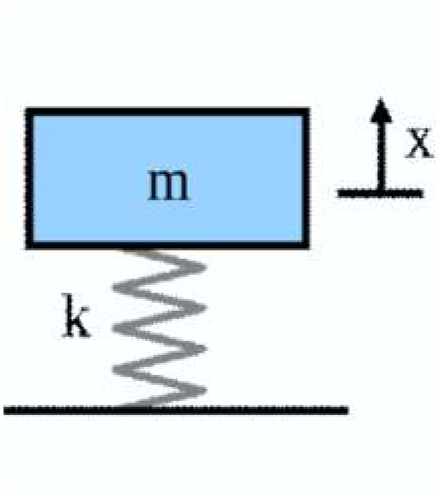

Fig 1. Spring Mass System

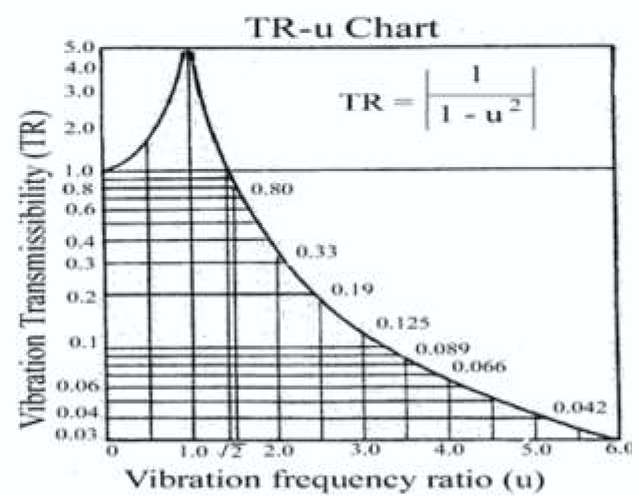

Fig 2. Transmissibility Curve

Transmissibility (τ) In a spring mass system Transmissibility is the steady state ratio of the amplitude of the motion of mass to the amplitude of the motion of the spring. If transmissibility is > 1 is in the amplification zone as shown in the transmissibility curve (Fig.2). Maximum amplification occurs when forced frequency is equal to natural frequency. The following formula is used for Transmissibility calculation:

$$\tau = \left| \frac{1}{\left\{1 - \left(\frac{fd}{fn}\right)^2\right\}} \right| \qquad (2)$$

The τ is kept below 1 to have maximum isolation of vibration.

III. Selection of Shock and Vibration Mounts

The following steps are undertaken for the selection of SV mounts for an equipment:

(a) Equipment footprint. The equipment footprint data is studied and the number of mounts is decided based on the weight distribution of the equipment.

(b) Weight of the equipment. Once the number of mounts is known, the load per mount is calculated using the weight data of the equipment. Few mounts are selected from an album of mounts as per its maximum loading capacity. These mounts are selected such that the percentage of loading per mount ranges between 60% – 90% of its maximum loading.

© Centre of Gravity. The position of the concentration of mass of the equipment plays a major role in spacing and selection of mounts. The C.G of equipment is set in the equipment model and calculations are done using the software.(d)Calculation of natural frequency. The natural frequency in all the directions is calculated with the equation at Para 3(a) or by modeling the equipment using software.

(e) Transmissibility. Using the equation in Para 3(b) the transmissibility of the mounting scheme is calculated. Transmissibility less than 1 offers good isolation characteristics.

(f) Finalisation of the mounting scheme.The most optimum mounting scheme is studied using various mounts, orientations (Mixed or Normal Fig.3) and iterations. Cascading of the mounts (Fig.4) is also studied to achieve the desired Transmissibility.

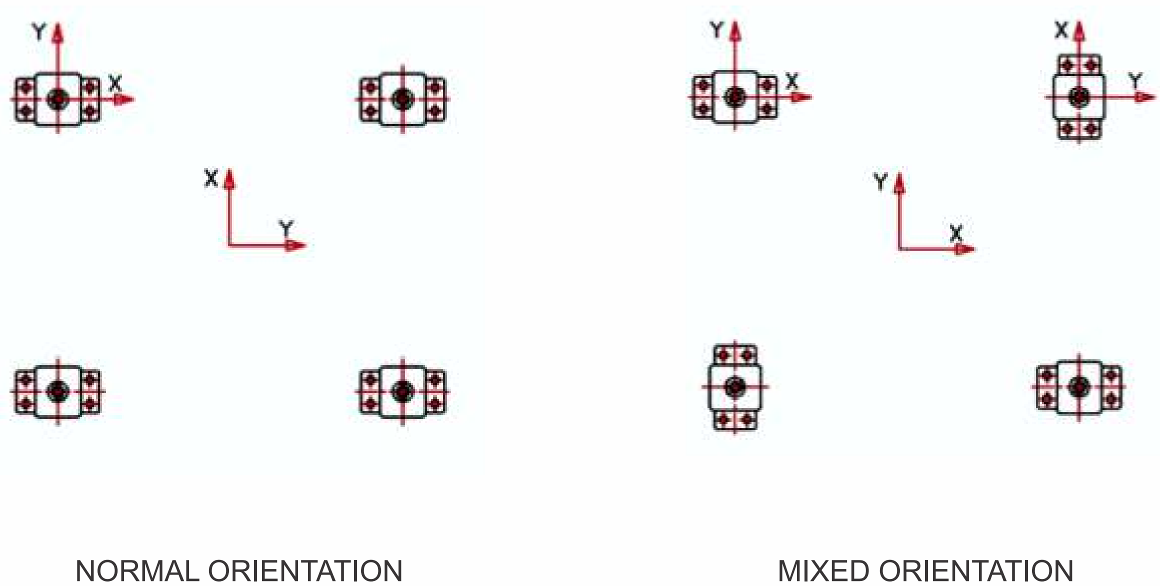

Fig 3. Orientation of Mounts

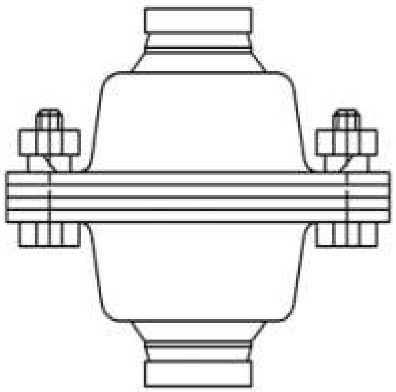

Fig 4. Cascade Mounting

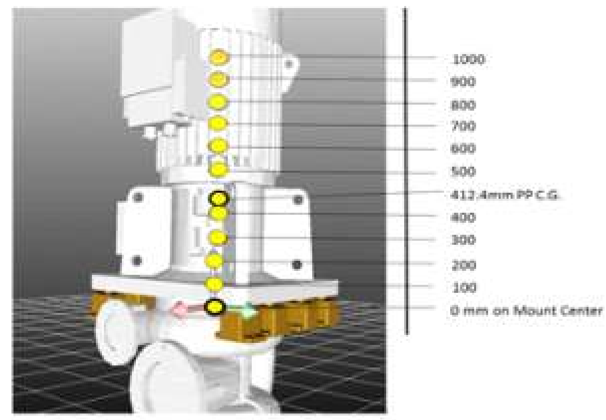

Fig.5 Effect of shift of CG on the Natural Frequency

IV. Effect of Change in Center of Gravity

Calculation of natural frequency of a mounting scheme is accurate using equation 1 when the Center of Gravity lies in the plane of mounting. Advanced software like ANSYS and COBRA are used to analyse the natural frequency of the mounting scheme accurately. A study was undertaken where in the effect of shift of C.G on the natural frequency of the scheme was undertaken and the results are as follows:

Table 1.Comparison of Natural Frequency

C.G POSITION	NATURAL FREQUENCIES (Hz)					
	X	Y	Z	XX	YY	ZZ
0 mm on plane of mounts	11.7	9.17	15.3	10.4	5.66	22.1
100 mm	11.9	8.83	15.3	10.8	5.57	22.1
200 mm	12.5	8.25	15.3	11.5	5.31	22.1
300 mm	13.4	7.67	15.3	12.4	4.96	22.1
400 mm	14.4	7.12	15.4	13.4	4.59	22.1
412.4 mm PP CG	14.8	7.18	15.7	13.6	4.59	22.1
500 mm	4.23	6.62	15.3	14.4	4.23	22.1
600 mm	3.9	6.17	15.2	15.5	17	22.1
700 mm	3.59	5.76	15.3	16.6	18.5	22.1
800 mm	3.32	5.38	15.3	17.7	20	22.1
900 mm	3.07	5.04	15.3	18.9	21.5	22.2
1000 mm	2.86	4.74	15.3	20.1	22.3	22

The above study was undertaken for a pump wherein the CG of the pump was shifted by 100 mm in the vertical direction and the results of the natural frequency were calculated. As shown in the table shift in CG in Z direction has very little effect on the natural frequency in the Z direction. There is a significant change in the natural frequency in X and Y direction due to the shift in CG in Z direction. This study clearly shows the implication of C.G in the selection of SV Mounts.

V. Case Study in Selection of Mounts

A case of high vibration was observed in a Steam Plant pump during its trials. The mounting scheme of the pump was studied to mitigate the high vibration levels. The pump was fitted initially with Type A mounts in cascade. The vibration levels at 25 Hz was found to be above the specified levels for the pump.

Various combination of mounting scheme using Type A and Type B mount in normal, mixed orientation and cascade was studied. The results are tabulated below.

Table 2. Transmissibility Study

Case 1

Mount Type B				
MODE	**Natural Freq. (Hz)**		**Ratio of Forcing frequency to Natural Frequency (ff/fn)**	**Transmissibility**
Translational X	fx	18.1	1.39	1.09
Translational Y	fy	9.3	2.68	0.16
Translational Z	fz	20	1.25	1.76
Rotational X	fxx	16.7	1.5	0.8
Rotational Y	fyy	5.8	4.3	0.06
Rotational Z	fzz	27	0.93	7.17

Table 2. Transmissibility Study

Case 2

Mount Type B Cascade				
MODE	**Natural Freq. (Hz)**		**Ratio ff/fn**	**Transmissibility**
Translational X	fx	13.06	1.91	0.38
Translational Y	fy	6.45	3.88	0.07
Translational Z	fz	14.12	1.77	0.47
Rotational X	fxx	12.06	2.07	0.3
Rotational Y	fyy	4.02	6.22	0.03
Rotational Z	fzz	19.06	1.31	1.39

Table 2. Transmissibility Study

Case 3

Mount Type A in Cascade				
MODE	**Natural Freq. (Hz)**		**Ratio ff/fn**	**Transmissibility**
Translational X	fx	20.95	1.19	2.36
Translational Y	fy	10.7	2.34	0.22
Translational Z	fz	23.12	1.08	5.91
Rotational X	fxx	18.97	1.32	1.36
Rotational Y	fyy	6.75	3.7	0.08
Rotational Z	fzz	31.19	0.8	2.8

VI. Results

In the above mentioned table the Mount Type B in cascade (Case 2) shows the best transmissibility possible. The transmissibility is high only in the rotational z mode out of the six vibration modes. Further trials of the pump with the Type B mounts in cascade showed significant reduction in vibration levels at 25 Hz.

VII. Conclusion

Optimal selection of mounts for equipment is very critical to ensure the isolation on the noise and vibration from the equipment with the hull. This isolation helps in making the platform silent to achieve the stealth criteria of the submarine.

With advancement in technology there is a diverse variety of mounts commercially available that can be used for equipment onboard. The selection of most optimal mounts is based on a number of diverse factors. Amongst these, in this paper the effect of Transmissibility and the shift in Center of Gravity of the equipment have been brought out.

Mounting scheme with a Transmissibility < 1 (Isolation Zone) in all directions is important to ensure the forcing frequency of the equipment is away from the natural frequency of the mounting scheme. This ensures maximum isolation of vibration forces from the hull.

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Author's Biodata

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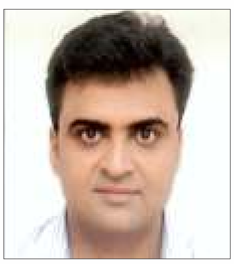

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article

8

ROLL MOTION CONTROL OF SUBMARINES AT FREE SURFACE USING JUXTAPOSITIONED STERN PLANES

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SUMMARY

Rounded shape and few or no appendages on the outer hull of a modern submarine results in very poor roll damping characteristics and the submarine exhibits large roll motions while operating at surface. Even though the motion characteristics of the submarine near or at surface has been estimated experimentally and numerically, the studies on the methods available to control the roll motion are scanty. In this paper, differential action of stern planes has been adopted as a means of controlling the roll motion. The seakeeping calculation was undertaken numerically, using potential flow theory and RANSE solvers, for different combination of speed, sea states and wave angles and the roll RMS values were compiled. Operability plots were generated for different NORDFORSK criteria, which specify the maximum value of RMS roll values permissible for different operational scenarios. It was found from the above studies that the selected hull form exhibits very poor seakeeping characteristics while operating at surface in beam seas. To estimate the stabilizing moment, which can reduce this roll motion, free stream characteristics of the stern plane were carried out. Using the stabilising moment, reduced roll motion has been estimated using a RANSE solver.

KEYWORDS: submarine, roll motion, stern planes, free stream characteristics, lift force, stabilizing moment, seakeeping, operability

NOMENCLATURE

GM_T	Transverse metacentric height
I_{ϕ}	Mass moment of inertia
I'_{ϕ}	Added mass moment of inertia
$B_{\phi a}$	Radiation damping coefficient
$B_{\phi v}$	Viscous damping coefficient
C_{ϕ}	Restoring force
$M_{\phi w}$	Moment due to waves
$M_{\phi f}$	Moment due to control surfaces
$\ddot{\phi}$	Roll acceleration
$\dot{\phi}$	Roll velocity
ϕ	Roll displacement
L_{OA}	Length overall
B_{OA}	Beam overall
H_{OA}	Height overall
WSA	Wetted surface area
$\Delta_{surface}$	Surface displacement
$\Delta_{submerged}$	Submerged displacement
k	Radius of gyration for roll
C_L	Coefficient of lift force
H	Wave height
T	Wave period
V_S	Speed
t	Time step
T_S	Simulation time
Φ_{RMS}	Root mean square value of roll

1. INTRODUCTION

There has been a remarkable change in the hull form of submarines over the last 100 years. The submarine designs of World War I and II were very much like a surface vessel that could dive when required. This was mainly due to the limited battery endurance available at that time which forced them to spend more time on surface because of which the hull form was optimized for greater speed on surface than submerged.

However with the advancements in nuclear technology and fuel cell, Nuclear/ AIP submarines were developed which could remain submerged for a longer duration. This led to the modern submarines adopting a role reversal than the ones operated earlier, i.e. spend very less time on surface and remain submerged for majority of the time of operation. Hence the hydrodynamics of the vessel when submerged became the primary factor of design. This requirement influenced the design of hull form and resulted in a rounded shape with very few appendages which is ideal for submerged conditions, but has very poor roll damping effects and such a submarine exhibits large roll motions when operating on surface.

It may sound contradictory that when a submarine is optimized for submerged condition, why the sea keeping in surface condition should be significant. It is, because of the fact there are various scenarios in which a nuclear / AIP submarine has to surface and it is unavoidable. It is for this reason that the present study has been conducted where the roll characteristics of the submarine while operating at surface are estimated and methods adopted to reduce the roll motion.

2. BACKGROUND STUDY

It is pertinent to mention that even though there are several nations operating submarines worldwide, very less literature is available on submarine seakeeping characteristics. This might be primarily because of the secretive nature of the submarine programme of major navies. However, Australian Navy in joint collaboration with Australian Maritime College has published a few papers, which are discussed below.

Lund (2005) focused on the overall parameters that affect a surfaced submarine in beam seas. He looked into the effect of control surface configuration, of entrain water in the casing of the vessel and the effects of green water on the deck of the vessel.

El-Atm (2006) studied on the roll motions of a surfaced submarine with various states of flooding in the outer casing. The aim was to investigate whether this entrained water could be used in a similar fashion to an anti-roll tank on a surface ship. The effects of a damaged condition were also investigated to understand how a flooding in a forward compartment would affect the performance of the vessel on the surface. This work also investigated the configuration of the aft control surfaces. Further to the work of Lund (2005) this paper included a comparison with a numerical simulation, in this case ShipMo3D, to gauge the effectiveness of this code as a tool for prediction. The results of this showed that the numerical prediction severely over estimates the roll response.

Davies (2007) looked in detail at the effect of appendages on the roll damping of a submarine in surface operations. This work was based largely on the data and testing of El-Atm (2006) thus allowing for a very good comparison of experimental results. The effects of tail configuration, control surface wing tips and the use of bilge keels were explored. A CFD analysis was undertaken to compare results for the effect of the wing tip modification. As a result of the study it could be seen that bilge keels provide an effective means of improving the roll damping on a surface submarine. Although it is worth noting that the stealth properties and flow noise of these appendages was not looked at. Given the importance of these properties bilge keels are in no way practical for naval submarines.

Hedberg (2006), investigated how to simulate the roll motion of a Australian Collins Class like mock-up submarine. The effect of adding appendages and transverse metacentric height at different sea states whilst the submarine is in surface condition was analysed. McKinley (2012), studied the effect of vertical centre of gravity on the roll motions of a surfaced submarine. Details of the roll damping afforded by both the shape of the submarine and its mass distribution were looked at. Both numerical and experimental tests were conducted on a generic diesel-electric submarine hull form. Letter(2009), investigated the roll motion experienced by a surfaced submarine in beam seas using CFD techniques and physical model scale experiments. The work focused on roll decay and 2D roll response and its prediction using numerical techniques.

From the above literature review it is evident that the roll motion of a submarine while at surface is a matter of concern and various options of reducing it have been looked upon by the Australian Navy in joint collaboration with Australian Maritime College. Further, Papanikolis (U 214) class submarines of Greece built by HDW have reported of poor surface sea keeping (roll amplitude up to 45 degrees) in high seas during sea trials.

However it may be noted that the same problem is faced by surface ships also and they have successfully deployed active fins as one of the means of roll stabilisation, but no work has been published on the use of active fins on submarines. From open source it was understood that the modern submarines of US and Russian Navy have the mechanism of deflecting a portion of the total movable area of the stern plane independently to control roll. However no literature has been published on the same. This when used, can create a stabilising moment which can reduce the amplitude or roll when operating at surface or in dived position. Presently majority of the submarines use a common tiller for deflection of both the port and starboard stern plane. By this, the stern planes could be deflected only in the same direction and can be used only for controlling trim. By making the starboard and port stern plane independent, it can be used for controlling both trim and roll.

3. SCOPE OF CALCULATION

The amplitude of roll motion of the submarine, without the action of the stern planes, at surface has been estimated in frequency domain using the software Paramarine and in time domain using the software STAR-CCM+. The submarine with the effect of stern planes has been studied in time domain software to determine the roll stabilisation. Already available horizontal stern planes were used so that no additional appendage had to be added. The details of the study undertaken are as follows:-

(a) Selected a parent submarine hull form.

(b) Created the submarine computer model and performed sea-keeping calculations, primarily to estimate the roll amplitude in the frequency domain, using the software PARAMARINE at different combinations of submarine speed, sea states, wave heading.

(c) Compared the results with those available in literature.

(d) Performed free decay tests numerically using the CFD Package STAR-CCM+ to establish the natural period of roll.

(e) Carried out sea-keeping calculations in beam seas (roll motion considered) at different speeds, wave heights and periods using STAR-CCM+

(f) Studied the free stream characteristics of the stern planes by modelling it alone independently to estimate the lift force generated by it at different angles of attack and speeds using STAR-CCM+ and validated the results with NACA report no.669.

(g) Using the lift force, estimated the stabilising moment that would be generated by the stern planes when deflected in equal and opposite directions.

(h) Fed values of the above estimated stabilising moments to the software STAR-CCM+ and obtained the reduced roll amplitude at different speeds, wave heights and periods.

4. PARENT SUBMARINE DATA

The parent submarine was chosen as the one used by Santhosh Kumar and Avinash (2013), the main particulars of which are as follows. These along with the offset data have been used as input for generating the model of the submarine.

Main Particular	Value
Length overall, L_{OA}	60 m
Beam Overall, B_{OA}	7.2 m
Height Overall, H_{OA}	12.2 m
Draft, T	5.26 m
Wetted Surface Area, WSA	1203 m^2
$\Delta_{surface}$	1790 t
$\Delta_{submerged}$	1970 t
Envelope Displacement	2070 t
Maximum Submerged Speed	20 kn
Maximum Surface Speed	10 kn
Transverse Metacentric Height, GM_T	0.478 m
Moment of Inertia	[1.136E7, 4.025E8, 4.025E8]kgm^2
Centre of Gravity	[32.002, 0.004, 3.823] m

5. ROLL MOTION ANALYSIS USING PARAMARINE

The software used is Paramarine™, which is an integrated naval architecture software tool for commercial ship, warship and submarine design. The integrated set of tools of the software address the concept design, performance prediction, strength and structures, radar cross section, powering, manoeuvring, endurance, sea keeping, vulnerability and design for production. It keeps the design spiral within a single working software environment. Since different modules are linked (via pointers), any change in a parameter automatically causes cascading changes through the entire design.

Co-ordinate Systems

When analyzing the motion of marine vehicles, it is convenient to use two co-ordinate frames. The moving co-ordinate frame X0Y0Z0 is fixed to the vehicle and is called the body-fixed reference frame. The origin of the body fixed frame is usually chosen to coincide with the centre of gravity (CG) when CG is in the principal plane of symmetry. For marine vehicles, the body axes X0, Y0 and Z0 coincide with the principal axes of inertia and are usually defined as:-

X0 – Longitudinal axis (directed from aft to fore)

Y0 – Transverse axis (directed to starboard)

Z0 – Normal axis (directed from top to bottom)

The motion of the body fixed frame is described relative to an inertial reference frame. For marine

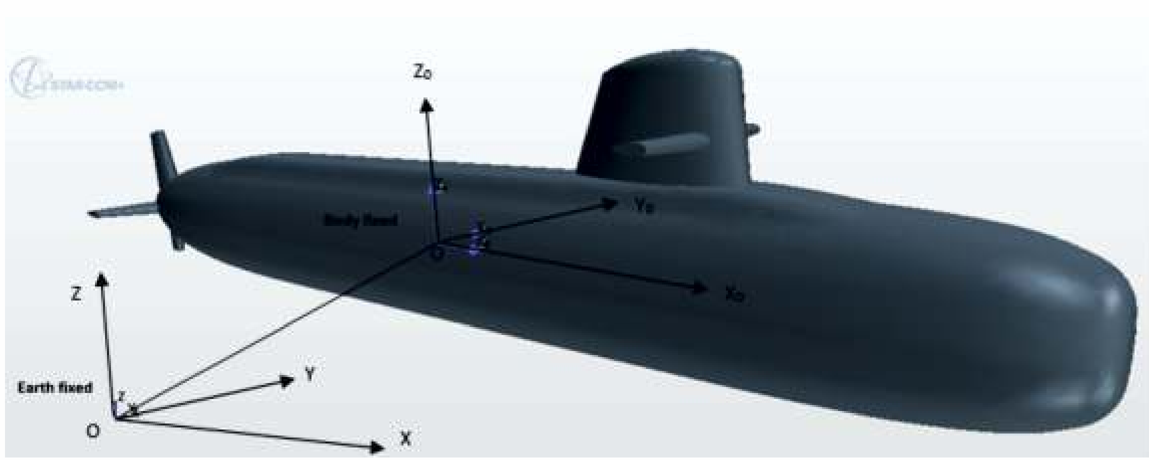

Figure 1: Body and earth fixed reference frames

From the offset data, 2 separate 3D models were created in the software and are given in figures 2 and 3 below.

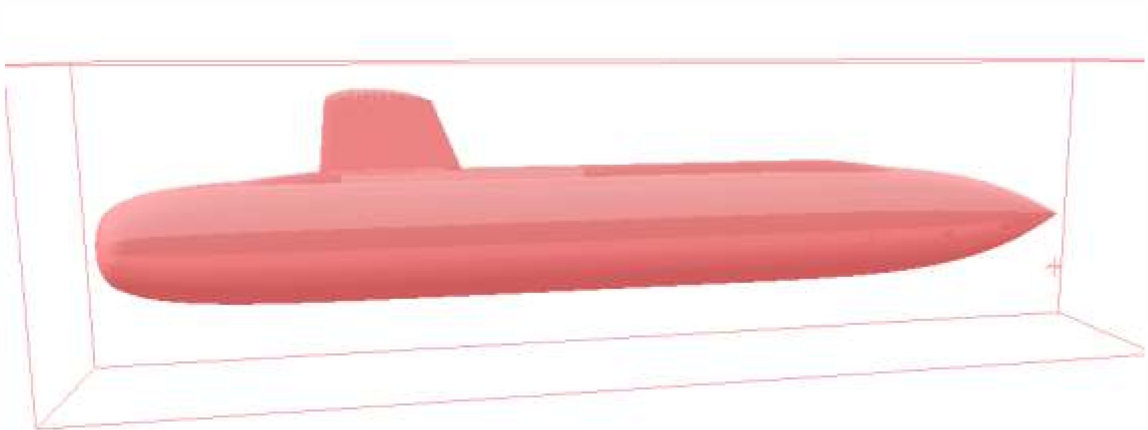

Figure 2: Bare hull

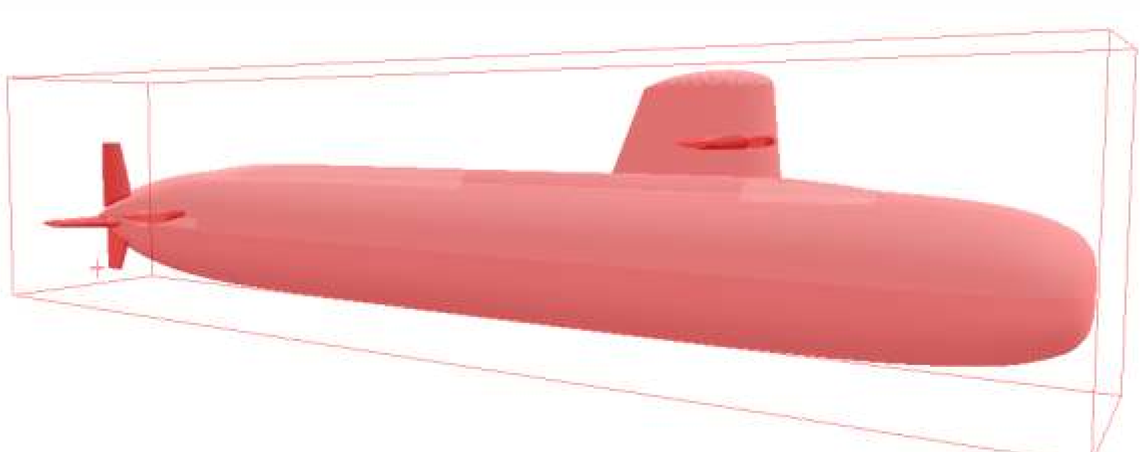

Figure 3: Appended hull (includes vertical rudder, stern planes and fin planes)

Layout of Control Surfaces

The configuration of control surfaces on the submarine used for present study is shown in figure 4. The forward planes and stern planes are used for controlling the motions in vertical plane. Vertical rudders (both upper and lower) are used for controlling the motions in horizontal plane. Forward planes are primarily used for depth keeping and stern planes for maintaining trim. When the depth has to be changed with a specified trim, both forward and stern planes are used in tandem where stern planes keep the submarine at specified trim and forward planes changes the depth. Vertical rudders are used for course keeping. Also shown is the design draft of the submarine and it may be noted that only the stern planes are below the waterline, rest all the control surfaces are above the waterline, when the submarine is in surface condition.

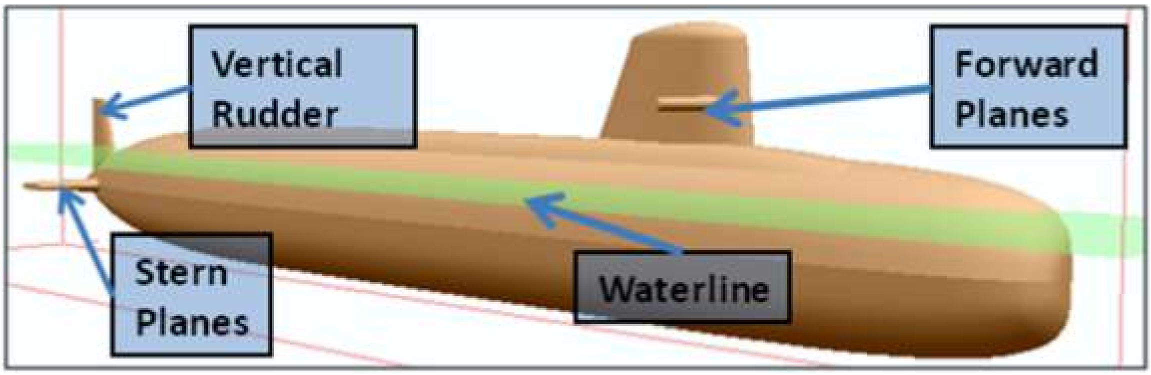

Figure 4: Configuration of control surfaces

Initial condition

The draft and centre of gravity of the vessel in the condition required for the sea-keeping calculations are specified. The range of speeds and headings at which the sea-keeping calculation module would generate the RAO information are specified. Submarine roll response spectra at different sea states are estimated from the RAO data and appropriate wave spectra is chosen with the range of frequencies.

ProteusF

For undertaking seakeeping calculations, Paramarine uses ProteusF and sea-keeping operability objects to compute the motions of the vessel. ProteusF is a frequency domain seakeeping module based on a 2D Rankine source solution of the hydrodynamic problem. The RAO's are calculated by solving the 5 degrees of freedom (Sway, Heave, Roll, Pitch and Yaw) by considering the hydrodynamic reaction/diffraction, hydrostatic restoring, viscous (from empirical methods) and incident wave (Froude-Krylov) forces. Short-term response statistics are calculated by the convolution of the RAO's and wave spectrum. This analysis was done to understand the excessive rolling of the submarine in high sea where the roll damping is too less. The module solves the general equation for roll motion as given below:-

$$(I_\phi + I'_\phi)\ddot{\phi} + (B_{\phi r} + B_{\phi v})\dot{\phi} + C_\phi \phi = M_{\phi w} \quad (1)$$

In the LHS of the equation, the first term is the inertial term, the second one is the roll damping term (radiation and viscous), which is the crux of the argument, and the last term is the restoring moment. The RHS of the above equation is the wave exciting moment in roll.

Since Paramarine uses frequency domain approach, large number of cases could be simulated within a short period of time. But it is to be noted that the viscous effects considered in the package have been estimated from empirical methods and hence would require further analysis using a RANSE based CFD package for a more realistic result.

Submarine motion calculations

Seakeeping calculations to estimate the amplitude of roll motion was undertaken for both the models (bare hull and appended hull) with the following input conditions:-

(a) Speed: 0 kn, 2 kn, 4 kn, 6 kn, 8 kn and 10 kn

(b) Sea State: 2,3,4,5 and 6

(c) Heading: 0 to 360 degrees at step of 15 deg. (Results complied for 0,45,90,135 and 180 deg.)

(d) Spectrum: Bretschneider

(e) Long crested (2D) and Short crested (3D) seas

The calculations were done for 4 combinations of hull forms:

(a) Bare hull - Long crested (2D) sea

(b) Bare hull - Short crested (3D) sea

(c) Appended hull - Long crested (2D) sea

(d) Appended hull - Short crested (3D) sea

Bretschneider spectrum was used for the calculations. The spectrum equation and the parameters specified are

$$S(\omega) = \frac{5}{16}\frac{\omega_m^4}{\omega^5} H_{1/3}^2 e^{-5\omega_m^4/4\omega^4} \qquad (2)$$

Table 1: Bretschneider spectrum characteristics

Sea State	Mean Period(sec)	Significant Wave height(m)
2	7.5	0.5
3	7.5	1.25
4	8.8	2.5
5	9.7	4.0
6	12.4	6.0

The generated spectrum and the roll RAO are multiplied to obtain the roll response spectrum. The results for all the hull configurations for different combination of speeds (0,2,4,6,8 and 10 knots), sea states(2,3,4,5 and 6) and wave headings(0,45,90,135 and 180 degrees), a total of 150 cases were compiled. The result for a particular case is given below.

Table 2: Roll RMS value in degrees for long crested sea conditions in Sea State 4 at different speed and headings

Heading (deg)	Speed in knots					
	0	2	4	6	8	10
0	0.0	0.0	0.0	0.0	0.0	0.0
45	12.4	4.6	3.4	2.6	2.0	1.6
90	19.3	6.8	5.0	4.1	3.5	3.0
135	12.4	3.9	2.6	2.0	1.6	1.3
180	0.0	0.0	0.0	0.0	0.0	0.0

It can be noticed from Table 2 above that the roll RMS value is maximum when the submarine is stationary (V = 0 kn) and decreases as speed increases. It could also be noted that roll RMS value is maximum at beam seas and zero for following and head sea in long crested sea condition. In short crested sea conditions, all the above statements hold true except that the value of roll RMS is non-zero in following and head seas. All the above results are as expected.

Table 3 (a): Roll RMS value in degrees for long crested sea conditions in beam seas

Sea State	Speed in knots					
	0	2	4	6	8	10
2	2.5	1.0	0.7	0.6	0.6	0.5
3	6.3	2.4	1.9	1.6	1.4	1.3
4	19.3	6.8	5.0	4.1	3.5	3.0
5	33.5	11.7	8.5	6.8	5.8	5.1
6	44.3	15.6	11.3	9.2	7.8	6.9

Table 3 (b): Roll RMS value in degrees for short crested sea conditions in beam seas

Sea State	Speed in knots					
	0	2	4	6	8	10
2	2.1	0.8	0.6	0.5	0.5	0.4
3	5.3	2.0	1.6	1.3	1.1	1.0
4	16.2	5.7	4.1	3.3	2.8	2.4
5	28.1	9.7	7.0	5.6	4.6	4.0
6	37.2	12.9	9.4	7.5	6.3	5.5

Tables 3(a) and (b) below give the roll RMS value for beam sea at different speeds and sea state for long and short crested seas respectively. It can be noted that the value of roll RMS value increases with sea state and decreases with increase in speed. It may also be noted that the value of roll RMS is lesser for short crested sea condition than long crested sea condition as expected.

Table 4 gives the comparison of roll RMS for long crested and short sea conditions at different speeds for both bare hull and appended hull in beam seas at sea state 6. It can be noted that at low speeds (0 and 2 kn), the roll amplitude for the model with appendages is considerably high than for the appended hull. At higher speeds (4kn and above), the roll amplitude for the model with appendages is less than for the bare hull model, as the fin effects increases with speed.

Table 4: Roll RMS value comparison for long and short crested seas at sea state 6

Speed (kn)	Bare Hull		Appended Hull	
	Long Crested	Short Crested	Long Crested	Short Crested
0	21.8	16.8	44.3	37.2
2	14.5	11.2	15.6	12.9
4	11.5	8.9	11.3	9.4
6	9.8	7.5	9.2	7.5
8	8.6	6.6	7.8	6.3
10	7.7	5.9	6.9	5.5

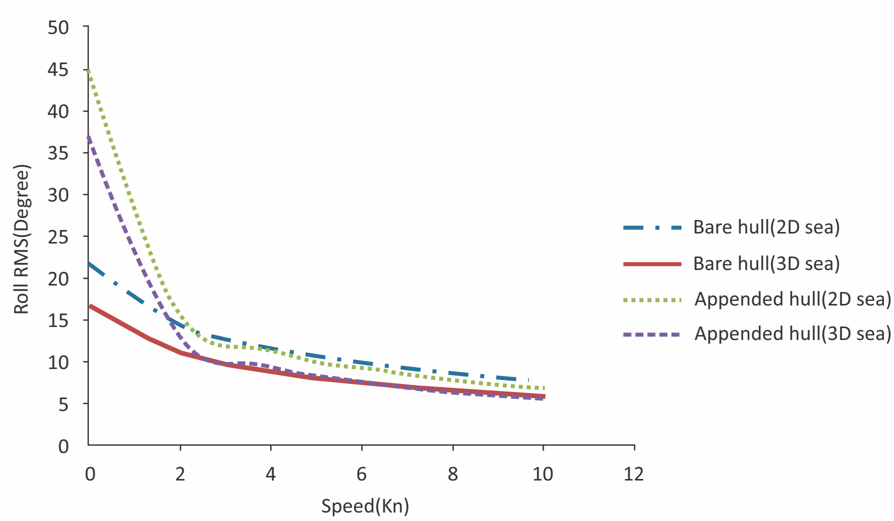

Figure 5: Roll RMS value for long (2D) and short (3D) crested sea conditions

NORDFORSK Criteria

NORDFORSK criteria (Table 5) were referred which specifies the maximum permissible roll angle for different scenarios as given below and the operability plot were generated for wave heights of 4m and 6m corresponding to sea state 5 and 6.

Table 5: NORDFORSK Seakeeping Criteria for Roll

Description	RMS Roll Motion
Light manual Work	6°
Heavy Manual Work	4°
Intellectual work	3°

Using the above criteria, operability plots were generated in Paramarine for different speeds and headings for a particular wave height. Green colour indicates safe zone where the submarine can be operated and the RMS roll is less than the limiting roll angle and red colour indicates the zone where the RMS roll is more than the limiting roll angle. It can be inferred from the plots below that as the roll criteria are becoming stringent from figures 6 to 8, the area of safe operation is decreasing as expected. It may also be noted that the area of safe operation reduces with increasing wave height. These plots would form part of the 'Seakeeping Instructions' issued to the crew to aid them in operating the submarine at various scenarios.

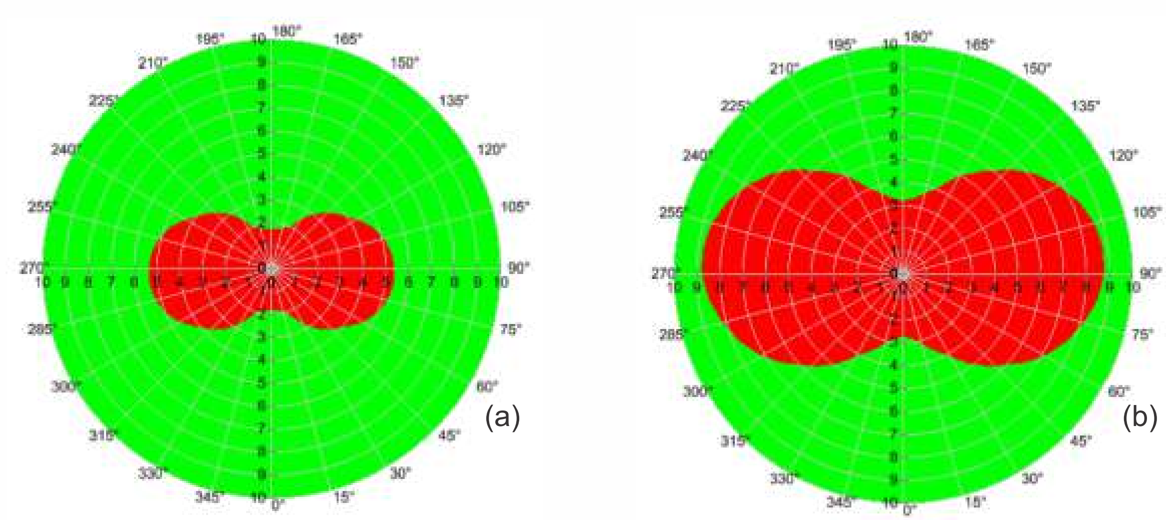

Figure 6: Operability plot for light manual work (a) wave height 4m (b) wave height 6m

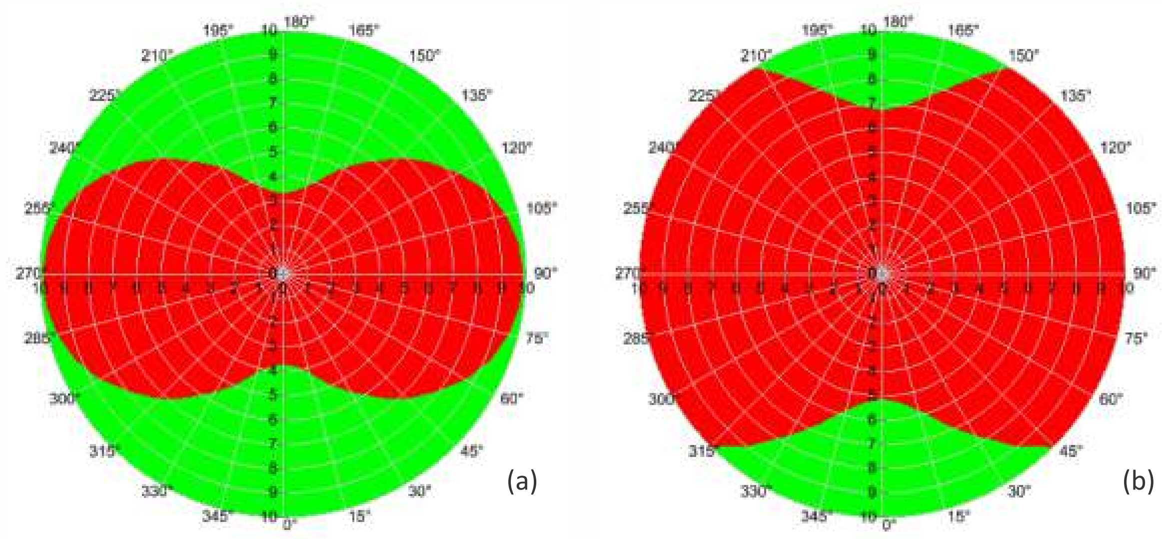

Figure 7: Operability plot for heavy manual work (a) wave height 4m (b) wave height 6 m

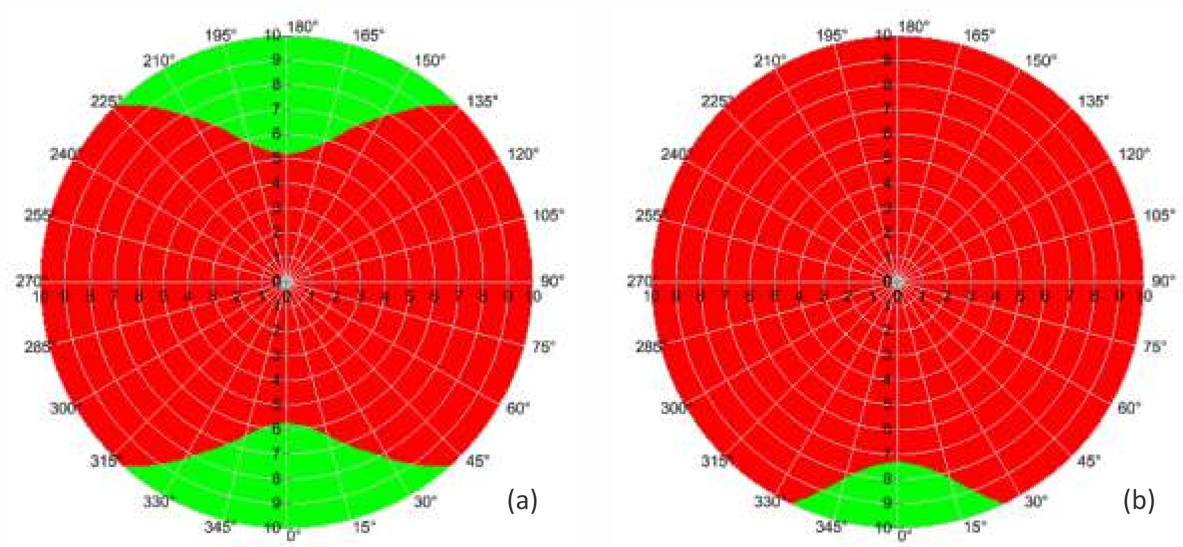

Figure 8: Operability plot for intellectual work (a) wave height 4 m (b) wave height 6 m

Comparison of roll RMS values

Data on roll motion of Collins class submarine at different sea states in beam seas is available [9]. It is important to compare the results obtained for the present submarine with these data, which is of an existing submarine. The roll RMS values for the present submarine and the Collins class submarine are plotted against significant wave heights in Figure 9.

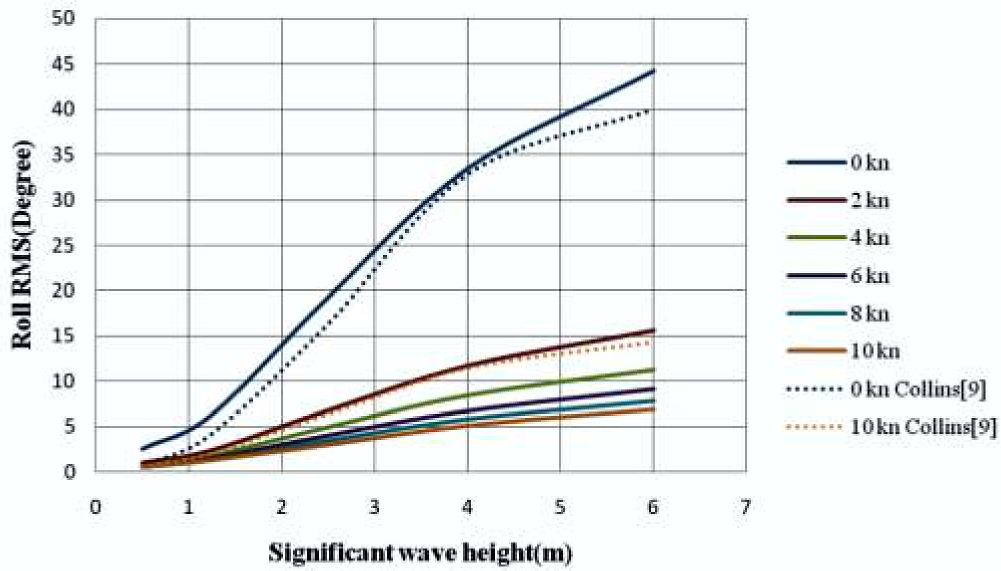

Figure 9: Comparison of roll RMS values

From Figure 9 it is observed that the maximum value of roll RMS is about 40 degrees for both the submarines at a significant wave height of 6m for zero speed in beam seas, also both the curves at 0 kn show a very good match. However at 10 knots, the value of roll RMS values for Collins class submarine is higher by about 40%. It is to be noted that in both the cases the value of roll RMS drops drastically at higher speeds. It is observed that the higher surface displacement and draft of 1300t and 1.3m respectively, for Collins class submarine is causing higher roll motions at a speed of 10 knots.

The CFD commercial software Star CCM+ is used for the numerical hydrodynamic study. It uses an “Algebraic MultiGrid Semi-Implicit Method for Pressure-Linked Equations solver” (AMG SIMPLE) for solving the discretized linear system iteratively. It also provides a powerful semi-automatic meshing tool, which allows the operator to generate both surface and volume mesh. The mesh is automatically generated upon the operator's inputs and is of good quality. Furthermore, the software has ability to automatically wrap surfaces in to ensure a complete closed model.

Geometrical Model Creation

The model was exported in parts (i.e. bare hull and appendages separately) from Paramarine. Then the main fluid domain is specified, as per the ITTC recommendations, and a sub - domain is modelled just containing the model of the submarine to enable volumetric control for capturing the desired parameters in a better way.

Domain Discretisation

The volume mesh is the mathematical description of the space or geometry of the problem. Star CCM+ offers three different types of volume mesh; tetrahedral, polyhedral and trimmed mesh. Of the three models the trimmer meshing model is more likely to produce a good quality mesh for most situations and the same was chosen for the present study. The meshed models are shown in figures 10 and 11 below.

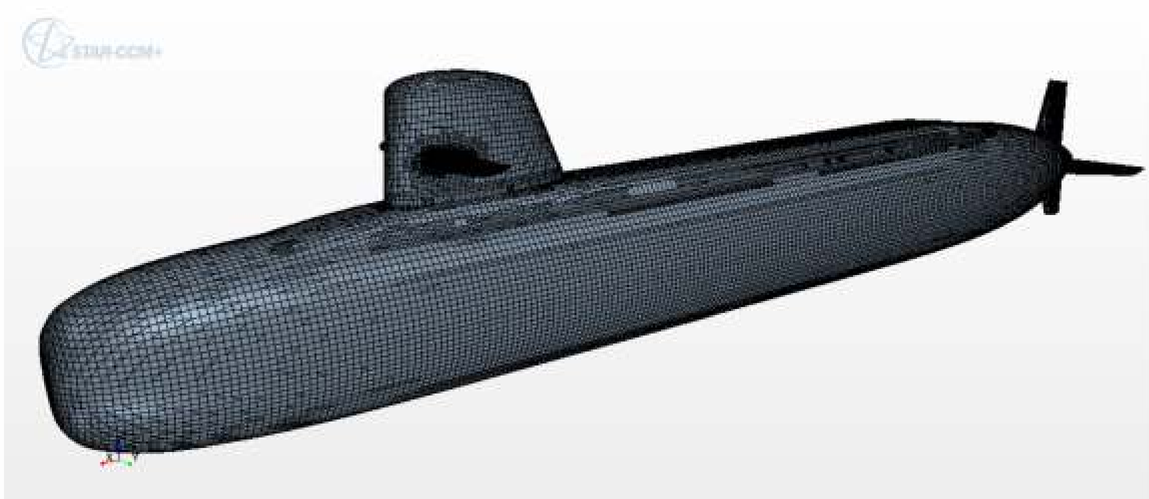

Figure 10: Meshed model

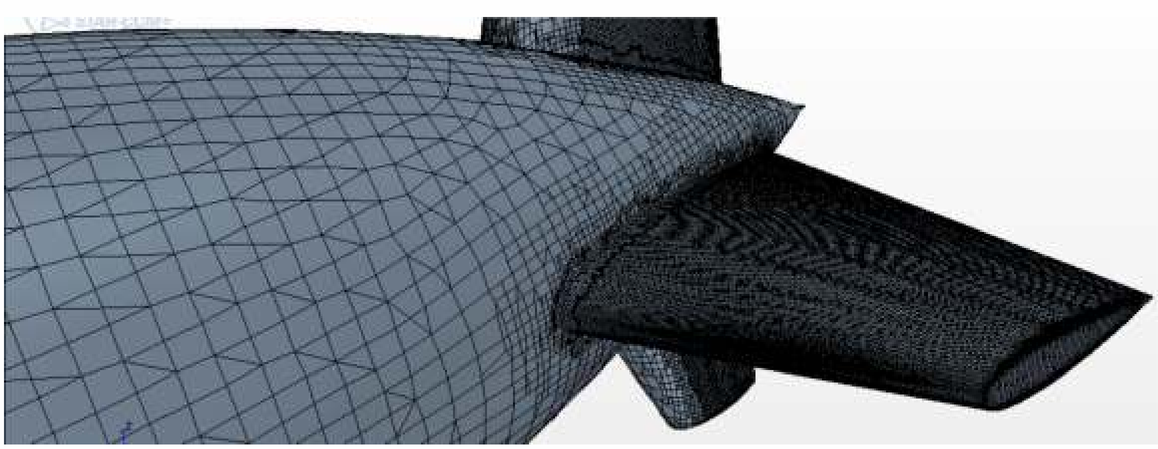

Figure 11: Finer meshed control surfaces

Physical Conditions

Several physical models are activated to simulate the forces acting on the hull. The simulation models the behaviour of two fluids (air and water) within the same continuum, and uses the Volume of Fluid model to do so. It is possible to define transient boundary conditions on the free surface using the VOF wave physics model. The VOF model generates a number of field functions that are based on wave parameters defined by the user. These field functions can be used as boundary and initial conditions in appropriate nodes on the object tree. As there are two fluids in different phases, the Eulerian Multiphase model is activated, and the effect of centre of gravity acting on both is included using the gravity model. The effect of turbulence on the fluid is modelled using the default K-Epsilon turbulence model.

For this study, the following were selected in the Physics module:-

(a) Implicit Unsteady from the time group

(b) Multiphase mixture from the material group

(c) Volume of fluid (VOF) from the multiphase model group

(d) Turbulent from the viscous regime group

(e) K-Epsilon turbulence from the Reynolds – Averaged Turbulence group

(f) Gravity from optional physics model group

(g) VOF waves from optional physics model group

Boundary Conditions

The numerical solution of the equations of fluid motion, for any given hydrodynamic problem requires boundary conditions to be defined. These represent a unique description of the state of the flow at the geometrical boundaries of the 3D space within which the equations are to be modelled.

The domains with boundary conditions and meshed models are depicted in the figure 12. The domain dimensions were fixed as per the IITC guideline 7.5-03-04-01. Darker region in the figure below indicates the sub-domain, the dimensions of which are kept as same as the domain in the longitudinal and transverse direction. In the vertical direction, it captures the free surface and has been meshed finer than the domain.

The boundary conditions specified in this study are elaborated below in Table 6. Velocity inlet was specified at starboard, top, bottom and forward. The physical value was set as 0 m/s for all the velocity inlets except for starboard, where the field function, 'velocity of beam waves' was chosen. This automatically calculates the velocity of the beam waves from the wave height and wave period specified earlier. However for simulations with forward speed, the hull is stationary and there is an option in the software to specify additional velocity in the opposite direction, which is similar to the hull moving forward. Since the wave was generated from the starboard side and propagating to port, pressure outlet was specified as the boundary on port and aft so that the energy of the wave gets dissipated and no reflection from the wall occurs. At the hull, a no-slip wall condition was specified so that the fluid will have zero velocity relative to the boundary.

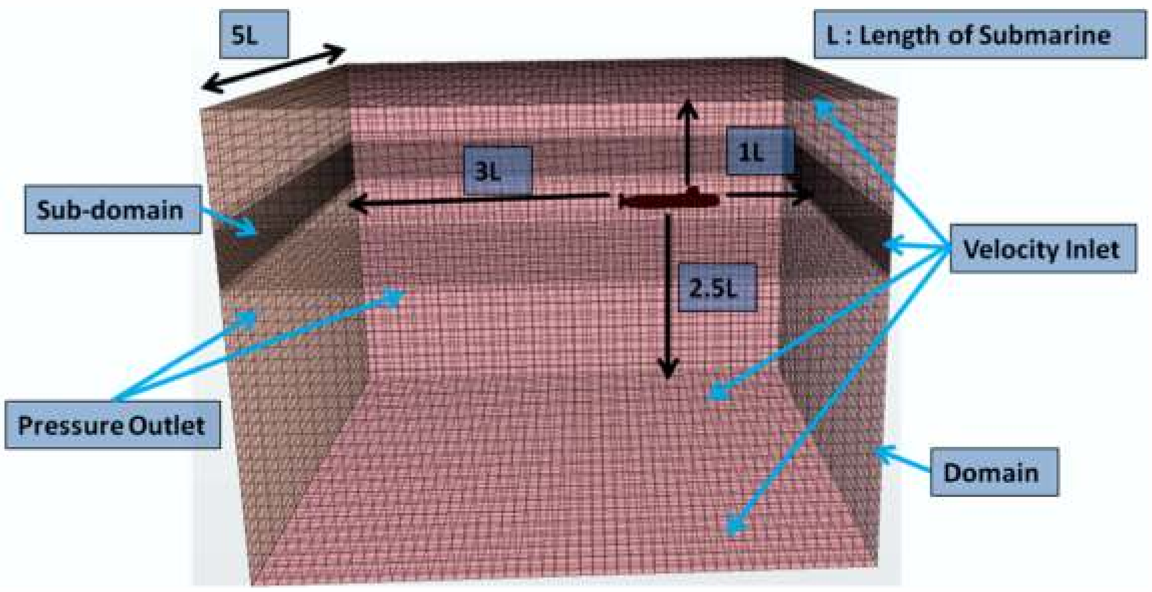

Figure 12: Domain and set up of Boundary Conditions

Table 6: Boundary conditions

Surface	Boundary condition	Physical value
Starboard	Velocity inlet	Velocity of beam waves
Forward	Velocity inlet	0 m/s
Top	Velocity inlet	0 m/s
Bottom	Velocity inlet	0 m/s
Aft	Pressure outlet	Hydrostatic pressure of beam waves
Port	Pressure outlet	Hydrostatic pressure of beam waves
Hull	Wall	no slip

Solver Settings

STAR-CCM+ uses a Finite Volume Method (FVM). In outline the numerical algorithm consists of the following steps:-

(a) Integration of the governing equations of fluid flow over all the (finite) control volumes of the domain

(b) Discretisation – conversion of the resulting integral equations into a system of algebraic equations

(c) Solution of the algebraic equations by an iterative method

In this study the solver characteristics specified are as follows:-

(a) Solver:- Unsteady, implicit

(b) Turbulence model:- Realisable $K - \varepsilon$ turbulent

(c) Wall treatment:- Two layer all $y+$ wall treatment

(d) Multiphase flow model:- Volume of Fluid (VOF), gravity

(e) Dynamic Fluid Body Interaction (DFBI):- The DFBI module couples fluid flow with body motions. The solution is achieved by formulating and solving the equations of motions in addition to solving the RANS equations. In this study the body is allowed to rotate about x-axis and translate in z-axis, i.e. roll and heave.

(f) Stopping criteria. The following stopping criteria were specified:-

(g) Maximum inner iteration = 5

(h) Maximum physical time = 40 sec

(I) Maximum steps = 1000

Post-processor

Some of the data visualization tools that are equipped in the software and were used for this study are:-

(a) Domain geometry and grid display

(b) Vector plots

(c) Line and shadow contour plots

(d) 2D and 3D surface plots

(e) Reporting, Monitoring and Plotting

(f) Exporting scenes for scene animation

Simulations Parametric Study

The geometry was imported from Paramarine and the model was meshed, initial and boundary conditions specified and various simulations were undertaken for the following:-

(a) Grid dependence study

(b) Time step dependence study

(c) Influence of wave period on roll amplitude

(d) Influence of increasing speed on roll amplitude

Dependence of roll motion on wave period

The natural roll period of the submarine was calculated as 8.15 sec using the formula,

$$T_{Roll} = 2\Pi k \div \sqrt{gGM_T} \quad (3)$$

where k = radius of gyration for roll = 0.4 B

GMT = Transverse metacentric height = 0.478 m

Simulations were carried out keeping the speed, time step and wave height same to find out the effect of wave period on roll amplitude. The plot obtained from 4 iterations has been super imposed and is given in figure 13. It can be concluded from the analysis that the roll amplitude is maximum at 8 sec, which is close to the natural roll period of the submarine calculated using the empirical formula at (3.4)

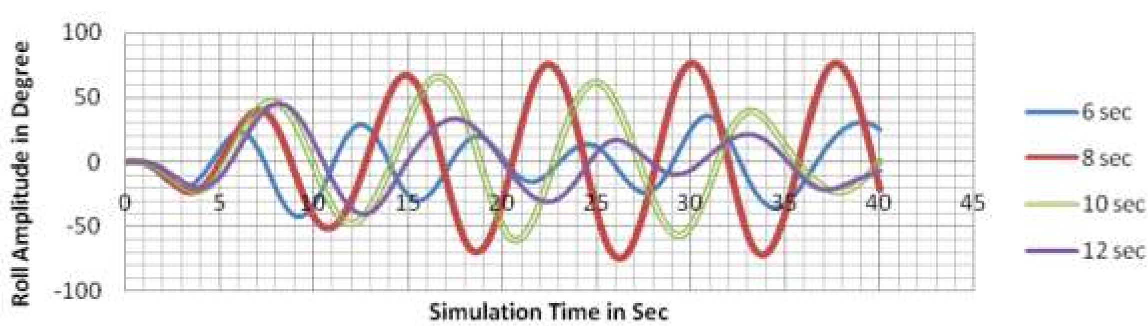

Figure 13: Comparison of roll amplitude for different wave period

Free Oscillation Test

Free oscillation tests were conducted to estimate the natural roll period of the submarine. The equation to describe free rolling of the submarine may be written as,

$$(I_\phi + I'_\phi)\ddot{\phi} + (B_{\phi r} + B_{\phi v})\dot{\phi} + C_\phi \phi = 0 \quad (4)$$

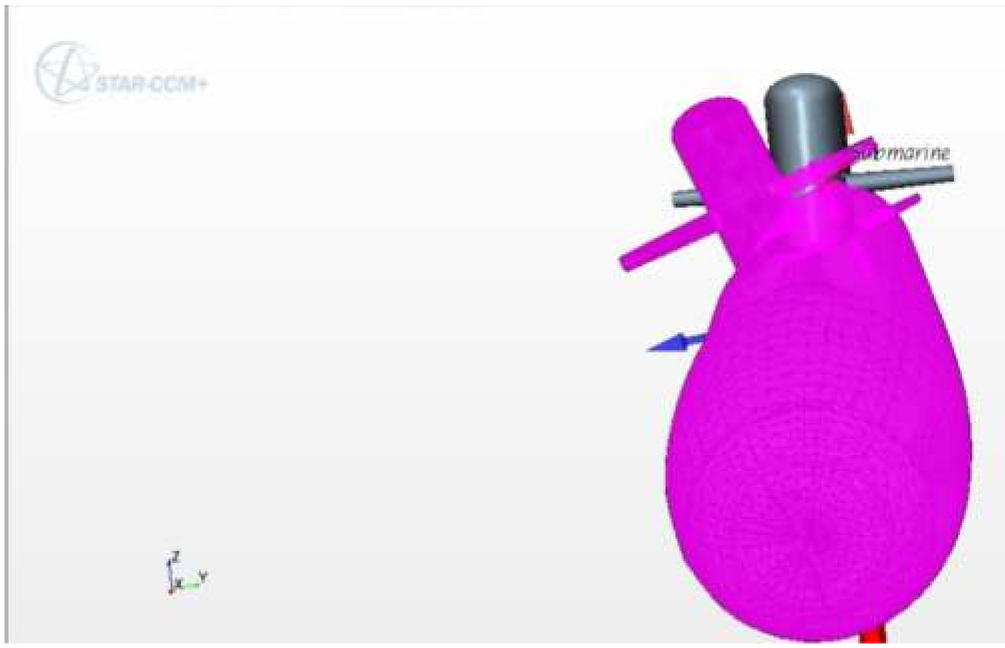

Figure 14: Set up in Star-CCM+ for free oscillation test

Set up for the test is shown in figure 14. For undertaking this in the software, the whole domain was tilted by 20 degrees about x-axis. It was then subjected to flat waves (calm water) and the actual draft was specified. When simulated, the disturbance decays and the natural period of roll could be estimated. Given below is the result of free oscillation test. It can be observed from the Figure 15 that the peaks occur at a time interval of 8 seconds.

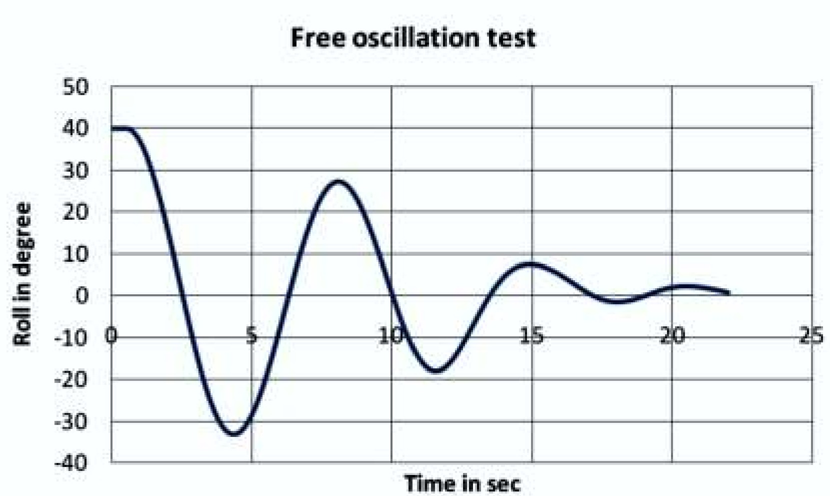

Figure 15: Free Oscillation test

Dependence of roll motion on forward speed

As speed increases the roll amplitude decreases, was one of the major conclusions from Paramarine. This was to be cross verified in Star-CCM+. For that purpose, keeping wave height, wave period and time step as same, the speed was varied and the obtained result is given in figure 16.

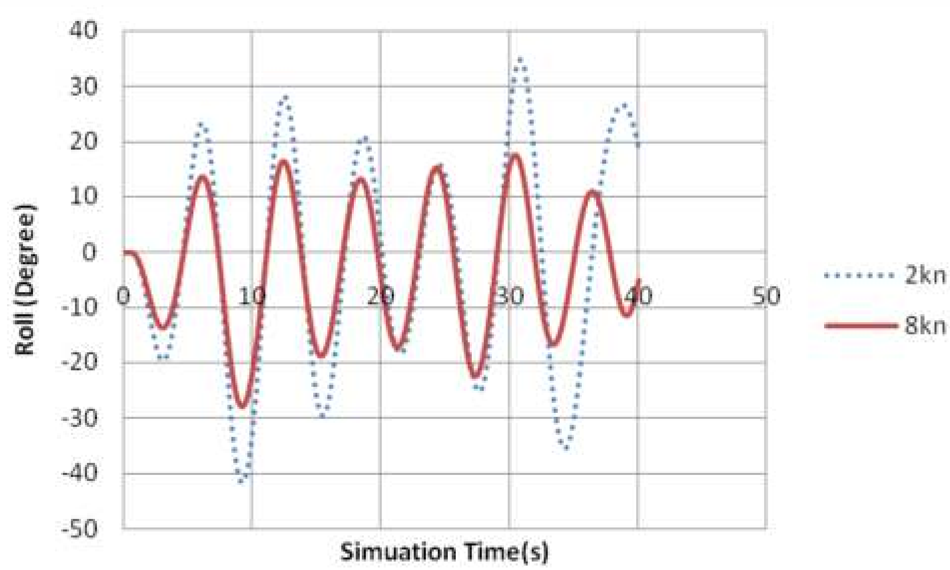

Figure 16: Comparison of roll amplitude for forward speed

It can be concluded from the above analysis that the roll amplitude decreases as the speed increases. The above plot shows the roll responses of the submarine for speeds of 2.0 and 8.0 knots.

Roll motions in Beam Seas

After establishing the model, simulations were carried to estimate the amplitude of roll motion with the following input conditions and the results are given in table 7.

(a) Wave Height(m): 1,3 and 5

(b) Wave Period(sec): 6 and 8

(c) Speed(kn): 0, 4, 8 and 10

(d) Time step: 0.005 sec

(e) Simulation time: 40 sec

(f) Wave considered: Stokes 5th order

Table 7: Roll motion amplitude in beam seas

H (m)	T (s)	V_s (kn)	Φ_{RMS}(Deg)
1	6	0	6.5
1	6	4	6.2
1	6	8	5.5
1	6	10	4.5
1	8	0	21.1
1	8	4	19.1
1	8	8	15.5
1	8	10	11.1
3	6	0	17.9
3	6	4	16.4
3	6	8	14.8
3	7	0	26.7
3	8	0	41.5
3	8	4	40.4
3	8	8	36.6
5	6	0	19.0
5	6	4	19.1
5	6	8	18.6
5	7	0	32.8
5	8	0	47.0
5	8	4	46.2
5	8	8	42.0

Free Stream Characteristics of Control Surface

The purpose of having a control surface on a vessel is to control the motion of the ship. The control surface may be composed entirely of a single moveable surface or a combination of fixed and moveable portions. Here the control surface being analysed are the stern planes at the aft portion of the submarine. In the original configuration of stern plane there is a common tiller, which makes the stern plane move in the same direction and is used for controlling trim. In the proposed configuration, they are not interconnected and are independent. Hence they can be moved independent of each other and therefore used for controlling both trim and roll.

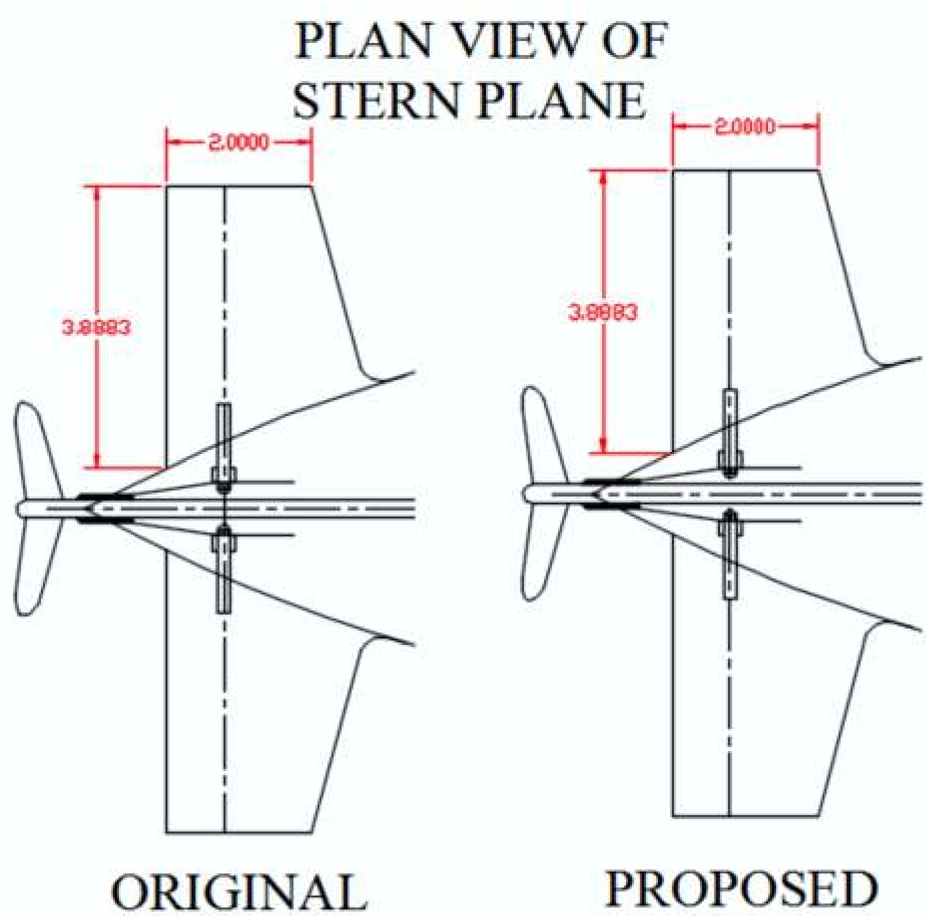

Figure 17: Plan view of stern plane in original and proposed configuration

Free stream characteristics were undertaken in Star-CCM+ to estimate the lift force for different angle of attack and speeds. This was also verified with the data available from NACA report for the selected shape and was found to be in good agreement.

7. ROLL STABILISATION

Stern planes in a submarine are used to control trim when tilted in the same direction. When tilted independently to same angle and in opposite directions, the stern plane generates a lift force and thus a stabilising moment as explained in figure 18. The forces are separated by a distance 2a, where a is called the characteristic lever, which is the distance between centre of gravity of the submarine and the point of action of the lift force, which is the centre of pressure. These lift forces in opposite direction creates a stabilising moment which counters the exciting moment for rolling due to waves.

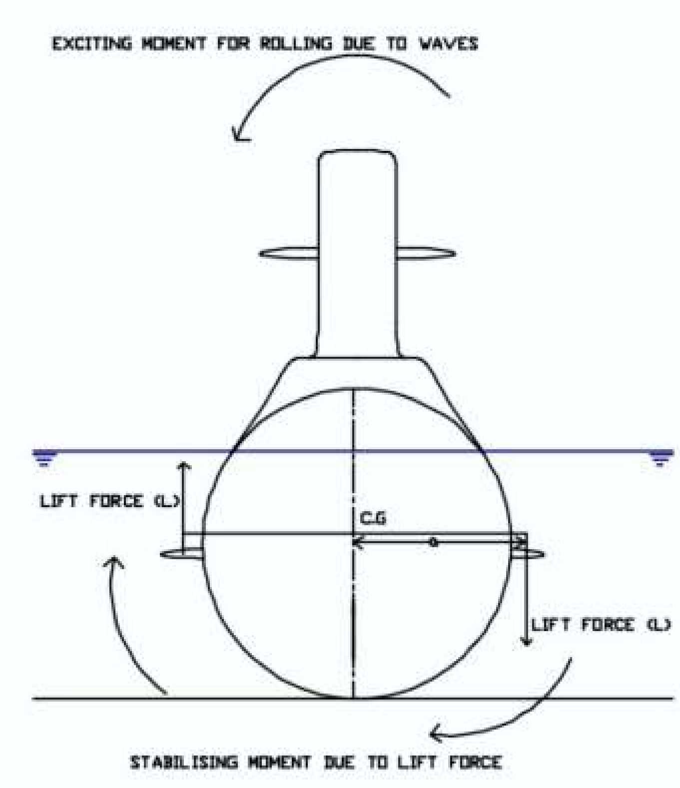

Figure 18: Layout showing the generation of lift force, exciting moment and stabilising moment

For achieving this, the stern plane configuration has to be modified as shown in figure 17. There has to be a separate tiller for each of the stern plane, so that it can be operated independently. The stern plane considered in this study is a NACA 0025 section with a moveable area of 15.5 m2 and fixed area of 5.5 m2.

In order to undertake roll stabilisation and estimate the reduced roll amplitude, the roll equation of motion at (1) has to be modified as given below:-

$$(I_\phi + I'_\phi)\ddot{\phi} + (B_{\phi r} + B_{\phi v})\dot{\phi} + C_\phi \phi = M_{\phi w} + M_{\phi f} \qquad (5)$$

In LHS, the first term is the inertial one, the second term is the roll damping term, which is the crux of the argument, and the last term is the restoring moment.

The RHS of the above equation is the exciting moment provided by the waves and the counter moment provided by the control surfaces, which is the stern plane here. There should be a phase difference of π between these moments to reduce the roll motion. The former is calculated using

Star-CCM+ and the latter by free stream characteristics of the control surfaces as explained above. Once the moments generated by the stern planes at each angle for different speeds are known, then equation (5) can be solved to estimate the reduced roll amplitude in Star-CCM+.

CFD Analysis of Stern Planes

Lift characteristics of the stern plane in hydrodynamic flow were studied for the following cases:-

(a) Speed: 4, 8 and 10 kn

(b) Angle of attack: 0 – 35 degrees with step of 5 degree

The boundary conditions specified in this study are elaborated below in Table 8. Velocity inlet was specified at starboard, port, bottom and forward. The physical value was set as 0 m/s for all the velocity inlets except for forward, where the flow velocity required was chosen. Pressure outlet was specified as the boundary on top and aft. At the hull, a no-slip wall condition was specified so that the fluid will have zero velocity relative to the boundary.

Table 8: Boundary conditions

Region	Boundary condition	Physical value
Domain starboard	Velocity inlet	0
Domain forward	Velocity inlet	Flow velocity
Domain top	Velocity inlet	0
Domain bottom	Velocity inlet	0
Domain aft	Pressure outlet	Hydrostatic pressure
Domain port	Pressure outlet	Hydrostatic pressure
Stern plane	Wall	no slip

After grid dependence study and iteration of time step in the set up shown at figure 19, a model with 75000 cells is selected and time step has been finalised at 0.005 sec.

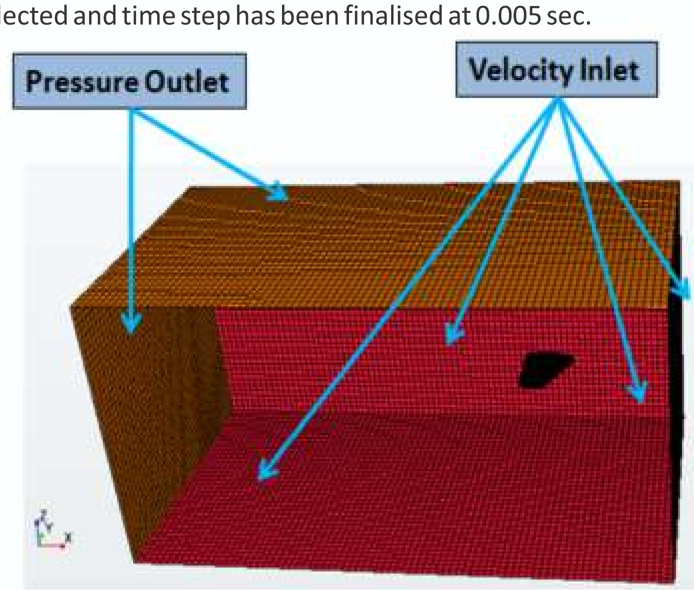

Figure 19: Model set up of stern plane with boundary conditions

From the simulation, lift force generated by the stern plane is obtained as an output for different angles of attack and speeds. The stabilizing moment due to the lift force generated by the stern plane for equal and opposite angle of attack at different speeds was obtained by multiplying the lift force by '2a', where 'a' is the characteristic length. The value of 'a' for the present configuration is 2.5 m. Lift force (L) and stabilising moment (Mst) at different angles of attack and speeds are summarised in Table 9 below. It is to be noted that the lift force is for a single plane, whereas Mst is the total stabilising moment generated due to the action of both the planes.

Table 9: Lift force and stabilising moment

	L (kN)		
α(deg)	4 kn	8 kn	10 kn
0	0.12	0.41	0.61
5	5.15	20.58	32.07
10	10.00	39.92	62.21
15	14.80	58.20	92.46
20	19.35	77.21	120.33
25	23.74	94.62	147.37
30	29.60	96.54	146.09
35	31.13	121.54	187.97
	M_{st} (kNm)		
α(deg)	4 kn	8 kn	10 kn
0	0.6	2.1	3.1
5	25.8	102.9	160.4
10	50.0	199.6	311.1
15	74.0	291.0	462.3
20	96.7	386.0	601.7
25	118.7	473.1	736.8
30	148.0	482.7	730.4
35	155.6	607.7	939.8

The stabilising moment considered for simulations at 4kn is 148 kNm which corresponds to angle of attack of 30 degree. For simulations at 8kn and 10 kn, the stabilising moment at angle of attack of 25 degree has been considered i.e. 473 kNm and 737 kNm respectively.

Roll Stabilisation at Different Stern Plane Angles

The calculated moment due to differential action of stern plane at Table 9 would be applied to the simulations in Table 7 in such a manner that the stabilising moment has a phase difference of π with the roll exciting moment due to waves. By doing this the reduced amplitude of roll motion could be estimated. Roll simulation at HW=1m, T W = 8 s; VS = 4 kn is shown in Figure 20 with and without the action of stern planes.

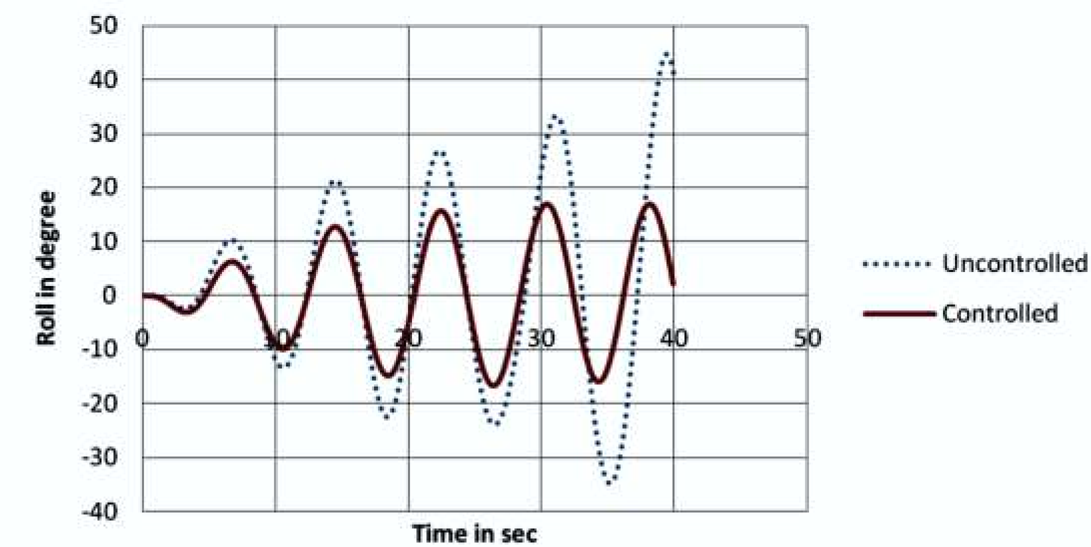

Figure 20: Comparison of roll amplitude. HW = 1m;
T W = 8 s; VS = 4 kn; Stern plane angle = 30 degree

From the above, the following were calculated:-

(a) Actual roll RMS = 19.1 degree

(b) Reduced roll RMS = 9.6 degree

© Percentage reduction = 50 %

Similarly the appropriate stabilizing moment was chosen for each case and all the simulations at Table 7 were repeated to obtain the effectiveness of stern plane on roll reduction in beam seas and the results are given at Table 10. It is observed that reduction in roll RMS varies from 30% for wave height of 5m to 50% for a wave height of 1m. Also it is observed that maximum reduction occurs at resonance, which is as expected. The comparison plots with and without the action of stern plane are plotted in figures 21 to figures 34.

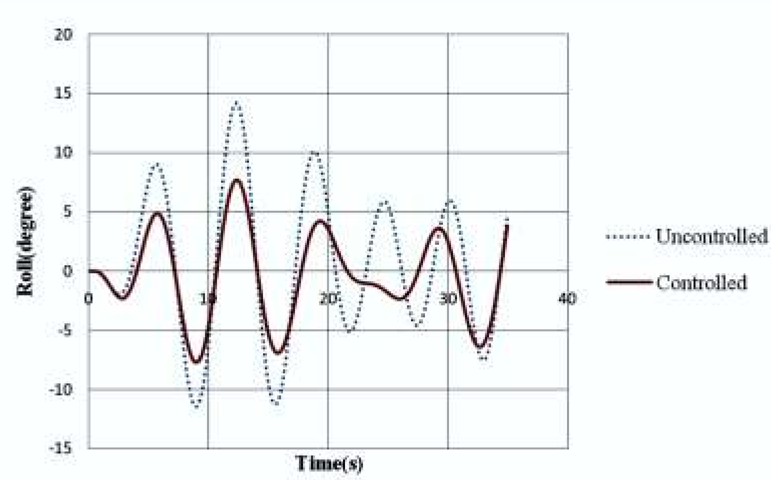

Figure 21: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 6 s;
VS = 4 kn; Stern plane angle = 30 degree

Table 10: Effectiveness of stern plane on roll reduction in beam seas

H (m)	T (s)	V_s (kn)	ΦRMS(Deg)	α(Deg)	Φ'RMS(Deg)	% Reduction
1	6	0	6.5	-	-	-
1	6	4	6.2	30	3.6	42
1	6	8	5.5	25	3.5	37
1	6	10	4.5	25	2.9	35
1	8	0	21.1	-	-	-
1	8	4	19.1	30	9.6	50
1	8	8	15.5	25	8.4	46
1	8	10	11.1	25	6.6	41
3	6	0	17.9	-	-	-
3	6	4	16.4	30	9.0	45
3	6	8	14.8	25	8.0	46
3	7	0	26.7	-	-	-
3	8	0	41.5	-	-	-
3	8	4	40.4	30	28.4	30
3	8	8	36.6	25	25.6	30
5	6	0	19.0	-	-	-
5	6	4	19.1	30	12.7	34
5	6	8	18.6	25	11.5	38
5	7	0	32.8	-	-	-
5	8	0	47.0	-	-	-
5	8	4	46.2	30	29.7	36
5	8	8	42.0	25	27.5	35
2.5	8.8	0	13.5	-	-	-
4	9.7	0	28.0	-	-	-

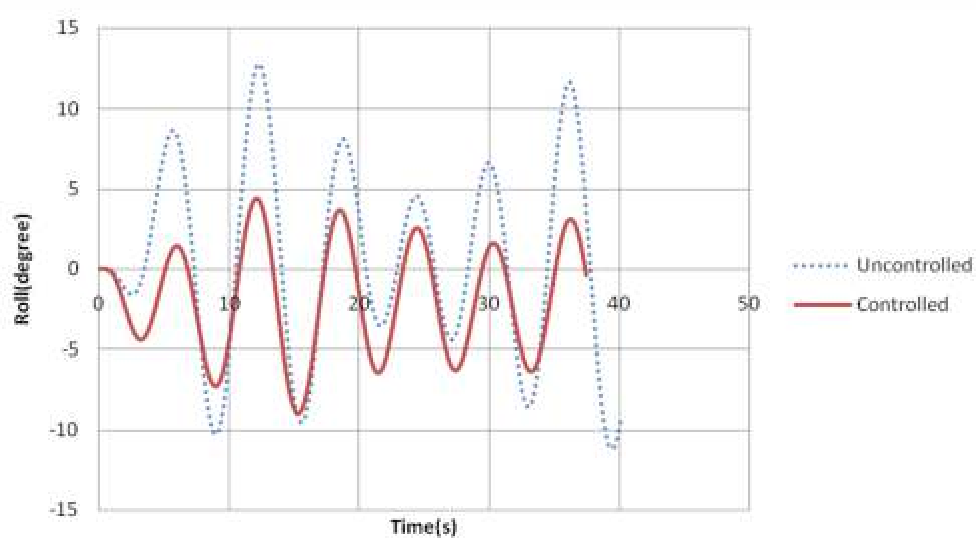

Figure 22: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 6 s;
VS = 8 kn; Stern plane angle = 25 degree

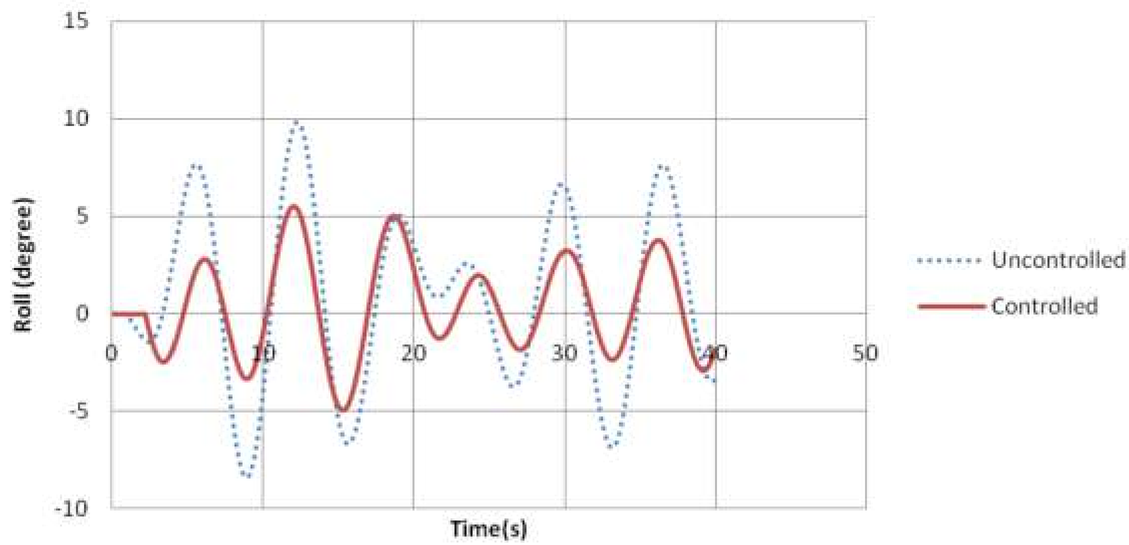

Figure 23: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 6 s; VS = 10 kn; Stern plane angle = 25 degree

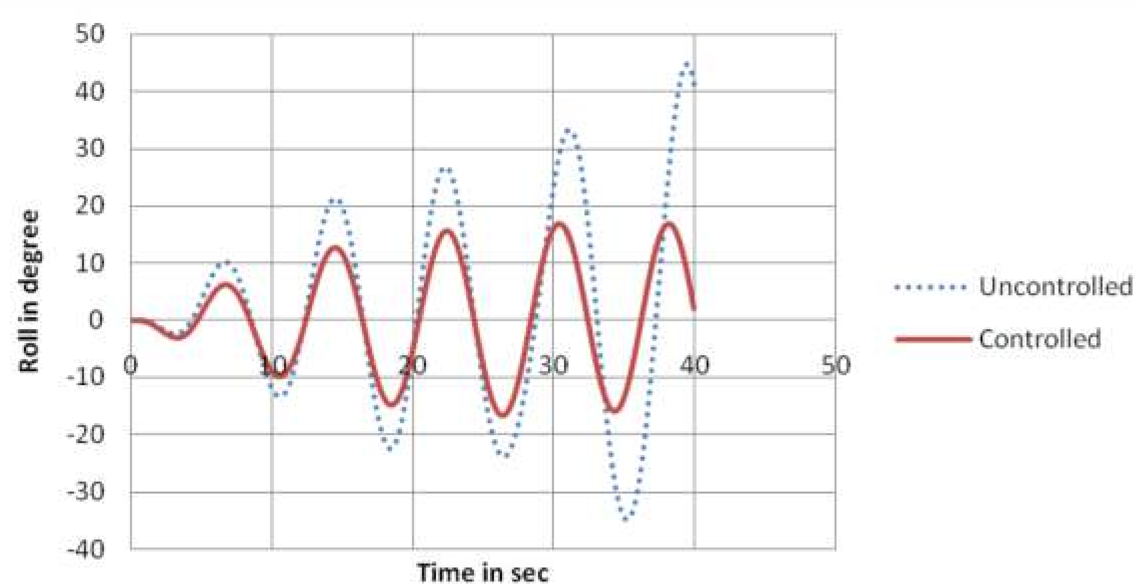

Figure 24: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 8 s; VS = 4 kn; Stern plane angle = 30 degree

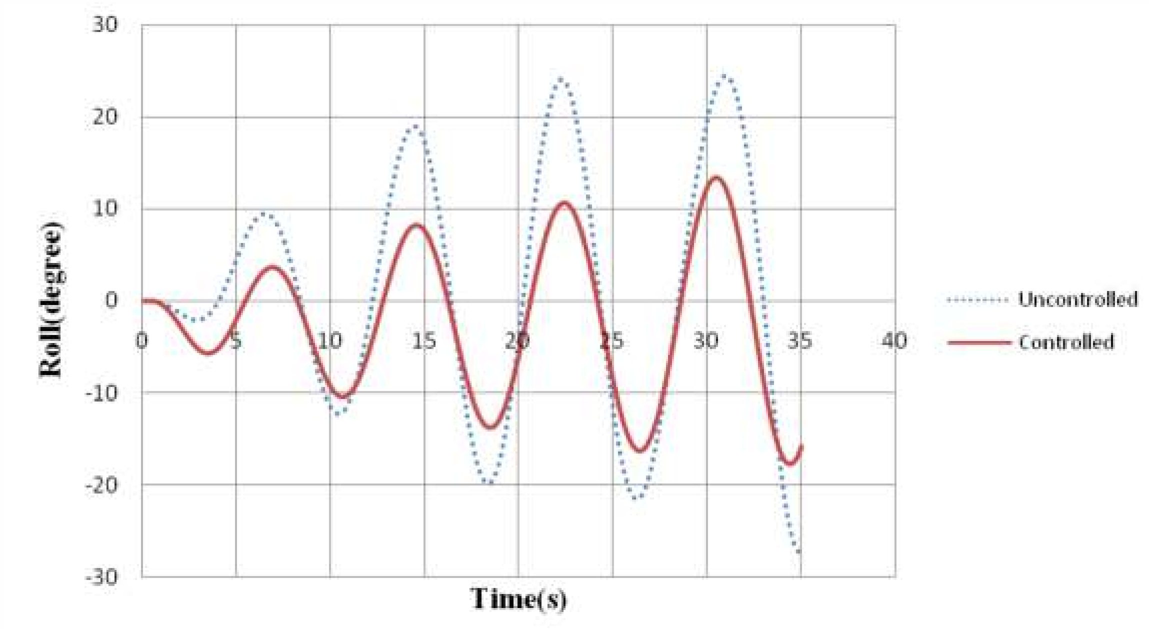

Figure 25: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 8 s; VS = 8 kn; Stern plane angle = 25 degree

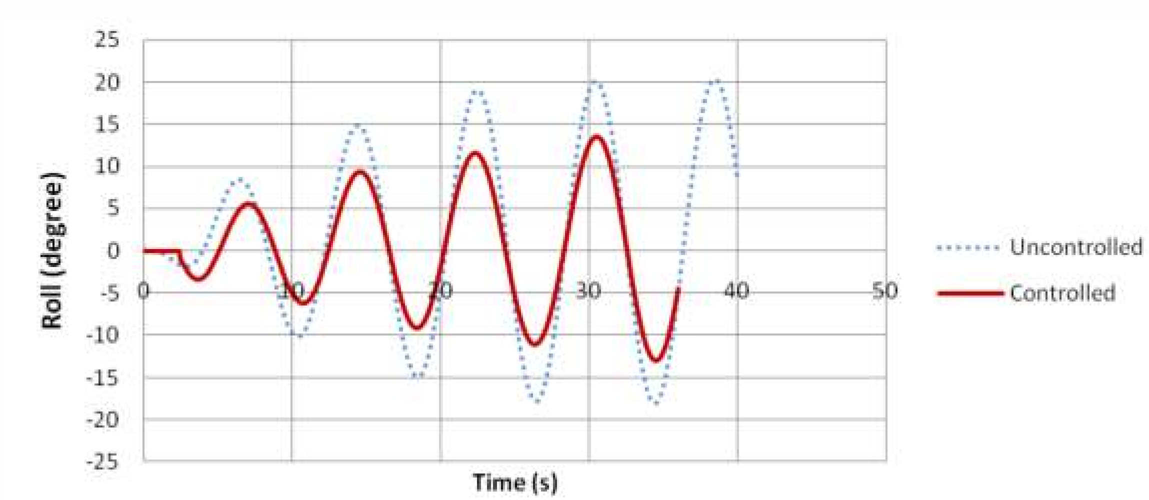

Figure 26: Roll amplitude in uncontrolled and controlled mode; HW = 1m; T W = 8 s; VS = 10 kn; Stern plane angle = 25 degree

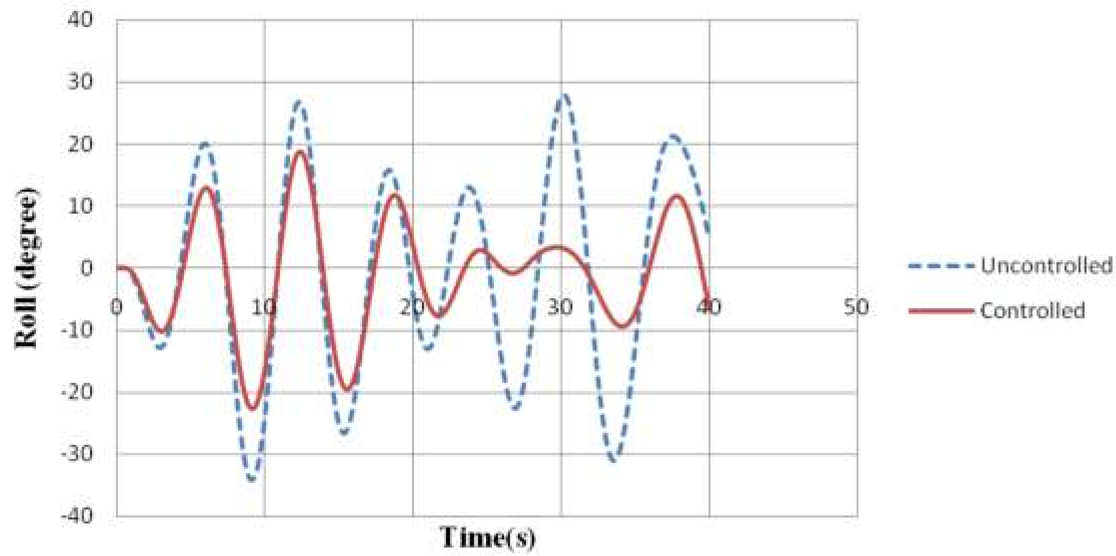

Figure 27: Roll amplitude in uncontrolled and controlled mode; HW = 3 m; T W = 6 s; VS = 4 kn; Stern plane angle = 30 degree

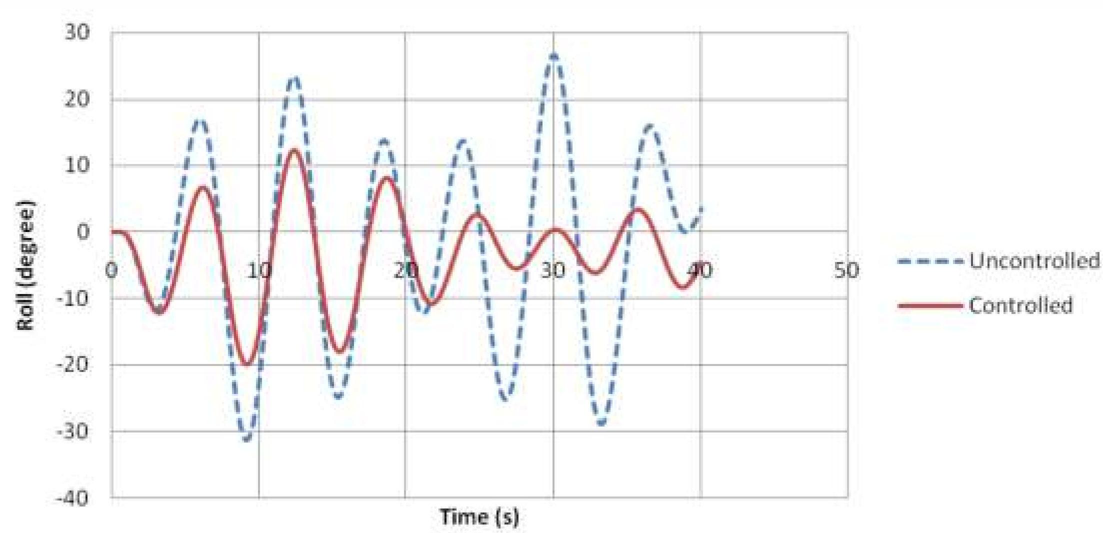

Figure 28: Roll amplitude in uncontrolled and controlled mode; HW = 3 m; T W = 6 s; VS = 8 kn; Stern plane angle = 25 degree

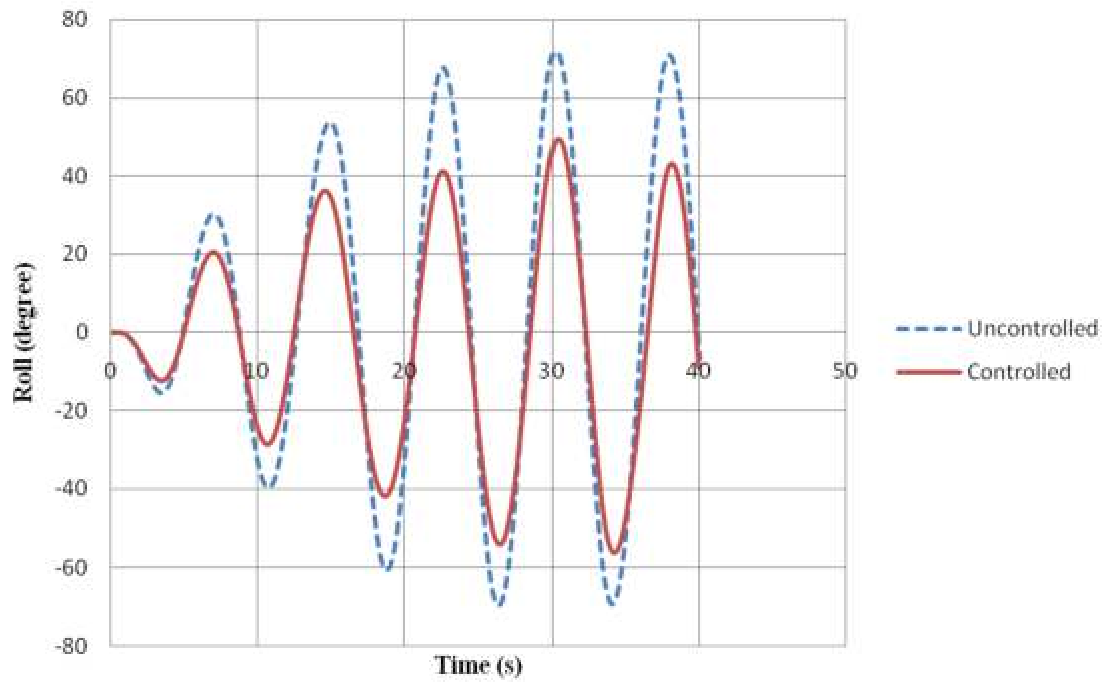

Figure 29: Roll amplitude in uncontrolled and controlled mode; HW = 3 m; T W = 8 s; VS = 4 kn; Stern plane angle = 30 degree

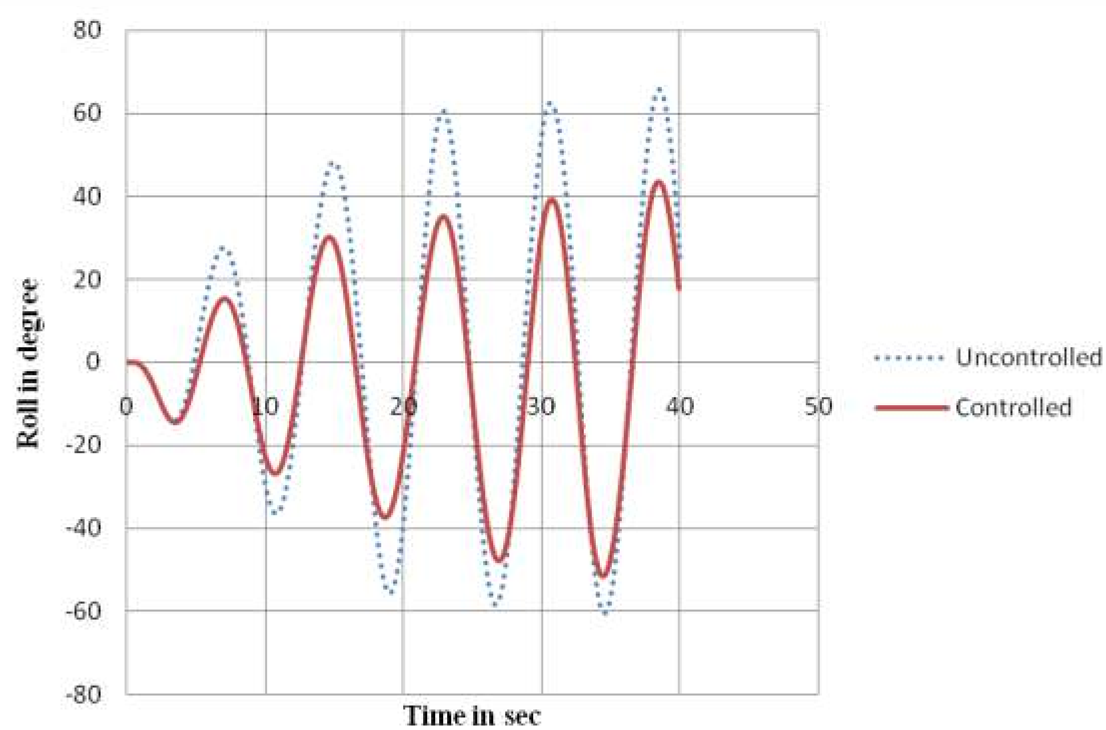

Figure 30: Roll amplitude in uncontrolled and controlled mode; HW = 3 m; T W = 8 s; VS = 8 kn; Stern plane angle = 25 degree

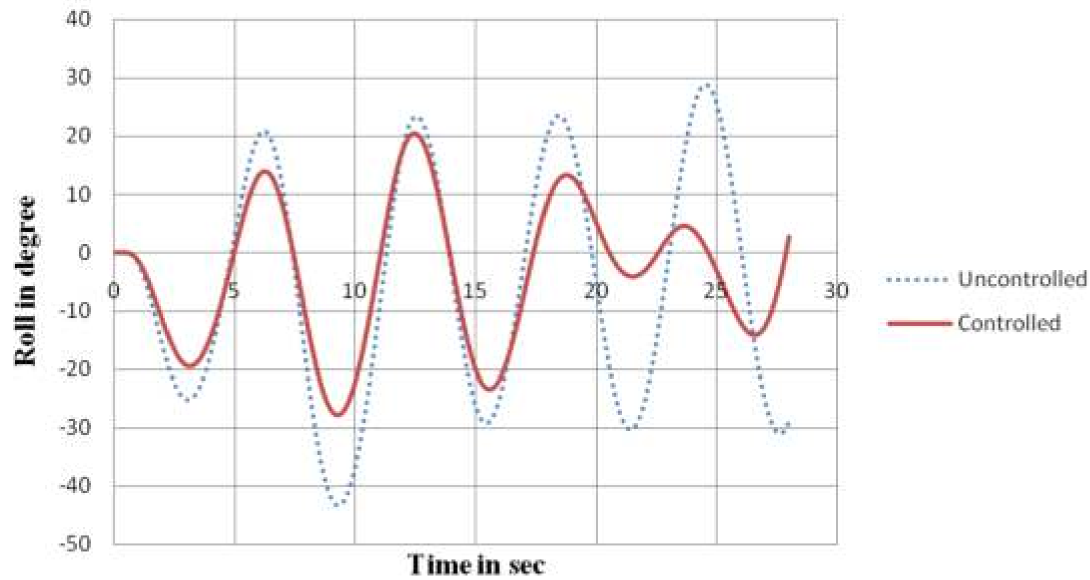

Figure 31: Roll amplitude in uncontrolled and controlled mode; HW = 5 m; T W = 6 s; VS = 4 kn; Stern plane angle = 30 degree

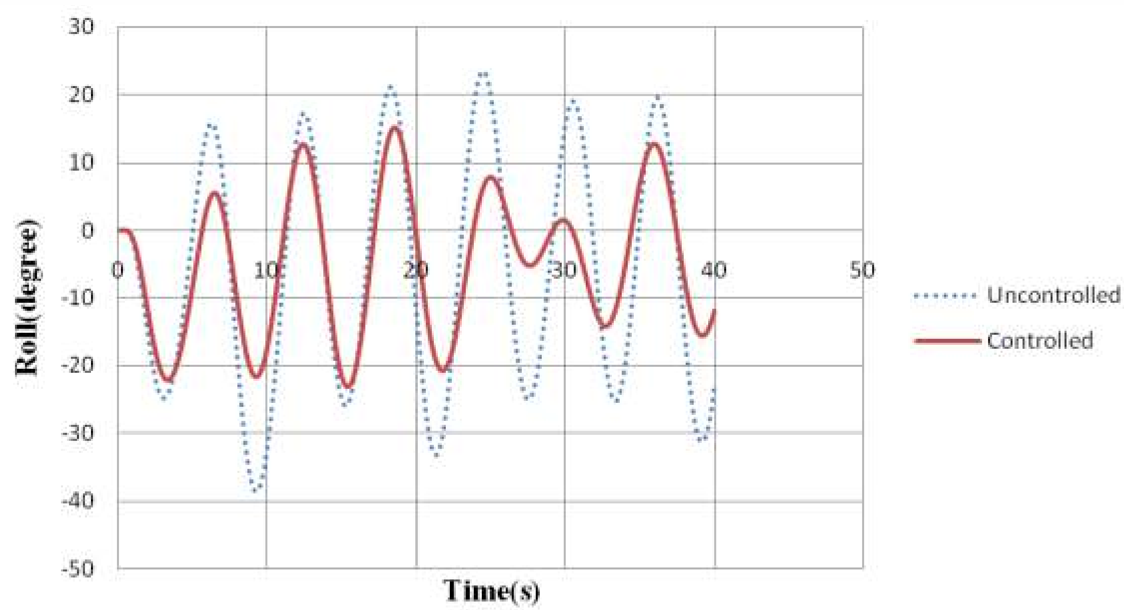

Figure 32: Roll amplitude in uncontrolled and controlled mode; HW = 5 m; T W = 6 s; VS = 8 kn; Stern plane angle = 25 degree

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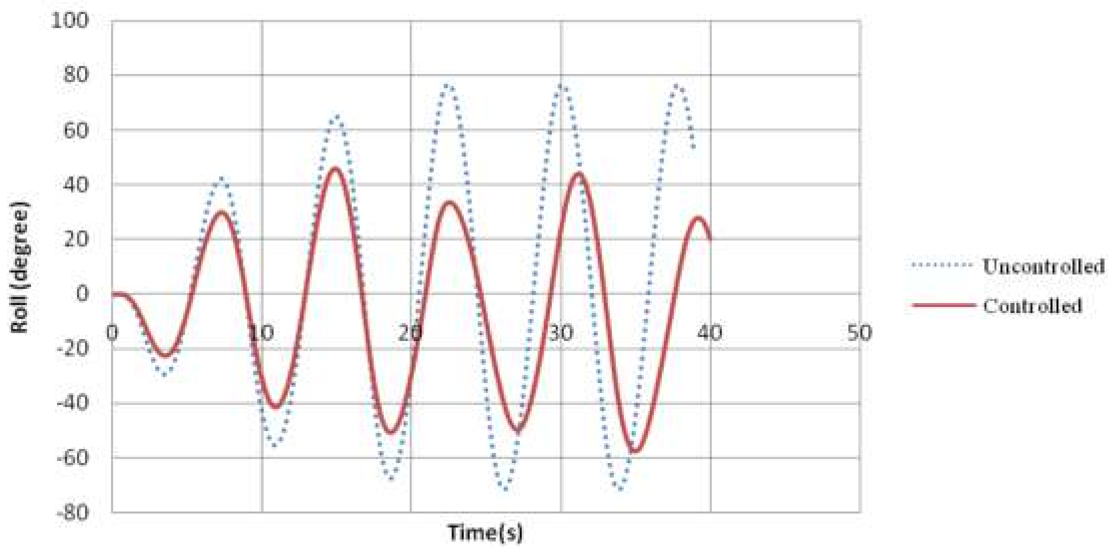

Figure 33: Roll amplitude in uncontrolled and controlled mode; HW = 5 m; T W = 8 s; VS = 4 kn; Stern plane angle = 30 degree

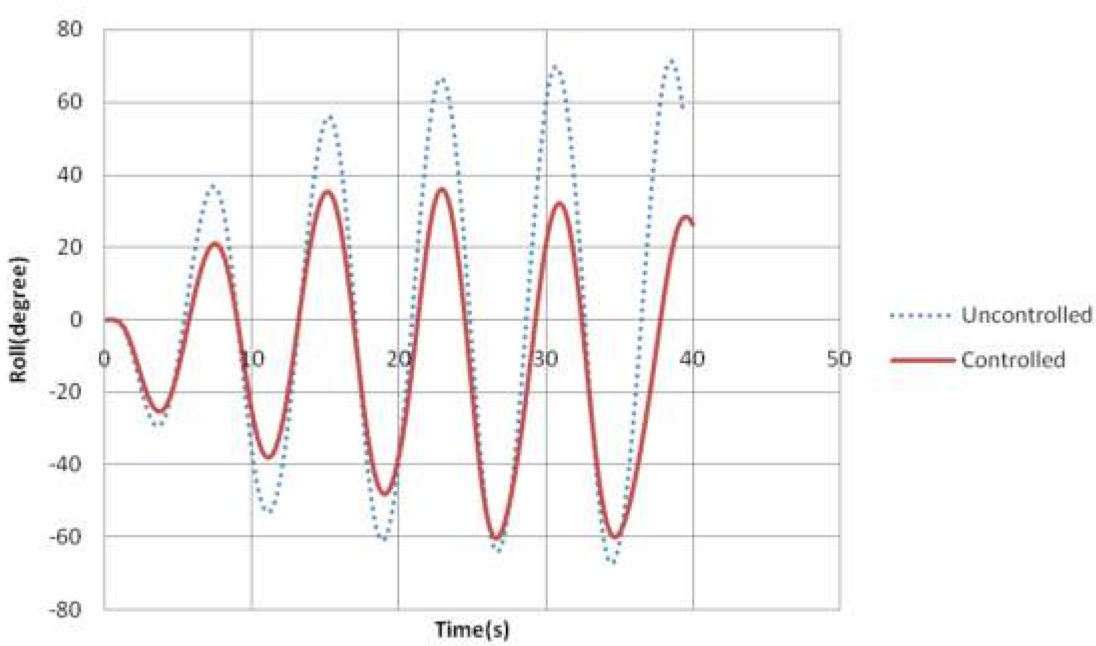

Figure 34: Roll amplitude in uncontrolled and controlled mode; HW = 5 m; T W = 8 s; VS = 8 kn; Stern plane angle = 25 degree

8. CONCLUSIONS

Seakeeping calculations undertaken in Paramarine gave the roll RMS values for different speeds, sea state and wave directions. It was found that the roll amplitude increases with sea state for same speed and heading. For a particular sea state and heading, the roll amplitude decreases with increase in speed. Operability plots generated gave the safe and unsafe area of operation in beam seas for roll criteria given by NORDFORSK. Maximum roll motion is observed when the heading is 90 deg (Beam sea) in all the cases and it was concluded that there is a need to reduce the roll motion for better seakeeping of submarine at surface.

The natural roll period was estimated as 8 sec from free oscillation test carried out in Star-CCM+ and also using empirical formula. Simulations carried out at same wave height and wave period revealed that as speed increases, the amplitude of roll motion decreases which is observed in the results from Parmarine also. From the free stream characteristics of the stern plane carried out in Star-CCM+, lift force for different angles of attack and speeds was generated. From the lift force, stabilizing moment and lift co-efficient were calculated. Validation with NACA Report No.669 gave reasonable agreement of the free stream characteristics. The stabilising moment when applied at a phase difference of 180 degree to the exciting moment caused by waves reduces the amplitude of roll motion. For wave heights less than 1m, the roll can be controlled and brought within the NORDFORSK criteria if the stern planes are moved in equal and opposite direction. There is reduction up to 50% in some cases. However for higher wave heights, the reduction in roll amplitude is in the range of 30 – 40 %, even though they do not meet the NORDFORSK criteria after stabilisation.

The present study shows that the unstabilised roll motion of the submarine considered here for analysis is excessive when it operates at the free surface, due to the wave action. The operability condition is very critical even in moderate beam seas. The stern planes of a submarine normally are used in tandem for the submarine diving or surfacing purpose. If these stern planes located at the aft end on port and starboard sides are used independently in a controlled way, it can be used as roll stabilising fin too. The present study also throws light into the effectiveness of these stern planes on roll stabilisation.

Scope for Further Work

(a) The present study has analysed the roll motion of the submarine primarily in regular waves. More cases of irregular waves could be analysed.

(b) The present study restricts the roll motion while operating at surface. Roll motion at periscope depth and dived condition could be analysed.

ACKNOWLEDGEMENTS

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article 9

APPLICATION OF COMPUTATIONAL FLUID DYNAMICS (CFD) AND HIGH PERFORMANCE COMPUTING (HPC) FOR SUBMARINE DESIGN

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1. INTRODUCTION

The basic submarine design approaches can be roughly classified into three major approaches. Each of these approaches has its own advantages and disadvantages.

The empirical/statistical approach involves design based on the past available data. These approaches combine a rather simple physical model and regression analysis to determine required coefficients either from one parent design or from a set of designs. The coefficients may be given in form of constants, formulae, or curves. It is fast, simple and cheap; however, has limited applicability. Detailed analysis cannot be performed with this approach. It is based on statistical evaluation of old designs and would have very limited applicability to newer designs. Extensive design data for submarine is not readily available.

Another approach is experimental approach, in which tests are performed on the scaled down models, required information is extracted and it is scaled (transformed) to full-scale model. Here main uncertainty is scaled down model to full-scale model correlation. The physics differs as the scale of the model changes introducing uncertainty about the results.

Numerical approach allows to perform detailed analysis on true scale model and can be used right from the concept level thus reducing total design cost and design cycle time. However, it requires special resources i.e. expertise in tool, domain knowledge, software and high end computer hardware. This paper discussed about applications of computational fluid dynamics (CFD) and High Performance Computing (HPC) technologies for submarine design.

2. CFD TOOL FOR SUBMARINE DESIGN

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze problems involvingfluid flow, heat transfer, mass transfer, chemical reactions, and related phenomena. CFD is an integral part of the engineering design and analysis work flow for many industries like Aerospace, Automotive, Energy, Oil and Gas, Life Science, Marine etc.

In CFD, computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high performance computing (HPC), better and faster solutions can be achieved for complex simulation scenarios.

The typical product design process includes concept design, detailed design and testing. This is an iterative process, which keeps on repeating until the product meets the expected performance. With the help of CFD and HPC this iterative process can be shortened to one or two interations. This virtual prototyping approach is an alternative to expensive scale model building and testing. This can save time in evaluating shape changes or modifications to submarines. CFD can be used in assessment of submarine designs, both in early stages of the concept design and in later stages of the design process.

The fundamental basis of almost all CFD problems is the Navier–Stokes equations. The governing equations for an unsteady, three-dimensional, compressible, viscous flow are:

Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{V}) = 0$$

Momentum equations

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u \vec{V}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f x$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla.(\rho v \vec{V}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho f y$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla.(\rho w \vec{V}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + \rho f z$$

Energy equation

$$\frac{\partial}{\partial t}[\rho(e + \tfrac{V^2}{2})] + \nabla.[\rho\left(e + \frac{V^2}{2}\vec{V}\right)] = \rho\dot{q}$$

$$+ \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) - \frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} + \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} +$$

$$\frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z} + \rho\vec{f}.\vec{V}$$

4. CFD METHODOLOGY

The basic CFD methodology is described in three major steps pre-processing, simulations and post-processing as described below and shown in Figure 1.

Pre-Processing:

- 3D CAD geometry can be imported into pre-processing software. Usually 3D CAD geometry prepared by the designer.
- On this CAD geometry, cleanup operation is performed. This process involves removal/simplification of geometry features which are of no interest for CFD analysis.
- On cleaned geometry computational domain is defined. The entire computational domain discretized into number of smaller control volumes known as volume cells. A grid or mesh is a collection of these volume cells. The grid generation involves defining the structure and topology and then generating a grid on that topology.
- Entire pre-processing is very time consuming process, it can take few weeks to months based on the geometry complexity.

Solving:

- In solving stage, the governing equations are solved for specified boundary conditions like pressure, velocity and temperature etc on HPC platform for entire computational domain.

Post-Processing:

- Post-processing of the results is done to study the detailed velocity, pressure, temperature contours and other post-processed data. The time for this step will vary from hrs to days based on the details of post-processing.

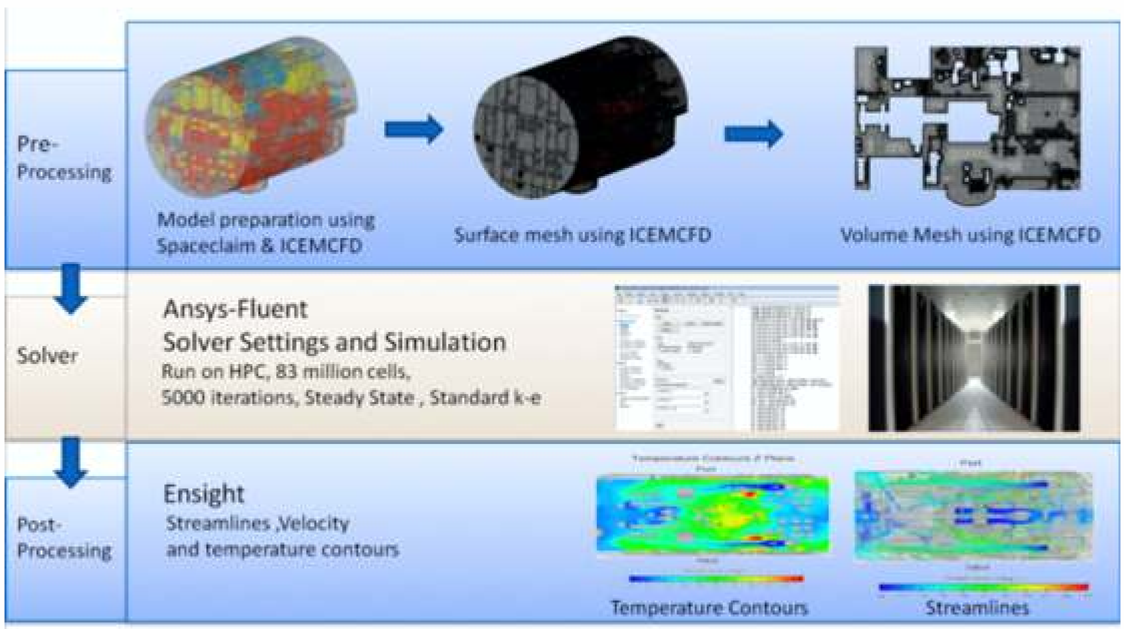

Figure : Typical CFD Workflow

This basic methodology need to be developed further for particular problem in terms of mesh topology, boundary conditions, solver settings etc.

4. CFD ANALYSIS OF HABITABLE COMPARTMENT

Physically it was observed that some cabins in habitable compartment are getting relatively hotand not getting adequate flow. Solution to this problem using traditional experimental methods has limitations as described in section 4.1. Hence, it was decided to undertake the CFD analysis of habitable compartment as detailed in section 4.2.

4.1 Limitations of Experimental Methods

With multiple flow outlets inside the cabins, flow modification at one outlet would affect the flow at all other outlets.

Here each modification involves preparation of design, CAD geometry/drawing generation, and prototyping of the parts. These modification needs to be installed and flow and temperature measurements needs to be carry out. This is costly and time consuming process.

Further, the end results of the process are not assured as this would be a trial and error method. Also detailed flow and temperature distribution patterns inside the cabins would be unknown.

4.2 CFD Analysis

The aim of the CFD study was to analyze the flow distribution and temperature patterns inside habitable compartment and subsequently to explore the possibilities to improve the flow & thermal state overall.

The generic CFD methodology described in Section 3 is applied and the details are given subsequent subsections.

4.2.1 Model Simplification

The geometry of Habitable compartment considered for the analysis included trunking, cabins, bunks, lockers, lights, Punkha Louvres etc. Cleanup operations were performed on the received CAD model and human dummy was added to get more realistic results. Final model used for the CFD analysis is as shown in Figure 2.

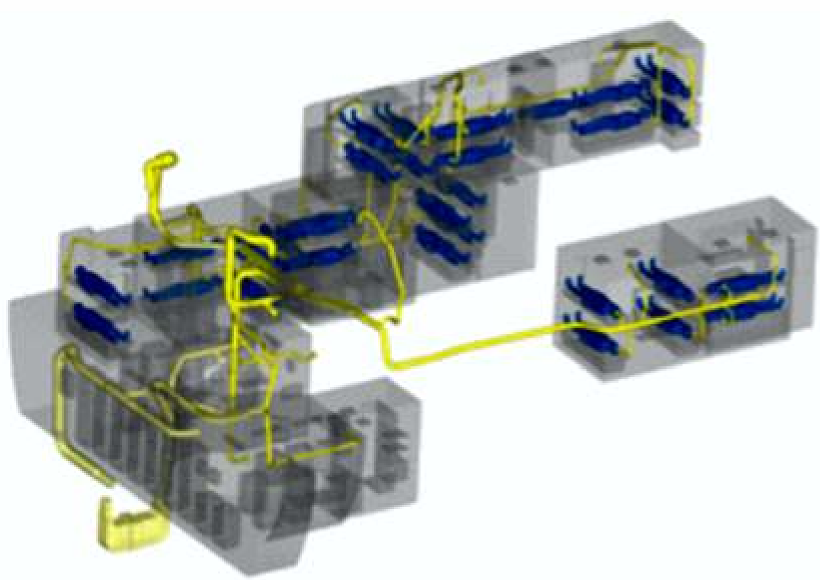

Figure : Cleaned up model (Cabins/Punkha Louvres/Trunkings)

1.2.2 Grid Generation

The entire flow domain (habitable compartment) discretized into number of smaller control volumes known as volume cells. A grid with around 20 Million tetrahedral elements and with around 2 Million triangular boundary elements is prepared for analysis. Figure3 shows the surface grid generated for entire habitable compartment.

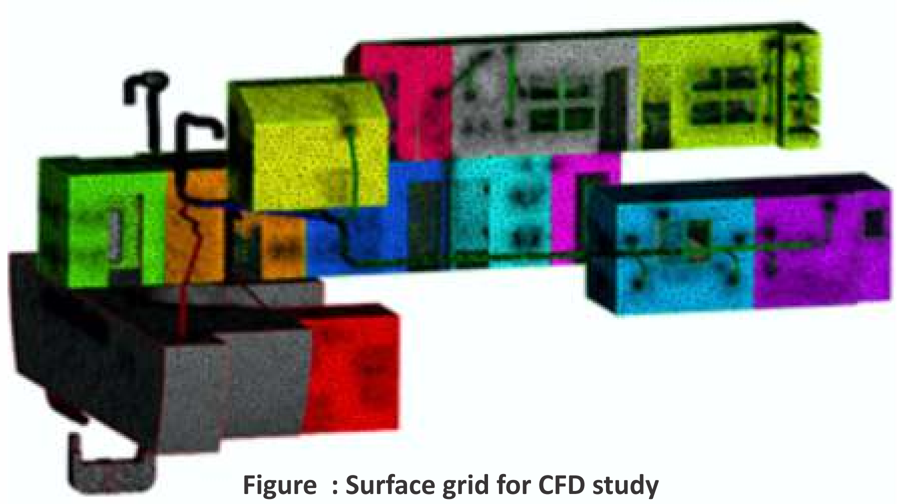

Figure : Surface grid for CFD study

4.2.3 Boundary and Initial Conditions

After discretizing the flow domain, boundary conditions are applied at the boundaries of the computational domain. The simulation starts from an initial guess and uses an iterative method to reach a steady state solution.

4.2.4 Solver Setup

For this case, Steady state simulation is set up with Semi-implicit pressure linked equation (SIMPLE) as pressure-velocity coupling algorithm and second-order discretization scheme for advection term. Realizable k-e turbulence model is coupled with viscous model. Convergence criterion of 1e-3 is chosen for all the residuals from the viscous model and 1e-6 for energy.

4.2.5 Results and Analysis

With CFD, detailed flow and temperature distribution analysis inside the cabins was done. The flow rate though each of the outlet was identified. The study revealed the uneven flow distribution in various cabins. The cabins which were close to flow source, were getting excess airflow (up to 120% surplus), whereas the cabins far from flow source were having significantly less airflow (up to 85% deficit).

Then with introduction of orifices and modifications to trunking the flow was balanced.Further, the distribution of the flow inside the cabin was improved with modified Punkha Louvre design for both central and individual location as shown in Figure4.

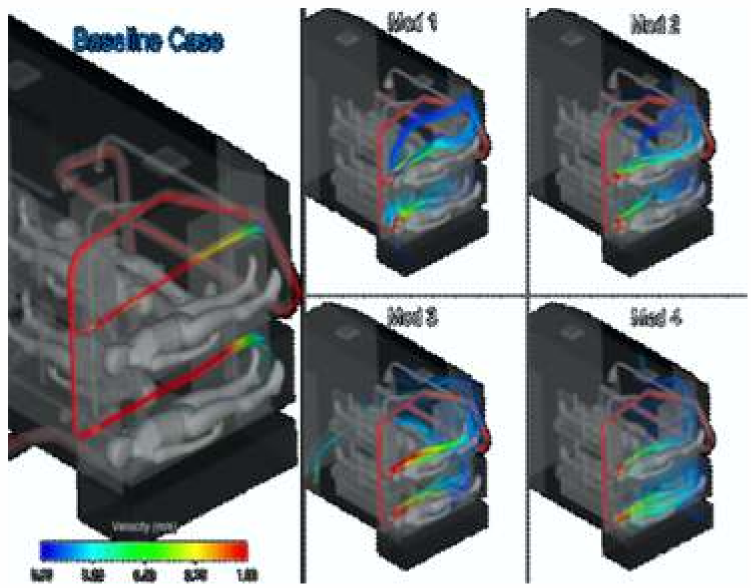

Figure : Velocity streamlines comparison

Optimized result achieved with an iterative process. The final flow balancing was achieved within 15% and minimum flow requirement through each Punkha Louvre was met.Four different designs for Punkha Louvre and two major design modifications to the trunking layout were implemented. The temperature inside the cabins found less than 250C with optimized trunking along with new punkha louvre design.

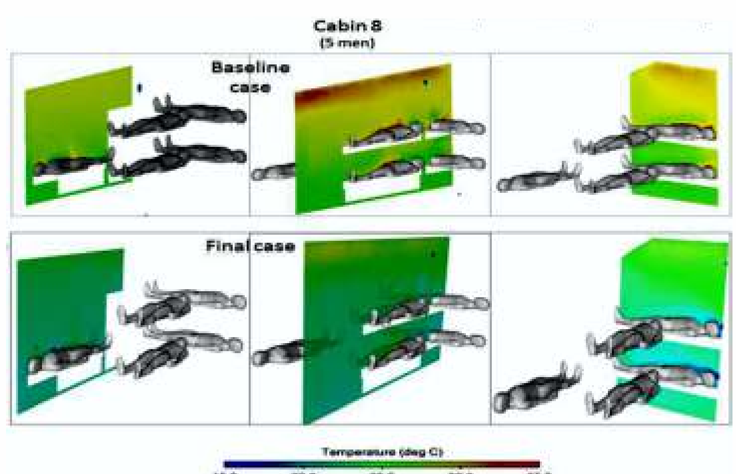

Figure : Temperature contours comparison

5. GENERAL CFD APPLICATIONS IN SUBMARINEDESIGN

The other areas of submarine design where CFD can be applied are enumerated in subsequent paragraphs.

5.1 External Hydrodynamics

The external flow CFD analysis as shown in Figure 6 is commonly used to study the behavior of objects submerged in continuous non static fluids, it aims to determine how efficiently a body can move through the medium and how they affect each other in the process.

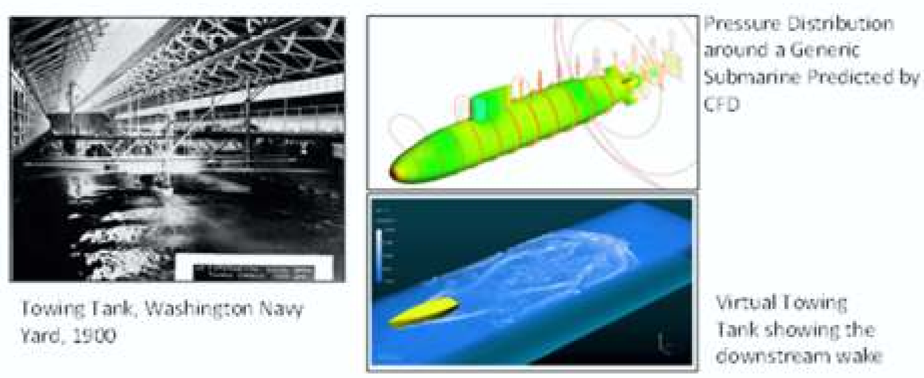

Figure : External Hydrodynamics Application Areas

Evaluating the pressure distribution on the structure generated by the resistances of the fluid, the engineers can optimize the design to decrease the amount of energy needed to move the body or the disturb impact on the fluid patch that leaves the pass of the structure.

5.2 Internal Hydrodynamics

- Dynamic Loads across a tank structure as a result of the motion of the free surface fluid confined inside the tank are an important safety issue. CFD can be used to track the fluid motion and analyze the sloshing impact loads as shown in Figure 8 where experimental and CFD results comparison is shown.
- Another example of internal hydrodynamics flow though pipes which can be done using CFD. To solve system level flow and thermal modeling problems 1D simulation tool e.g. Flowmaster can be used.

5.3 Acoustics

The evaluation of the noise generated by a submarine is of most importance in defense space. The acoustic signature of a submarine is made up of a number of individual elements which includes Machinery noise, Cavitation noise and Hydrodynamic noise.

Propeller operates in spatially non-uniform wake of the submarine. The propeller thrust and boundary pressure of the Submarine Hull are fluctuating, which generates significant acoustic signature. A general representation of this is as given in Figure 9.

Combination of the CFD and finite element models are the trend for future studies of the propeller induced submarine hull vibration and underwater noise radiation. The numerical prediction of the noise and vibration of a submarine under axial excitation from a propeller and excitation from the flow noise induced by the pulsating pressure of the hull can be evaluated by CFD as shown in Figure 10.

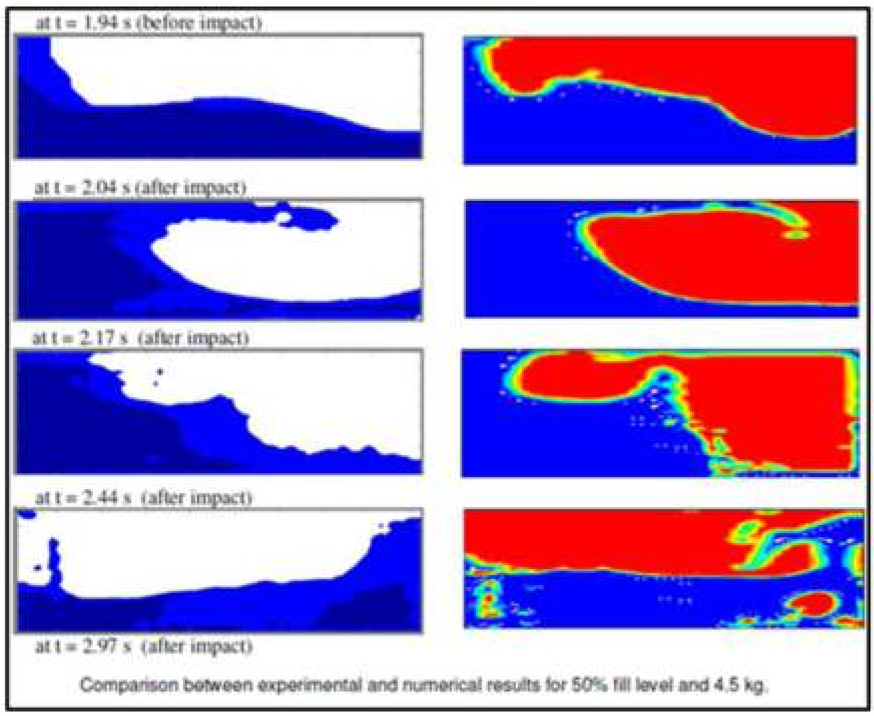

Figure : Internal Hydrodynamics Application Areas (Tank Structure)

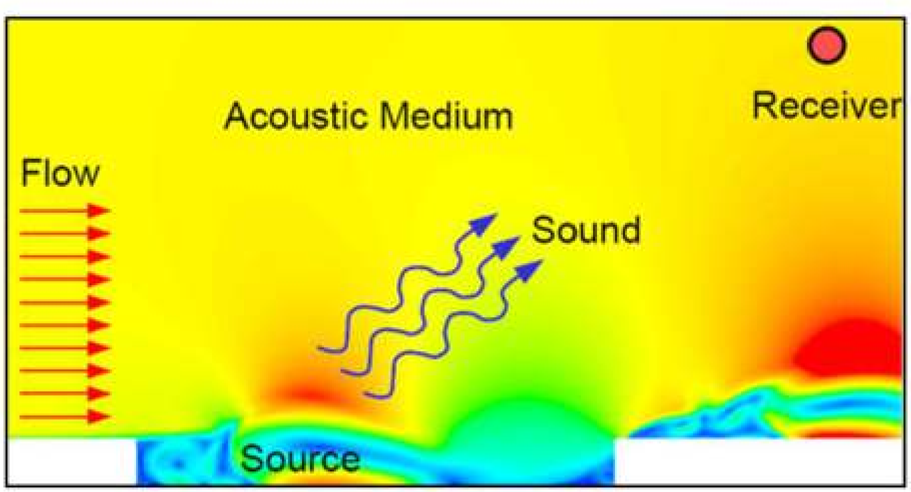

Figure : Flow induced Acoustics

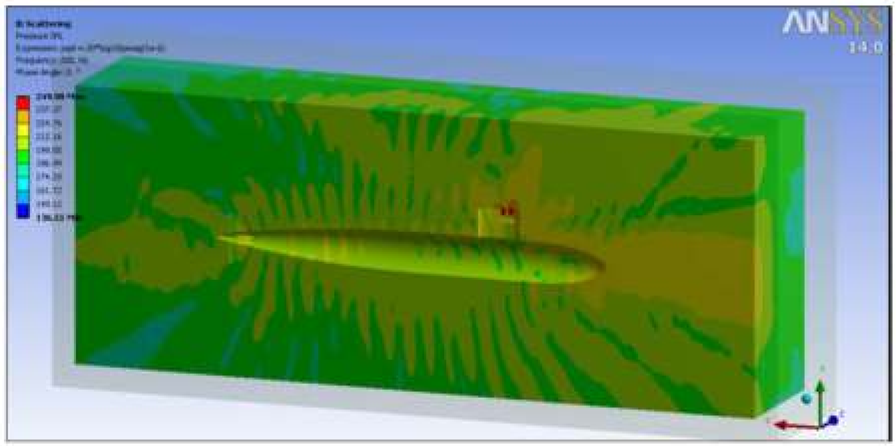

Figure : Scattering of acoustic waves around Generic Submarine predicted by CFD

6. CONCLUSIONS

Traditional approaches used in the submarine design have limitations in terms of time, cost and accuracy.

Numerical approach using CFD and HPC allows to perform detailed analysis on true scale model and can be used right from the concept level thus reducing total design cost and design cycle time. Number of prototypes when CFD is integral part of the design process is significantly lowerthan the traditional design cycle.

CFD is a promising tool which allows the parametric design, design evaluation and systematic optimization. CFD has a vast applicability to submarine design; hence it should be an integral part of the design process.

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article 10

INTEGRATED CONTROL SYSTEMS AND SMART SENSORS FOR FUTURE SUBMARINE

(Cdr Yoginder Sharma)

Abstract

1. Modern submarines are one of the most complex types of machines that exist today, only beaten by space shuttles. A submarine operating autonomously in deep waters is an extremely potent and lethal arm of any defense force. The historical intentions of military submarine are attacking enemy surface ships or other submarines. Today they also serve as portable missile launchers and their subtle nature, makes them suitable for surveillance and reconnaissance missions. In recent years, technological advances in the field of control system design, networking technologies and development of smart sensors have led to integration of different control systems onboard into a single system providing central control and monitoring of various typical systems distributed across the length and breadth of the submarine.

Introduction

2. Submarines, i.e., underwater vehicles, come in many shapes, depending on if they are intended for underwater research, maintenance or military purposes. A typical military submarine nowadays is a costly, highly sophisticated vessel, with a very strict requirement for accuracy, reliability and safety in all the aspects during design, production, trials and operations. Over the past few decades, the submarines have evolved, turning the cheap solution they were, into a tactical and strategic solution that must fulfill precise tasks and last for decades.

Typical Control Systems

3. There are various control systems onboard typical submarines which are responsible for automatic / remote control and monitoring of different systems. The platform systems / equipment are generally distributed throughout the Boat in the form of stand-alone systems with very little interconnectivity among the units. This approach lead to installation of multiple equipment, employing a variety of user interfaces, which required more space than desired. It also promoted congestion of control room because of different control panels and displays. Different control systems on board a submarine are listed below:-

   (a) Propulsion plant control system responsible for control and monitoring of main propulsion system.

   (b) System for control and monitoring of general engineering ship systems to ensure survivability, comfortable habitability and execution of special functions.

   (c) Submarine motion and position control system to control the motion of submarine by controlling the movement of the rudder and horizontal planes in all regimes.

(d) Data logging and retrieval system.

(e) Power supply distribution, control and monitoring system to provide control and monitoring of following systems:-

(i) Power generation and distribution equipment.

(ii) Reserve propulsion motors.

(iii) AC/DC switch boards.

(iv) Frequency converters.

(f) Depth measuring system to measure the depth of Boat with respect to surface by using depth sensors.

(g) Air regeneration system which is basically an electrochemical process through which fresh air for breathing is generated while beneath the sea.

(h) Battery health monitoring system to monitor parameters like Voltage, Electrolyte level, Temperature, etc of the battery bank.

(j) Gas monitoring system to monitor concentration of various gases in different compartments as well as in battery area.

4. Individual conventional control systems had their own control panels / consoles, system controller, network of sensors, actuators and associated cabling. Provision of redundancy at every level of the system added to the number of hardware requirements for the individual system leading to many prominent disadvantages like:-

(a) Large number of controllers.

(b) More number of operators required for the system.

(c) Additional cooling requirements.

(d) Complex cable routing.

(e) Multiple and complex interfacing requirements.

(f) Congestion of limited space available onboard.

(g) Effect on overall weight of the submarine.

Integrated Control System

5. Modern techniques allow physically distributed equipment to be networked together to derive the maximum benefit of synthesis of data from different sources. This fused data can then be accessed through integrated display and central control cabinet which promotes higher operational efficiency, space optimisation and smooth decision making process for a new "Integrated Control System". Various field equipment / sensors, spread across the length and breadth of the submarine are interfaced with Digital Input / Output Controllers. The digital signal / data, from I/O controllers, through Programmable Logic Controllers (PLCs), are

interfaced with the redundant fibre optic network running throughout the submarine. The data, through the network, is available at the Central Control Panel (CCP) located at a prominent place (Control Room) in the submarine. The Multifunctional Consoles (MFC) or the Central Control Panels are operated in pair, in hot standby mode, to ensure redundancy. The system allows the operators in the control room to monitor and/or control the platform systems distributed over the submarine.

Integrated Control System Architecture

6. A typical architecture of an Integrated Control System is depicted in Figure 1 below:-

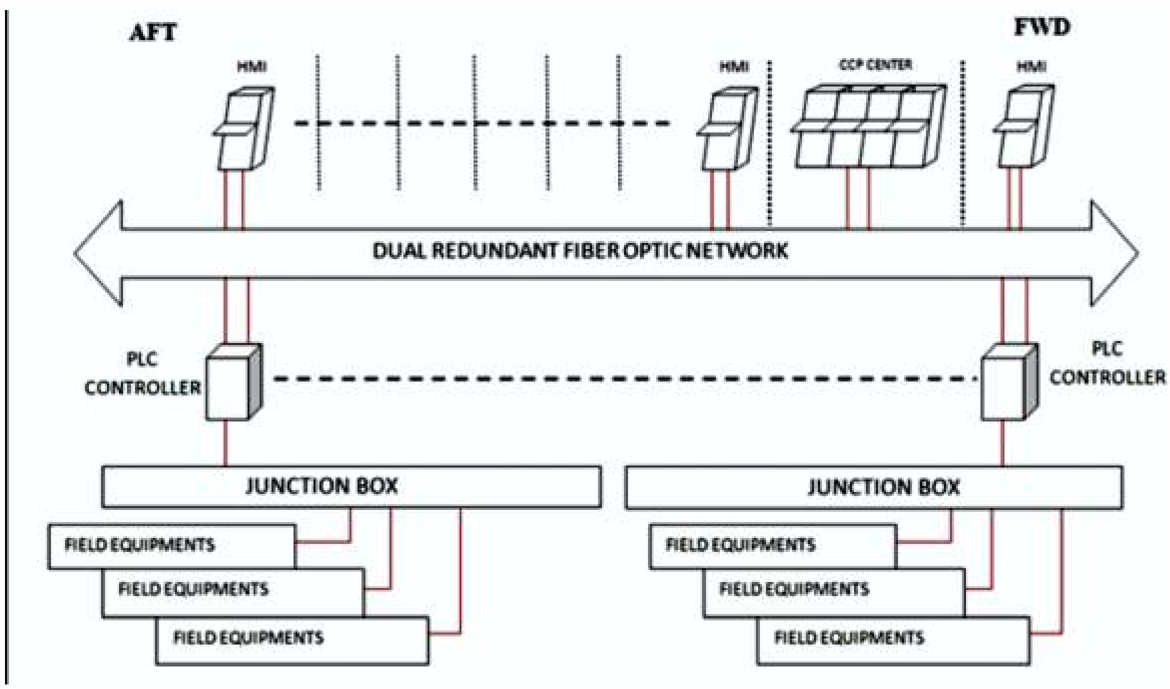

Fig.1 - Typical Architecture of an Integrated Control System

7. Details of various constituents of the Integrated Control System shown in Figure 1 are as follows:-

(a) Central Consol Panel (CCP).Dual redundant Multi Function Consoles (MFCs) are provided in the Control Room. Depending on the system monitored, one or several specific picture(s) can be displayed. CCP is intended for representation of information on display facilities, entering and processing of operator commands and their transmission to the lower level devices, control of channel of data exchange reception and processing of information coming from the equipment of lower level.

(b) Human Machine Interface (HMI). Human Machine Interfaces (HMIs) are intended for local control and monitoring of various systems as per requirement.

(c) Programmable Logic Controllers (PLCs).The PLCs provide all the necessary automated process sequences for all the systems. The controllers are generally distributed onboard the submarine according to each system. A PLC is a digital computer used for the automation of electromechanical processes. PLCs are used to capture data and control machinery. PLCs are relatively simple computers, designed with reliability and durability.

(d) Field Equipment.Various sensors and actuators are the field equipment distributed all over the submarine.

(e) Dual Redundant Fibre Optic Network.The dual redundant fibre optic network is a bus running across the submarine. The data communication between the Central Control Panel and Controllers is through the bus.

8. The term 'Integrated Control System' is generally used to encompass the following systems:-

(a) Propulsion including propeller, prime movers, shaft line, brakes and gearbox.

(b) Propulsion auxiliaries including steering and stabilisation systems, main forced lubrication system, main lubricating oil transfer and renovation system, low pressure sea water system, fuel supply renovation and transfer system.

(c) Auxiliaries including refrigeration system, sewage system, fresh water system, bilge and sullage system.

(d) The electrical system including battery monitoring, power generation and distribution system.

(e) Nuclear Biological Chemical Defence (NBCD) systems including chilled water system, ventilation system, low pressure air system, high pressure air system and high pressure sea water system.

(f) Damage Control including the state of the ship with respect to fire, flooding, smoke, stability and the operational state. The operational state includes the state and requirements for hatches and other compartment penetrations.

(g) Inclusion of new integrated systems with provision to take into account the future need to supply and receive information from Weapons and Navigation systems.

9. Advantages of Integrated Control System are as follows:-

(a) Display.Only two MFCs offer display of parameters of the desired category of systems against individual displays for each system in the conventional control systems resulting in optimum space utilisation in the control room.

(b) Cabling.Extensive point to point cabling from individual cabinet to process control actuators and sensors of the conventional system results in increasing the complexity of the mesh network. Interface between different systems is through different types of cable. Single network interface across all levels of the Integrated Control System requires no special software for communicating over the network thereby providing cost savings in communication cable material and installation. Further, it facilitates DI/DR and eliminates complex data network.

(c) Bulkhead Penetrations.Reduction in dedicated cables results in reduced number of bulkhead penetrations.

(d) Operators.Considerable reduction in manpower is achieved due to control and monitoring from the Central Control Panel when compared to dedicated manned displays for each conventional system.

(e) Training.Reliable and real-time simulation and training facility available on the Integrated Control System ensures focused on job training.

(f) Spares.Commonality of spares ensures reusable hardware and software components for network management thus providing superior solutions.

(g) Reliability.Faster and secure communication is offered on the network. Reliability is not compromised even on complete (or partial) loss of the PLC of a specific system or its communication equipment. This would result in transfer of control in local mode for the installation or half-installation during the repair.

(h) Configurability.Modules are reconfigurable for multiple purposes, therefore, change in one module will have minimal impact on the rest of the system compared to conventional systems where rigid interfaces offer little scope for further reconfiguration.

(j) Expansion.The Integrated Control System offers scope for future expansion and a compatible system can be interfaced with the existing system at a later date.

10. Such integration enhances information and functional capabilities of the crew in the process of controlling the maritime object, ensuring navigational safety of voyage and use of special equipment. The advantages of the integrated control system are as follows:-

(a) Considerable improvement of the contents of information about the state of on board resources in routine operation mode during damage control and in combat conditions by means of creation and maintaining the common information environment available for all functional subsystem.

(b) High performance achieved by means of application of uniform component base common interfaces and uniform set of operation documents which also improve reparability.

(c) Common interface and advanced facilities for ensuring access to information.

(d) High reliability and endurance owing to functional and structural redundancy.

(e) Opportunity of upgrading the system to obtain additional functional, capability for modernization.

(f) Comprehensive training of operators in training modes.

(g) Besides, the system is upgradable, reconfigurable and it has modernization capability for meeting the changing functional requirements to modernization of technical facilities throughout the life cycle of a ship.

Smart Sensors

11. Conventional Sensors.Traditionally a ship comprises of various machinery and control systems running hand in hand for performing different functions. These machineries communicate with the control systems via different parameters like temperature, pressure, speed, etc. measured at various points of the machinery for control, indication and alarm functions. These different parameters of the machines are measured using Sensors. For this purpose, the industry has always and mostly resorted to use of Conventional Sensors. Few drawbacks of conventional sensors are:-

(a) Communication is unidirectional.

(b) Large amount of cabling is being used both for powering the sensor as applicable and also for routing the signal from the sensor to the control system.

(c) Limited or no scope for in-situ calibration, settings or range adjustments.

(d) Lack of health monitoring or fault indication status of the instrument.

(e) Individual tagging of sensors for identification is not possible i.e. non addressable.

(f) They need an A to D Converter separately when a digital output is required.

12. **Smart Sensor**.The modern control systems, being based on computer based network technology, can utilise smart sensors for achieving various control and monitoring tasks. A smart sensor is an analog or digital transducer combined with a processing unit and a communication interface. A smart sensor takes input from the physical environment and uses built-in computing resources to perform pre-defined functions upon detection of specific input and then process data before passing it on to the next layer of a network. It has intelligence capabilities with on-board microprocessor or microcontroller. It is used for digital processing, analog to digital conversions, and can be used for other purposes like decision making, two-way communication, and logic functions. Smart sensors enable more accurate and automated collection of environmental data with reduced error. A typical setup using Smart Sensors integrated with the control system is depicted in Figure 2. In Figure 2, four smart sensors measuring pressure, differential pressure, water level and temperature are depicted. The sensors are interfaced with a two core data bus. The digital data from individual sensors is multiplexed by a multiplexer with facility for Human Machine Interfacing through a screen and keyboard. The modulated digital data through a network switch is transmitted over the network and is available to the Central Control Panel (CCP) for further processing. A portable calibrator / laptop is used for health check and calibration of sensors.

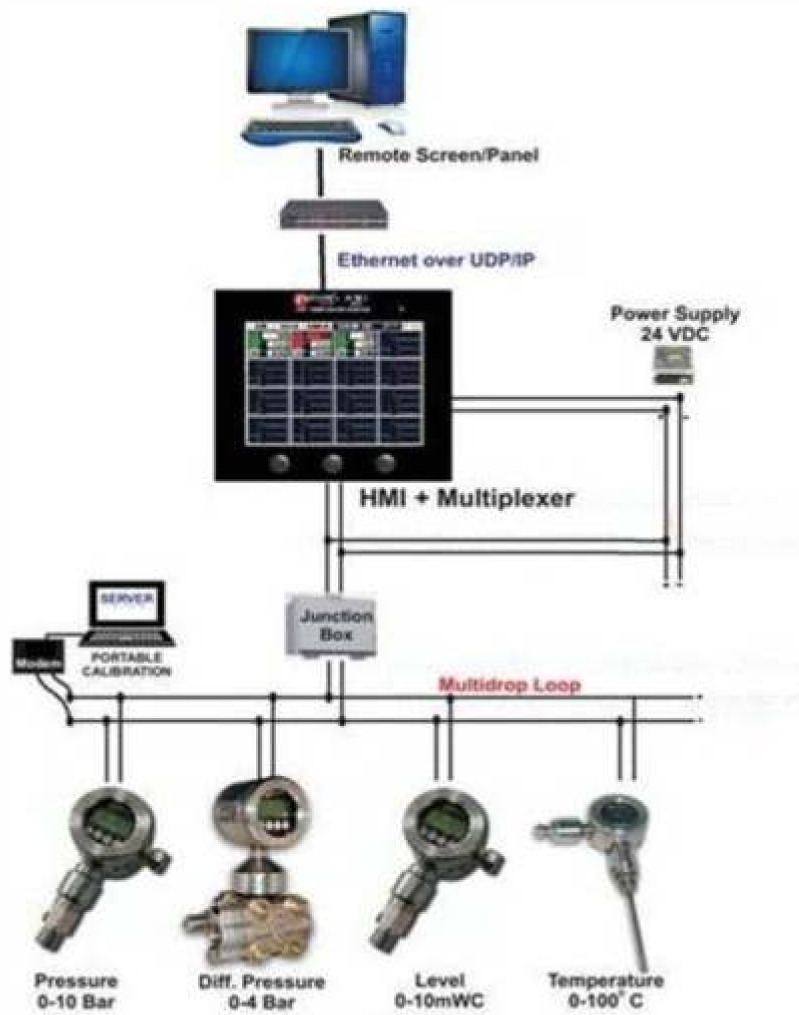

Fig.1 Typical architecture of an Integrated Control System

13. Advantages of Smart Sensors. The various distinct features of smart sensor in comparison to a conventional sensor like smaller size, low power consumption and bi-directional communication, make the smart sensors highly efficient. Some of the key features of Smart sensors are as follows:-

(a) Self-identification (Addressable) with each sensor having its own Identity i.e. address, tag number and name with self-diagnostic features.

(b) Output is available in analog and digital data in standard (changeable) engineering units and can be used as per requirement.

(c) Provision for remote/ local in-situ calibration and compensation.

(d) Facility for configurable alarms and parameterization.

(e) Feature of self test and analysis.

(f) Considerable reduction in on-board cabling since multiple sensors are interfaced with a single Data Bus.

(g) Since output is also available in Digital form, it can obviate the requirement of an Analog to Digital Converter.

(h) These sensors can be loop powered using only two cables to connect multiple sensors thereby mitigating requirement of individual hard wire connections for individual sensors.

(j) Smart sensors allow change of range of a sensor which is fixed in a conventional sensor. This allows interchangeability and would reduce Inventory.

14. A comparison between prominent features of Smart sensor versus conventional sensor is enlisted in Table 1 below:-

Table 1 - Comparison between prominent features of Smart and conventional sensors

Sl	Parameter	Conventional Sensor	Smart Sensor
(a)	Power Supply & Output	4 wire 3 wire 2 wire	2 wire
(b)	Output	Analog or digital	Analog + Digital
(c)	Calibration	Limited adjustments or No facility for Zero / Span adjustments	Zero / Span can be adjusted either locally using digital display / Modem or remotely using HMI
(d)	Cabling Reduction	No	Yes
(e)	Interfacing	Point to point	Point to point Multi-drop loop
(f)	Identification	No	Yes (Each sensor has its own Identity i.e. address, tag number and name)
(g)	Self diagnostic function	No	Yes, with fault indication
(h)	Sensor Info	No	Yes
(i)	Local Indicator	No	Yes, with advance features
(j)	Interchangeability	No	Yes, can be set & used for different ranges

Conclusion

15. The Integrated Control System with Smart Sensors will result in a perceptible level of automation for all the systems. Depending on the frequency of use / availability / safety constraints suited to each system, it will maintain the highest availability level for the safety actions, ensure a strict technical and ergonomic coherency between the different control / monitoring subsystems of each of the submarine systems and homogeneity of the Man Machine Interfaces with possibility to easily operate reconfigurations between the different consoles in case of need. The system will relieve the operators from the laborious, simple or repetitive actions, minimise the risk of control mistakes and will allow the crew to focus on the more important activities (analysis, supervision, decision, etc), improving, consequently the reliability and efficiency of the watch team.

Author's Biodata

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article 11

INTEGRATED CONSTRUCTION MANAGEMENT SYSTEM

by Lt Cdr Aheesh Gaur (DD(PGD)

Summary

1. Integrated Construction Management System (ICMS) is an advanced innovative assimilation system, which offers a comprehensive single point proactive solution to most of design, material, manufacturing, planning, trial and quality concerns. Its objective is management of information through the life cycle of naval vessels, which in turn will increase productivity, reducing vessels design and manufacturing· schedules, saving costs and improving the quality of the whole process. It has the power to drastically reduce timelines, costing and sharply improve durability through simulated outfitting and survivability tests by converting long thought sequential construction activities into parallel processing. Its tools, techniques and processes are built on four foundation pillars - Talk Sense, CAD Intent, Virtual Yard and Unified Database. All these four pillars will work on integration between the Shipbuilding CAD system and various PLMs.

2. Unified database, the role of data is central to this integration effort. Unified database is a common repository, covering relevant information, sharable across all stake holders (designers, yards, OEMs and trial agencies) building a web of interdependencies needed for integration. Further, to extract meaning from data and power bi-directional harmonization of various CAD / CAM systems and PLMs. A collative agreed model (Talk sense) will be formulated covering both static and dynamic associations between data and real-world physical / conceptual objects it describes. This would include rules for use, exchange and modification of the data. The same will set a platform for real time correct mapping (one-to-many and vice versa) of dynamic design changes, ensuring that 2D drawings / 3D models are not only always accurate technically, ergonomically but also all surrounding environmental effects, specific OEM requirements are also considered (CAD intent). Prediction of correct construction timelines, Digital mock-up of critical construction / outfitting activities, identification of possible bottlenecks, slippages and subsequent proactive remedial actions with auto generated feedback on status of milestones will be facilitated by concept of Virtual Yard. In totality, ICMS can provide a single point, comprehensive solution to all construction related activities and that too, on click of a button.

PRESENT SYSTEM

3. In the present scenario of shipbuilding, a very simplistic unidirectional departmental or unit level CAD (Computer Aided Design) and PLM / PDM (Product Lifecycle Management / Product Data Management) system harmonization is employed. Until now, the implementation of different PLM systems is to locally manage all the information being shared by several departments in a unit (engineering, purchasing, planning, operations, productions, etc). CAD

tool is being used to just make and share 3D Models / 2D designs through local PLM. So far, there is no concept which is employed to make CAD-PLM systems communicate with each other intelligently and automatically, sharing and using data both effectively and efficiently for mutual benefits of the organization in totality. Also, a very basic model of data sharing is employed wherein PLM is used merely as a directory to only access 3D / 2D files and, once loaded, there is no communication between CAD and PLM software. In such a structure design, planning, material and quality issues are technically treated separately with no automated solution. The reason for the same, though these sub-system / units of a project (Designer-PLM, Yard-PLM Knowledge Management System (KMS), mail servers with pan India / world connectivity) are available, there is no intelligently bi-directional communication between each of them. ICMS is the missing link for intelligent bi-directional information exchange system with facility to extract, harmonize and broadcast the information automatically. Therefore, with minimal setup cost and superior background data management and harmonization, tremendous improvement in all spares of construction can be achieved. For details refer Figure1.

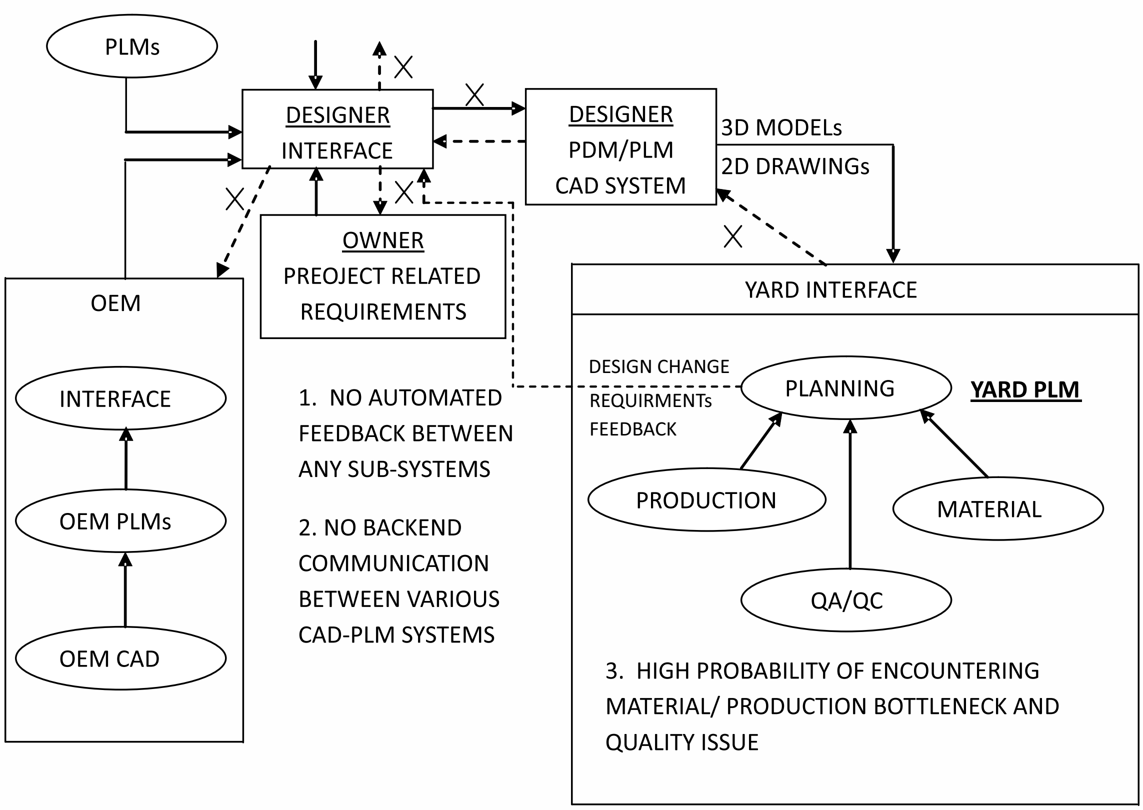


Fig. 1 - PRESENT UNI-DIRECTIONAL SYSTEM

Introduction To Icms

4. ICMS (Integrated Construction Management System) has the power to convert long thought sequential construction activities into parallel processing through implementation of an advance network which enables auto information exchange and implementation among all stake holders, PLMs and CAD systems.

5. ICMS will facilitate effective interoperability between Computer Aided Design (CAD-3D/2D Models) & Product Lifecycle Management (PLM/PDM Documents) Systems in order to increase productivity, reduce vessel designs and manufacturing schedules, save huge costs, improve the quality of whole process and, most importantly, augment current shipbuilding process and environment to next altitude of customization and automation. Features such as real time feedback on computer-generated simulations of critical construction activates, auto-updation and scrutinisation of drawing changes simultaneously by both designer and production with quick resolution of all material issues can be easily achieved using ICMS. Pre-requisites for implementing ICMS or any intelligent bi-directional information exchange featuring advanced CAD-PLM integration are as enumerated below:-

(a) Facility for automated real-time mapping of 2D drawing, DAF, DCR & design query / changes to 3D models.

(b) Sharable data and attributes between CAD and PLM systems in a format understandable by all such systems.

(c) Auto-updation of documents / data from CAD to PLM.

(d) Product structure in CAD systems should auto-update product structures in PLMs.

(e) Management of all documents generated by CAD systems.

(f) Knowledge sharing / management of all lessons learnt by various sub-systems.

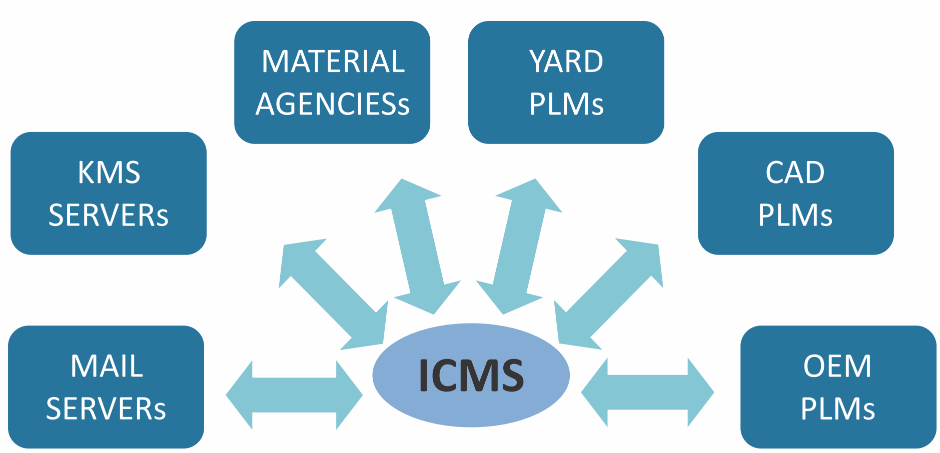


Fig. 2 – ICMS - QUALITY VESSEL WITH OPTIMIZED TIMELINE

Pillers for Intergation

6. A detailed analysis of pre-requisites mentioned in Para 3 have revealed that four pillars, (two for laying foundation of ICMS and other two for deriving required functionality) are essential for ICMS namely Unified Database, Talk Sense, CAD Intent, Virtual Yard.

(a) **Unified Database.** It is a conceptual data model that is capable of expressing information and interpreting data stored within every department in a system. The logical data structure of general database management system cannot totally satisfy the requirements for a conceptual definition of data, view limited scope and bias towards the implementation strategy adopted by the local data base management system. Therefore, the need to define data from a conceptual view derived from semantic data modeling techniques i.e. techniques to define the meaning of data within the context of its interrelationships with other data. Such models are expressed by binary relation between data elements. This unified data will be stored and accessible to all stake holders PLM systems depending on their privileges, on both routine and need to know basis. The interoperability of data / information within a project in ICMS, facilitating effective and efficient commutation between all stake holder PLMs depends on three main standardized models for data exchange within departments / units.

(i) Real world (functional) model is a structured representation of the functions activates or processed of the modeled project.

(ii) Database (information) model represents the structure and semantics of information of the modeled project.

(iii) Synchronized (dynamic) model is representation of time varying behavioral characteristics of the modeled project.

(b) **Talk Sense.** Intelligent bi-directional information exchange between CADPLM system will be implemented using two mechanisms namely, Broadcasting Mechanism and Harmonization Mechanism. The information going out from CAD to PLM is termed as broadcasting mechanism. Likewise, feedback / updations received from PLM to CAD is termed as Harmonization mechanism. Further, for communication between different agencies employing a variety of CAD PLM systems, a neutral network framework will be required for communication between these sub-systems. Details on these models and information exchange mechanism are covered in technical architecture of ICMS.

(c) **CAD Intent.** CAD-PLM integration has the potential to do wonders for design management. It ensures that the design (both 2D & 3D) is both always correct and up to date. Its main advantage is that the design construction can be set in from designer sitting in some part of country, feedback by production and added inputs from OEMs ensuring all stake holders requirements are met, all of this in real time. This will minimize the design change at the time of advance construction / outfitting stages. Also, using broadcasting and harmonization mechanisms and standardized vessel tree structure (explained in Technical Architecture of ICMS), chance of wrong feedback and human errors cab be mitigated to a bare minimum. It will also support Yard and industry-specific designing process to help creativity and innovation. It will reduce development cycle time, improve quality of design (3D & 2D), simulation, manage project knowledge and allows collaboration or virtual data management. Further, it will offer numerous integration features which make seamless hybrid installation possible improving the current analysis and furtherance of design quality.

(d) **Virtual Yard.** Imagine a scenario wherein majority of construction events including outfitting, degutting and critical activities are visualized prior to commencement of actual activity through 3D simulations. Also, timeline bottle necks, planning inaccuracies or miscalculation are identified and resolved beforehand prior going ahead with actual construction itself. This is the concept of virtual yard. ICMS standardize the interoperability of information in many aspects of product design, manufacture, delivery and support to such an extent that virtual yard can be actually achieved. Ship design projects go through a number of different phases from conceptual design, detailed design, planning and generation of construction deliverables. Virtual yard is a system-based solution that provides process planning and launching in a 3D environment, addressing construction requirements for all ICMS shipyards. The same is achieved by utilizing upstream process planning using design data stored in the engineering database and construction data stored in the construction database. It will also allow yards to implement their digital enterprise, thus creating and simulating the entire construction life cycle from initial concept to commissioning in service.

Technical Architecture of ICMS

7. The architecture of the ICMS employing various CAD-PLM system integration and interoperability is based on the following components:-

(a) Vessel product structure in the PLMs should reflect the CAD Product Structure at any time during the vessel project development.

(b) The current PLM classification structure for all sub-systems should support themanagement of standard part between the CAD and PLM system.

(c) A mechanism to transfer data from the CAD to the PLM (Broadcasting Mechanism).

(d) A mechanism to transfer feedbacks from the PLM to the CAD (Harmonization Mechanism).

(e) A neutral framework for the integration of the various CAD systems with different PLM systems.

(f) Vessel Construction Tree (VCT) created within the PLM where the CAD model items will be broadcasted.

(g) A set of relational tables in CAD database that will support the Broadcasting and Harmonization processes between various CAD, PLM and vice-versa will be referred as CAD-PLM Harmonization table. For detail explanation, refer Figure 3.

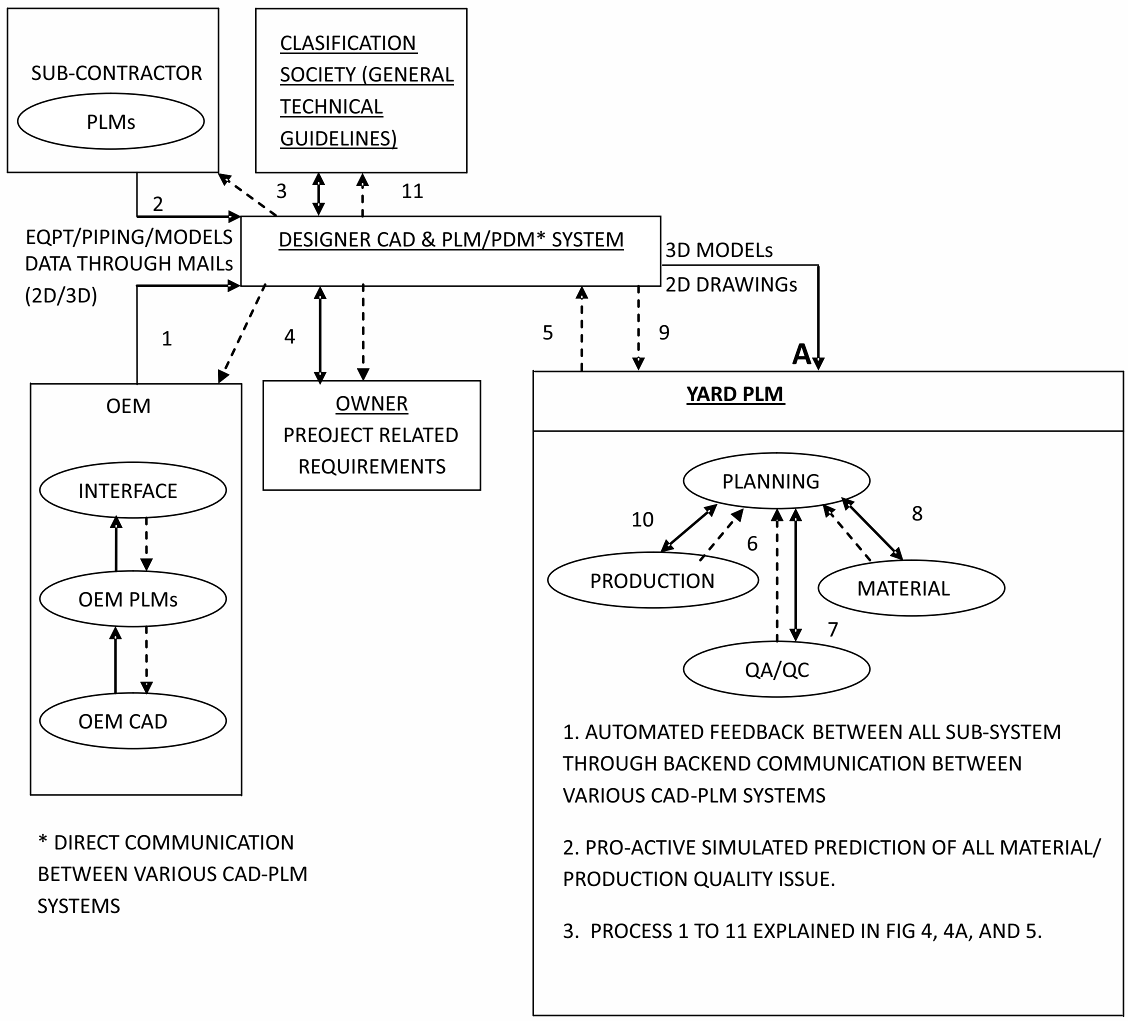


Fig. 3 - Proposed ICMS System

SL.No.	PROCESS NO IN FIG 4	FROM CAD-PLM SYSTEM	TO CAD-PLM SYSTEM	TOPIC
1	1	Designer	OEM	acceptability / OMA (Operatibility maintainability accessibility) issues of equipment w.r.t. layout/ environment
2	2		Sub-Contractor	Acceptability issues of any sub-assembly w.r.t. other structures/ sub system of the vessel.
3	3		Classification Society	Issue of obsolete/ out dated technical fuidelines view. alternation/ modification in technology
4	4		Owner	Issues related to usability /general guidelines
5	9		Yard	Comments/observation on updated BOM (bill of material) or other related details.
6	5	yard	designer	'CAD INTENT' (a)Acceptability/ OMA / technical issues of design experienced while undertaking actual/virtual outfitting (b) Design change requirements (c) Effect of design change on vessel environment (d) Acceptability of design change in parallel by designer, yard and owner (e)General technical requirement /rules for auto correct drafting designing of 2D/3D models
7	11	classification society		
8	7	QA/QC	Planning	Inspection completion status vis-a-vis planned timelines
9	8	Material		material bottle neck issues
10	10	Planning	Material	Suitability issue of supplied material. exact timeline based requirement of material.
11	12	Production	Planning ↓ Owner/ Designer	'VIRTUAL YARD' Observation on automated digital mock up of outfitting/ critical activities. prediction of future issues/problems envisaged with possibility of validation of probable solution in design

Fig 4. Simulated Automated Feedbacks Between Various Cad-Plm Systems In ICMS System Internal Communication in YARD PLM

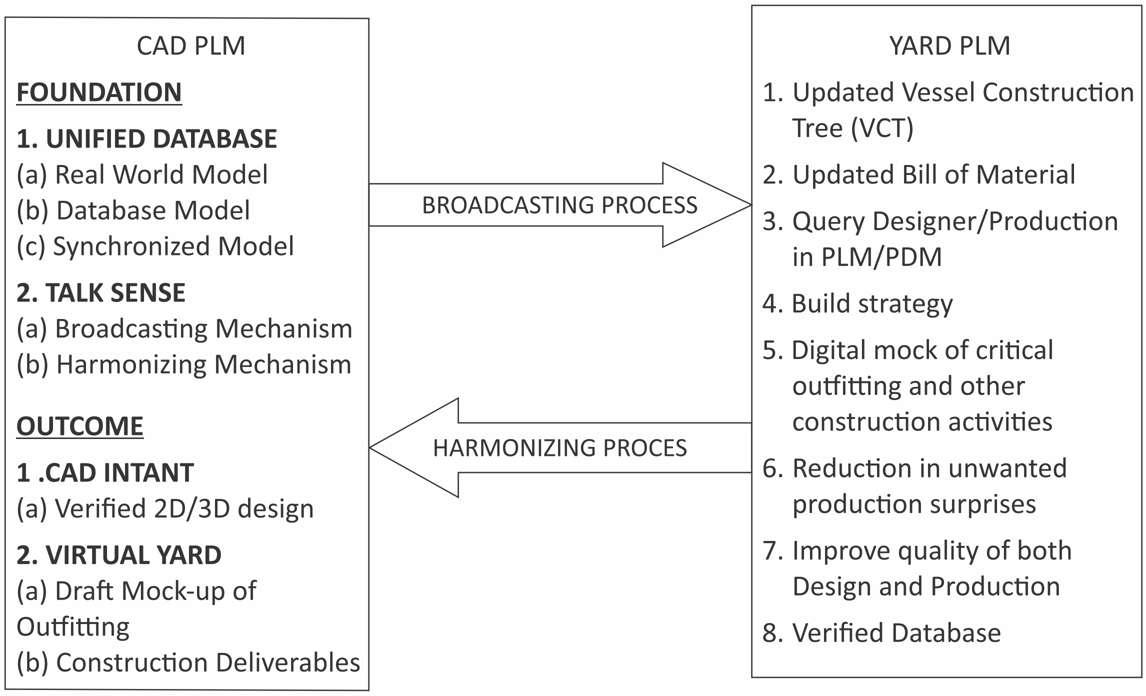


Fig. 5 - Layout Of ICMS System

The Integration Scope

8. The integration covers all stages of the vessel life-cycle, from the conceptual and basic design to the maintenance of the ship. It implies that in basic design stage, the information must be transferred to PLM automatically with related BOMs (equipment lists, piping fitting, electrical fittings, cables, etc.). As the project evolves and 3D product model of the vessel is built in the CAD database, 3D information of the routed systems must also be transferred to PLM. Likewise, the construction trees in PLM should also evolve automatically, considering project diagrams and 3D models.

(a) Standard Part Integration.Integration of the standard parts (components) between CAD and PLM classification structure will be used by both Broadcasting and Harmonization mechanisms (explained later). The defining of standard parts in PLM will be automatically transferred to CAD by the Harmonization Mechanism and will require the assignment of some fixed attributes for identification. These attributes will depend on the type of the standard parts.

(b) Vessel Construction Tree (VCT). VCT (Vessel Construction Tree) is automatically built and modified during broadcasting processes & will provide PLM users with an up to date view of CAD product model during project development. VCT has a structure very similar to that of CAD Product Model, so the position of modeled item in PLM tree will depend on item type. VCT will be synchronized with CAD 3D model & will be able to control CAD product model trough model locks as well be able to add or modify all necessary information required by the management of the vessel along the whole life cycle. It will automatically define standard part in PLM which are transferred to CAD by Harmonization Mechanism.

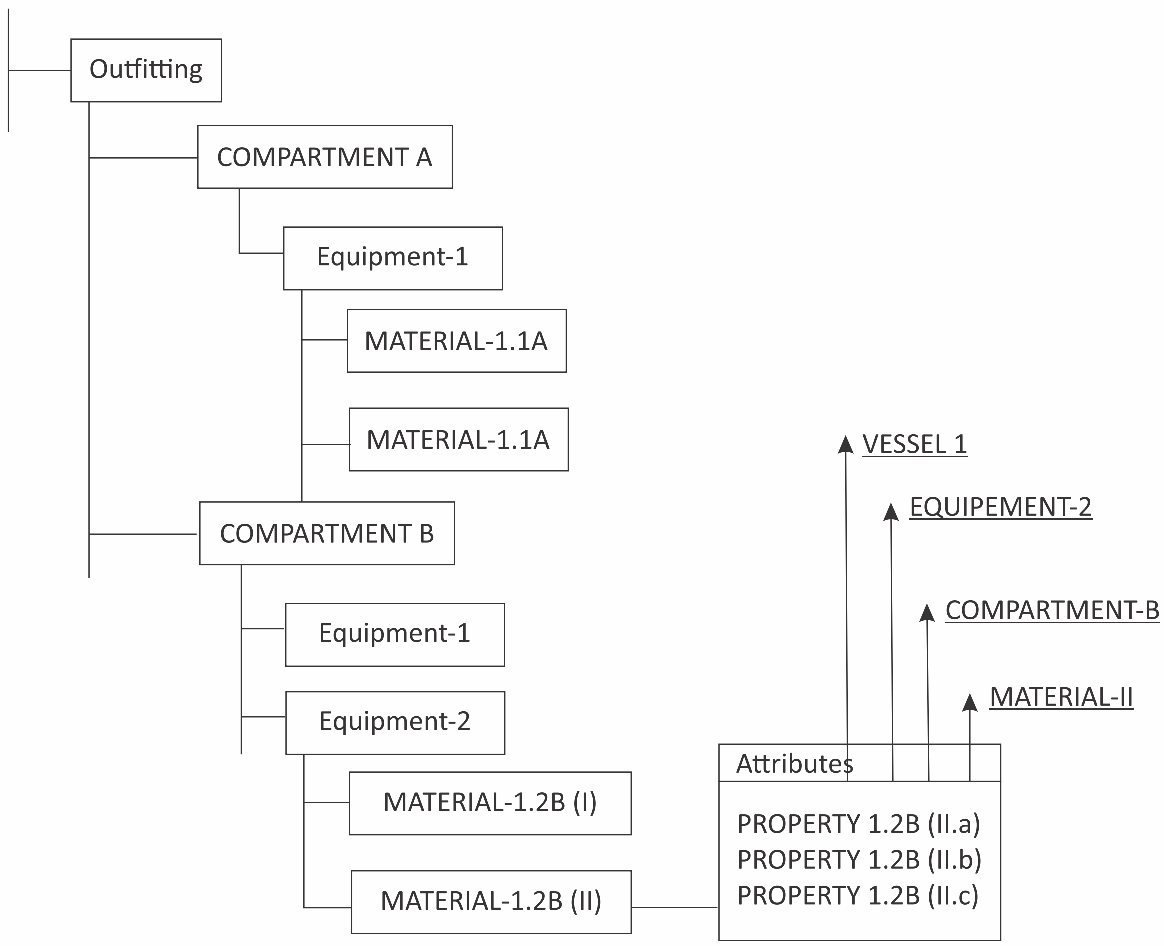


Fig. 6 Vessel Construction Tree

(c) The Broadcasting Mechanism.Broadcasting is the process of sending the following information from the CAD to PLM systems.

(i) Model item created or modified in the CAD.

(ii) Standard part created or modifies in the CAD.

(iii)Intelligent diagram.

(iv)Build strategy trees created or modified in the CAD.

(v) Drawings or other files handled in the CAD.

(vi)Items deleted in CAD.

(d) Repetitive production assemblies defined in the CAD (e.g. cables) are also transferred to the VC Tree in the PLMs which are created during broadcasting process. All necessary relationships with the model items are recognized in VCT and in turn contribute to a more mature status of the model itself.

(e) Broadcasting Modes. A specific Broadcasting process has been devised to facilitate and customized for all broadcasting tasks. The broadcasting process will provide tools to facilitate selection of massive information to be broadcasted. Another relevant feature of this process will be the capacity of being launched in a scheduled way. The Broadcasting process will connect with the PLM through the CAD-PLM by means of specific PLM web services. The aim of this Broadcasting process is to facilitate and automate the Broadcasting tasks, reducing the impact of these tasks in the normal operation of all the CAD and the PLM systems being employed by sub-units.

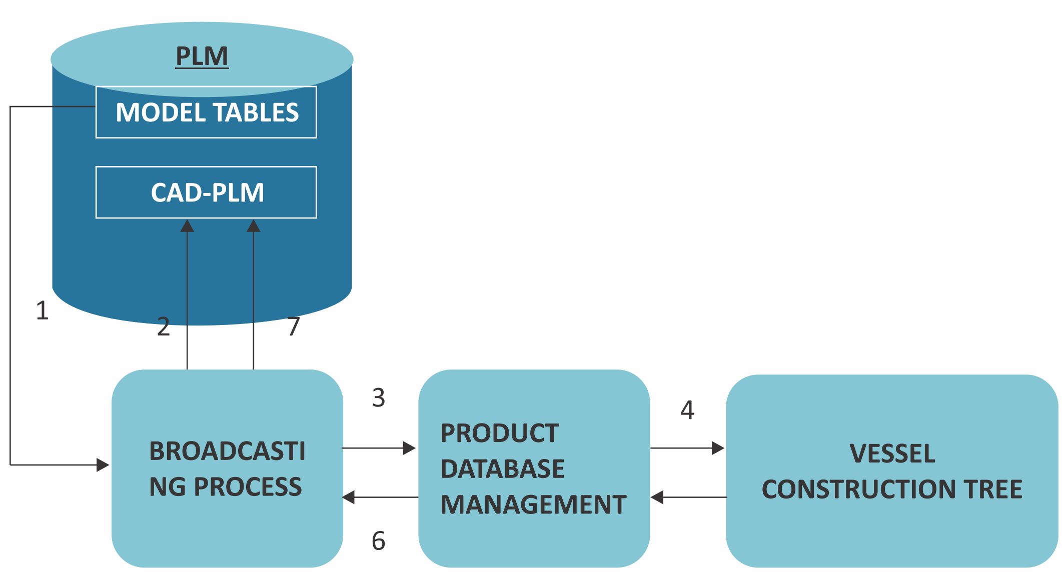
(f) Information Broadcasted The Broadcasting process will transfer attributes of the Broadcasted items as well as the geometry of the items, if available. A restricted number of attributes will be transferred from the CAD to the PLM (those shared by the CAD and the PLM and those CAD attributes selected for Broadcasting but not editable in the PLM). The Broadcasting process will automatically export to the PLM the geometry of the items. Usually the geometry will be transferred at the level of elementary items (e.g. one part), but in some cases, it will also be possible to Broadcasted the geometry at a higher level (e.g. one spool). The Broadcasting process will automatically export geometry of item in PLM. A CAD entity can only be broadcasted when it meets below specific conditions.

The entity is marked as broadcastable.

(i) The entity has not been deleted in PLM.

(ii) The entity .is not locked in PLM.

(iii)The CAD-entity date is later than the entity Broadcasting date.



SL	Note	Process
(i)	Checking relation mapping between CAD & PLM for attribute	Process 1
(ii)	Broadcasting process extract form the model table all info to be broadcasted (geometry & attributes)	Process 2
(iii)	Broadcasting sends all relevant data to PLM/PDM	Process 3
(iv)	PLM/PDM sends to VCT the data to be broadcasting by means of Web Services	Process 4
(v)	PLM/PDM receives from the VCT the result of the broadcasting	Process 5
(vi)	PLM/PDM sends to broadcast the results of broadcasting	Process 6
(vii)	Broadcast updates the CAD-PLM Table with results of broadcasting	Process 7

Fig. 7 - Broadcasting Mechanism

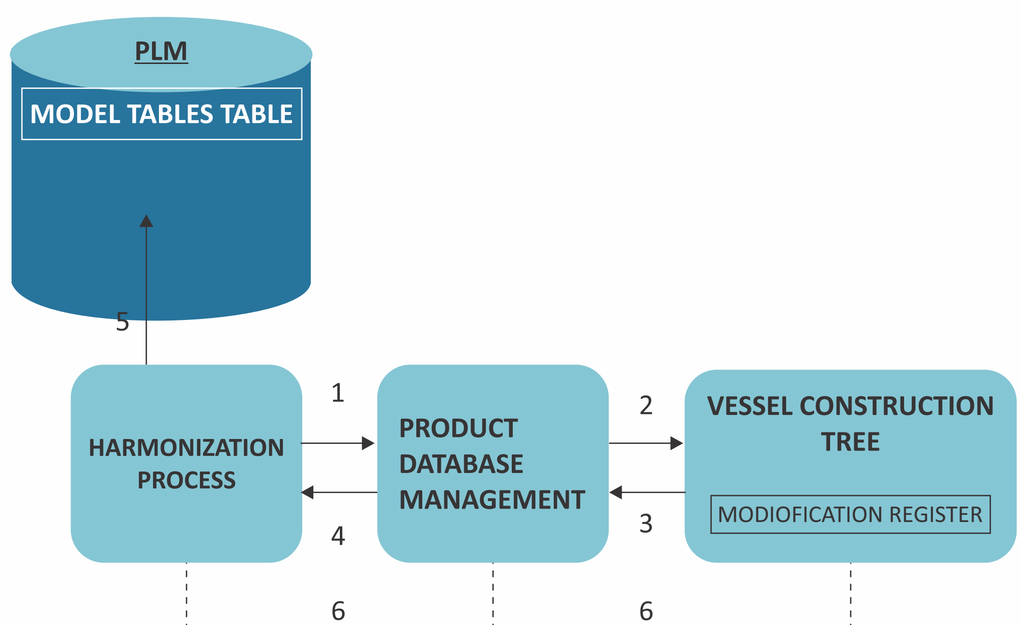
(g) The Harmonization Mechanism. Harmonization is the process of automatically sending Information from PLM items created, modified or deleted in the PLM to CAD, through the Harmonization Table. The Harmonization process will connect with the PLM through the CAD-PLM Harmonization Table by means of some specific PLM web services.

The Harmonization process will be running permanently and will perform two types of harmonization:-

(i) Urgent harmonization.

(ii) Scheduled harmonization.

(h) Entities requiring harmonization of any type will be managed in the PLM through a Modification Register. The harmonization will also inform to the PLM of the entities successfully synchronized to allow removal of the entities from the Modification Register. Model items will be locked by the PLM. This locking will avoids the modification of the item in the CAD. The same is explained in Fig 8 below.



SL	Note	Process
(i)	Harmonization starts scheduled/urgent harmonization	Process 1
(ii)	PLM/PDM launches Web Services (WS) to get data from the Modification register	Process 2
(iii)	PLM/PDM receives response from WS with data to be created in CAD-PLM table	Process 3
(iv)	Harmonization receives response from PLM/PDM with data to be created in CAD-PLM Table	Process 4
(v)	Harmonization update CAD-PLM database	Process 5
(vi)	Acknowledgment process	Process 6

Fig.8 Harmonizing Mechanism

(j) The CAD-PLM Harmonization table. The CAD-PLM Harmonization Table (Harz Tab) is a Set of relational tables in the CAD/PLM database that contain all the necessary information to manage whole CAD- PLM Integration process. Harmonizing Table contains information related to entities participating in CAD - PLM integration process, such as:

(i) Identification of entity in CAD and in PLM.

(ii) Unique identification of each entity (provided by the PLM).

(iii)Broadcasting process related information.

(iv)Harmonization process related information.

(v) Entity maturity information.

(vi)Entity locking status.

(vii)Entity shared attributes.

(k) Definition of Model item in PLM. The automatic management of VCT by Broadcasting Mechanism will allow the definition of new model items in PLM. For VCT to be transferred automatically from the PLM to the CAD the process as follows:-

(i) Model items are created in the PLM.

(ii) These models items must have the necessary attributes to be uniquely identified.

(iii)The harmonization mechanism will use these special attributes to identify the items to be transferred to the CAD and to transfer the model items to the set of relation table in the CAD database supporting the integration.

(iv)The CAD reconciliation tools will allow the use of these items on the CAD side, completing the item information.

(v) The Broadcasting Mechanism when required will broadcast these model item in the VCT.

(l) Links CAD Drawings-PLM BOMs When broadcasting the drawings for CAD side The system will create and maintain the relationship between CAD drawing and the items themselves (BOM lists). These links must maintained for the most relevant types of drawing in all design stages (e.g. drawings, layout drawings, manufacturing drawing, etc). The Broadcasting of drawings has been designed in such a way that the process maintains automatically this connection.

(m) The CAD and PLM neutral framework

Its objectives are as follows.

(i) To facilitate and to simplify the integration of CAD/ CAM with different PLM system.

(ii) To make the CAD-PLM integration as independent as possible from the specific characteristics of each PLM system.

(iii)The CAD-PLM is composed of several processes.

(iv)CAD-PLM client: A set of utilities integrated in the CAD modules to interact with the PLM server, common to all PLM integrated systems.

(v) CAD-PLM server: A java process to manage CAD business objects and their mapping to the PLM objects.

(vi)CAD-PLM Plug-in: A set of PLM dependent libraries and tools which map the CAD-PLM objects and perform the communication with the PLM server consists of two parts.

(p) A set of java classes and methods embedded in to the CAD-PLM server will provide a specific PLM context and data model to the neutral CAD-PLM object and data type. The PLM adapter will be a set of web services and PLM templates that are embedded and run into the PLM server. It will provides the appropriate CAD-PLM data environment for the PLM. The bidirectional communication CAD-PLM will be done through the use of specific PLM Web services. Many of these Web services are standard PLM Web services existing in most of the current advanced PLM systems. Generally speaking the rest of required Web services could be developed by using or specializing existing Web services.

Conclusion

(9) This paper presents first of its kind, Integrated Construction Management System (ICMS) an advance bi-directional integration of various shipbuilding specific CAD systems with superior PLM systems in a Naval shipbuilding environment. The proposed system presents several important advantages.

(a) Comprehensive single point proactive solution to most of design, material, manufacturing, planning, trial and quality concerns.

(b) Platform and facility for digital mock up of critical outfitting and other construction activities pin pointing issues envisaged thereby reducing unwanted production surprises.

(c) Improves the quality of both design and production by providing a single point of truth for the whole organization.

(d) ICMS is a scalable solution, capable of handling hundreds of designers in the CAD designer side and thousands of various PLM users in the whole shipbuilding organization. It is mutually beneficial for both CAD PLM as it allows PLM to take benefit of all the vessel information handled by the ·CAD from the early stages of the design and ·facilitates real time auto updates/feedback from PLM to CAD.

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(b) R Penas, C Gonzalez, 'integration of DB oriented CAD systems with product lifecycle management', COMPIT 2011, Berlin, 2-4 May 2011.

AUTHOR'S CERTIFICATE

I hereby certify that I have not used any information and/ or material classified RESTRICTED and above, or any classified information obtained in any official capacity, while writing the material that,I am submitting for approval prior to its intended publication and/ or dissemination to/ through the Media.

Signature: . . . .

Rank & Name: . . . .

Personal Number: . . . .

Recommendation

Signature:

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Commanding Officer/ HoD officer-in-Charge

PD/APSO at IHQ, MoD

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article 12

POWER QUALITY IMPROVEMENT AT LOAD/CONSUMER IN IN SHIPS & SUBMARINES

By Lt Cdr Aheesh Gaur DDND(SDG)

Abstract Electronics and other large range of systems in Indian Naval Ships & Submarines, specially, those based on power electronics, can cause high disturbances in the supplied electricity. In this paper, the power quality characteristics are addressed with the possible measures to increase it onboard afloat platforms. Going from single to three phase networks and discussing passive and active filtering solutions, the paper presents possible solutions which can be connected before delicate onboard equipments to preserve their power supply modules from possible damages. This will not only ensure better operational availability but also will facilitate reduce onboard maintenance cost.

Introduction

1. The explosive growth in onboard power electronics has generated a major concern in the ship building industry. Due to their circuit interface, which usually is a diode bridge rectifier followed by a large DC capacitor, these power electronic equipment draw current near the peak of the mains voltage. Examples of such nonlinear loads include the following:

   (a) LED lamps and phase-angle controlled lamp dimmers.

   (b) The DC power supplies of any electronic product, whether linear or switch-mode.

   (c) Three-phase power converters.

   (d) Arc welding, electric furnaces, electrolytic processes or other onboard applications like variable speed controllers.

2. The harmonics generated by the most common nonlinear loads have many hazardous effects. The lower order harmonics tend to dominate in amplitude. If the waveform has half-wave symmetry there are no even harmonics and the harmonic emissions from a large number of nonlinear loads of the same type will be added. Small electronic devices are usually single phase loads, with only tens or hundreds of watts of mains power, but their proliferations are causing important effects in the mains voltage. Also, medium/high power nonlinear loads cause similar problems. The major problems caused by the mains harmonic currents are those associated with the harmonic currents themselves, and those caused by the voltage waveform distortion resulting from the harmonic currents flowing in a finite supply source impedance. This waveform voltage distortion can cause serious damage. Power electronics based applications draw non-sinusoidal currents, despite the applied voltage being sinusoidal. Effects in direct non-line induction motors, ranging from a minor increase in internal temperature through excessive noise and vibration to actual damage; electronic power supplies may fail to operate adequately; increased earth leakage current through EMI filter capacitors due to their lower reactance at the harmonic frequencies.

3. **Power quality and harmonic emissions standards.** With the increased use of electrical and electronic equipment, telecommunication and broadcasting transmissions, the electromagnetic spectrum has become saturated. The equipment within IN(Indian Navy) spectrum or onboard installations has become increasingly sensitive to some type of electromagnetic interference both from internal or external sources, especially because of the use of digital technology. Therefore, there is a need for control of electromagnetic environment, namely by limiting of the harmonic emissions caused by any type of electrical or electronic equipment. In the European Union, this problem has been addressed by the 89/336/EEC Directive, (called the EMC Directive) which came into force in 1992. In the United States the main guideline come from the IEEE Std 519. There are also similar standards followed in Indian Navy, but their explanation is beyond the purview of this paper. In this paper, for analysis, an electrical installation with particular characteristics is considered: a very large number of PCs, 3-Phase motors with soft starters, and other power electronic equipment; LED lamps, and control systems instrumentations. The presence of low frequency harmonic currents demanded by the referred loads, the large number of inductive loads and the layout of the installation itself are the main causes of the poor power quality observed.

Low frequency harmonic currents and voltage distortion.

4. The problems caused by harmonic pollution can be divided into two categories, namely, those caused by the harmonic currents themselves, and those caused by voltage waveform distortion resulting from the harmonic currents flowing in the electrical installation. The main problem with the harmonic currents is that they can cause overheating in the local supply distribution transformer and in the installation itself. Also, harmonic currents in the neutral conductors of three-phase supplies present reliability and safety risks, where neutral conductors have not been suitably dimensioned.

5. The standards dealing with low frequency harmonic currents have evolved with the objective of promoting power quality by limiting the harmonic currents imposed on the mains supply. Before we begin exploring the possible solution, there is another term that needs to be understood, "special wave shape", it is defined by an envelope, which is effectively a means of distinguishing electronic power supply circuits, which normally draw their current for less than a third of the supply half-cycle. Equipment is deemed to be non harmonically polluting, if the input current wave shape of each half period is within the envelope shown for at least 95% of the duration of each half period.

Active filtering

6. Different solutions to minimize the effects of nonlinear loads in electric distribution systems (non-sinusoidal voltages, harmonic currents, resonance) have been proposed and implemented. Even though the harmonic contribution of any overhead projector, Personal Computer, printer, or 200 W power supply, is negligible on its own, with hundreds of similar units connected to the same onboard supply, their contributions are additive and present a particular problem, depending on the capacity, impedance, and layout of the network.

7. Main signalling voltage and resonance. The non-sinusoidal current drawn from the supply causes distortion of the supply voltage, it is due to the fact that the inductance of the supply increases the source impedance as the harmonic order increases. This waveform distortion can cause serious effects in various connected loads. In modern single phase low power equipment, the main interface is made with the capacitive components in the circuit. System resonance effects at the harmonic frequencies can also create a cumulative effect wherein areas of the power distribution network where the voltage is more heavily distorted than elsewhere, and/or has significant over- or under-voltage. Also, some areas of the network can suffer from much higher levels of current than elsewhere, at a few harmonic frequencies.

8 The general solution for power quality onboard falls into addressing one of two categories: controlling ripples (for harmonic frequencies in range from 100 Hz to 3 kHz) and addressing communication systems (ranging in frequencies from 3 kHz to 148.5 kHz). Both these categories have their permissible voltage levels. In a general installation, the presence of (limited) signalling voltages can produce resonance, the highest resonance occurring under low load conditions. The main control categories are of two types:-

(a) The line frequency switching compensators and

(b) The high frequency switching compensators.

9. In the first control mode the line current conduction time is extended to almost the entire line period. High frequency switching solutions include the large family of power factor correction circuits. All of these AC/DC converter stages provide sinusoidal current absorption, using various kinds of series and shunt compensators, like the active filters. For the case of medium/high power three phase networks, it is important to have balanced conditions and sinusoidal voltages. This can be achieved using flexible AC power transmission systems, incorporating power electronics circuits and other static compensators providing increased controllability.

10. Different types of compensators have been proposed to increase the electric system quality. The active filter control strategy is very similar to the one applied to the pre-regulator circuit in the high frequency switching mode with continuous current. The strategy allows power factor correction to the unity, harmonic elimination and load unbalance compensation.

Active filter operation

11. Various different control algorithms can be applied to the active filter correction technique. But almost all of them require a low processing time and allows the calculation of the current reference for one of two strategies.

(a) Power factor correction using harmonic elimination and load unbalance compensation.

(b) Voltage regulation using harmonic elimination and load unbalance compensation.

12. The control algorithm needs the measurement of several variables like the three phase AC source voltage and the DC link voltage. The active power balance in the DC link determines the reference current of the AC source and the use of a PI controller allows a smooth control of the filter current and improves the system dynamic response. This is followed by the

modulation stage in which the total reference currents are subtracted from the source current, obtaining a current error adapted according to the amplitude of the triangular carrier. A triangular waveform also introduced to stabilize the converter switching frequency by forcing it to be constant and equal to the frequency of the triangular reference signal. Since the current error signal is always kept within the negative and positive peaks of the triangular waveform, the system has an inherent over current protection. The result of using such active power protection, is mostly a mains current gets a sine waveform, being only slightly distorted in the instants of the diode switching. This is due to the high change in current occurring in various high current density points in the circuit, which is impossible to compensate unless with a very high DC voltage or a very low AC inductance. To solve the same, there should be a compromise between the active filter dimensioning and the characteristics of the load current to be compensated.

Solutions

13. Harmonics generated by nonlinear loads are one of the major causes of a poor power quality. So, harmonic elimination, in the source or with active filtering, is needed to achieve a better power quality onboard Indian Naval Ships & Submarines. The paper addresses the problem of active filtering in low power single phase networks and medium/high power three phase networks.

14. In modern single phase low power equipments they should have a pre-regulator stage, achieving an almost sinusoidal input current. In medium/high power single or three phase networks when it is not possible to eliminate the harmonic currents in the input stage in some connection point, the active power filter is the solution to be implemented. The active filter operation in the harmonic elimination mode allows an increasing in the power quality due to the achieved sinusoidal current flowing in the network. In order to address power quality issues we have to address.

15. Onboard ships, harmonics are mostly caused due to control equipment & PE devices, while fluctuations are due to faulty operations of the source. These are often associated with voltage flickers (faulty operation of the grid and connected equipment and frequency deviations due to Source and prime mover fault. In order to have effective and automated power quality regulation, it has to catch instantaneous interferences (in both I and V) quickly including, amplitude variation, waveform distortions and rate of variation. This paper proposes the possible solutions such as

    (a) Active Power Filter Correction Circuit which uses combination of active and passive filters. A low cost solution but having slower response time.

    (b) SVC (Static VAR Compensation), a shunt connected device capable of generating or absorbing reactive power having limited phase balancing capabilities and control frequency.

    (c) STATCOM (Static Synchronous Compensation), a VSC (Voltage Source Convertor) based device used for Voltage regulation in transmission and distribution system. It can rapidly supply dynamic VARs required system disturbances and faults for voltage supports. It comprises of an energy storage element (Ultra/super capacitor), integrated with the device to mitigate over-currents and trips during and after system disturbances.

16. Conclusion. Advances in technology already have a profound bearing on the eqpt onboard Indian naval platforms, be it new construction ships or retro-fits. In the earlier era, if one could provide uninterrupted power supply maintaining r.m.s voltage and frequency, it was good enough. However, Due to shift from analog systems to state of the art digital systems in the field of power generation & distribution, machinery controls, communications, Nav-aids and Weapons & sensors, increased attention to Power Quality has been inevitable i.e providing voltage and current flow in the purest sinusoidal form without swells, sags, notches, harmonics etc. In the present scenario, Power Quality is more significant due to vulnerability of sophisticated electronic systems being used onboard our platforms and the associated cost of their respective Power supply modules. Applying an external power quality protection device as explained in the paper before the load can prove to be breakthrough solution for better operational availability with reduced maintenance cost.

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article 13

CFD ANALYSIS OF A MISSILE LAUNCH FROM A STATIC UNDERWATER PLATFORM

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Abstract Stability of a launch platform is an important aspect for operation of a missile and more so in case of an underwater platform. Availability of a platform dynamics estimation tool for missile launch evolution analysis during initial design stages is critical for designers. In this study a transient numerical analysis has been carried out to study the motion of an underwater platform post launch of a missile. A very simplistic setup was modelled to understand the physics of the problem. The motive of the work was to develop an understanding of the problem and to prepare a foundation for analysis of the actual system – static/mobile platform.

Introduction

Launching of a missile is a complex operation even from a ground based station, the complexities increase as we move from land to sea and even more when it is from an underwater platform. Projectile launch from a submarine is an advanced military technology. Such launching methods possess the advantages of flexibility and elusion. The projectile is accelerated by the high-pressure propellant gas and departs from the launch tube. The effect of the various parameters during vertical launch is of great interest for naval architects to understand the dynamics that happen during the launch of a vertical launch missile.

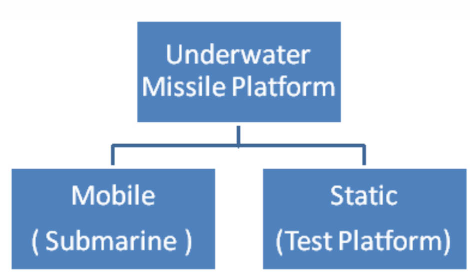

Fig. 1. Types Missile Launch Platform

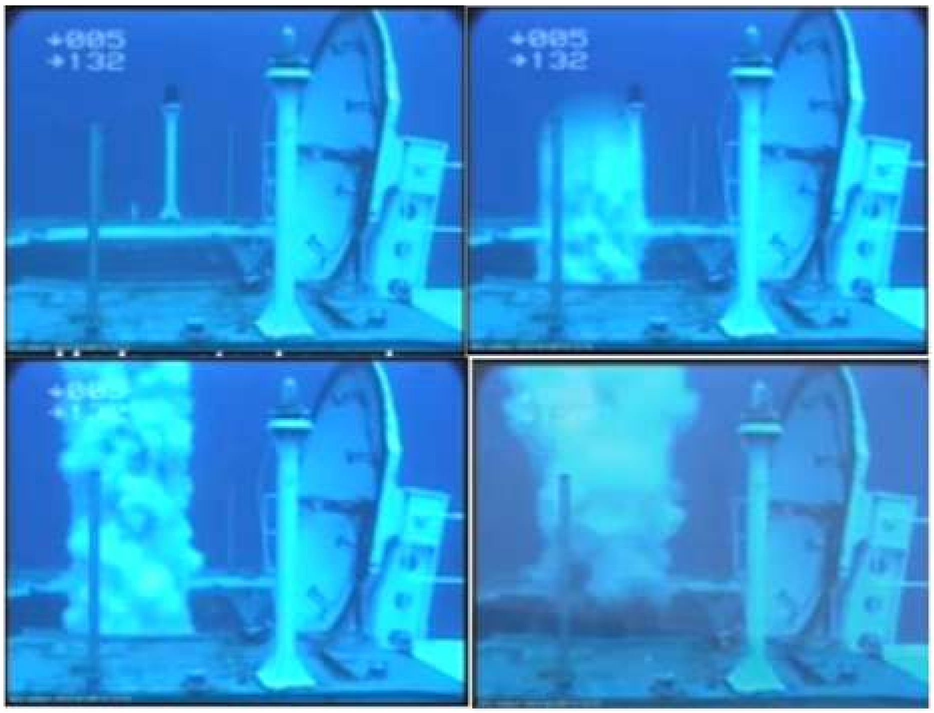

Fig. 2. A Missile Launch

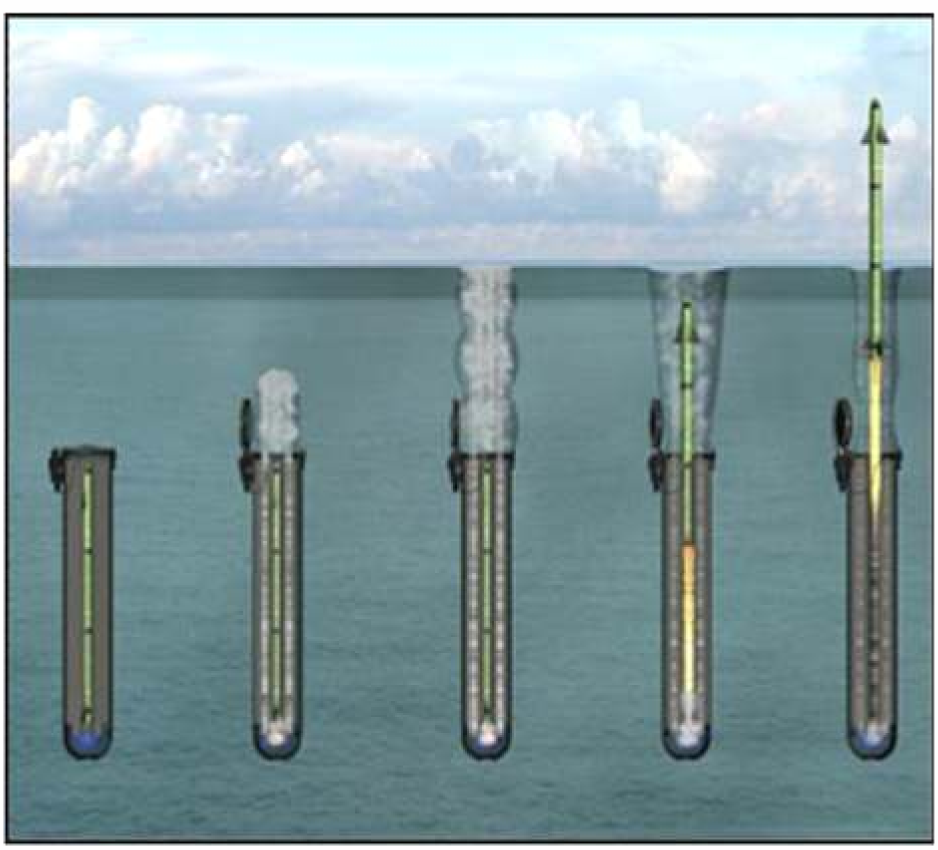

Fig. 3. Stages of a Missile Launch

The launch of a missile involves various stages starting from opening of the missile silo cover then breaking of a water tight seal by the pressure of the gases released for ejecting the missile, ejection of the missile which is followed by filling of the missile silo by gravity thereafter some amount of water needs to filled in the compensating tanks to stabilize the platform. The launch of the missile from the submarine causes the submarine to lose weight and the submarine moves up due to the imbalance in the weight and buoyancy. This is problematic as the corridor for launch of the missile is very less i.e. the missiles have a booster based on hydrostatic pressure of the water. The submarine moves up which causes a situation in which the submarine has to be stabilized before next missile can be launched. Water taken into the silo and compensating tanks also causes destabilising effect on the platform. Hence, studying the various parameters that are affecting the launch of missile from a submarine is of paramount importance the dynamics of a submarine increases the complexity of the problem the study hereafter is based on a static underwater platform.

B. Motivation

Today we are in a positon to design and construct state of art missile systems as well as nuclear submarines. The ability to develop our own missile systems and testing them from underwater platforms will empower us to become self-sufficient in this field to a great extent. The study of effect of a missile launch will help in design and construction of such platforms to test various systems developed in the country. A numerical simulation of the missile launch and its effect on the static platform will enable in designing a platform with minimum displacements due to the forces exerted on it during the launch. The analysis and validation of result with the observations at the existing facility or by conducting an experimental setup will help in developing a better understanding of the motions and develop a comprehensive method for actual prediction of the dynamics of the system.

C. Literature Survey

a. Vertical Launching Systems

A Vertical Launching System (VLS) is an advanced system for holding and firing missiles on mobile naval platforms, such as surface ships and submarines. Generally vertical launch system consists of a number of cells, ranging from 8 to 120 and even more which can hold one or more missiles ready for firing. Typically, each cell can hold a number of different types of missiles, allowing the ship, flexibility to load the best set for any given mission.

b. Hot Launch and Cold Launch

A vertical launch system can be either hot launch, where the missile ignites in the cell using its own propulsion module, or cold launch, where the missile is expelled out of the cell by gas produced by a gas generator which is not part of the missile itself and then the missile ignites once it is out. "Cold" means relatively cold compared with rocket engine exhaust mechanism because the missile is not generating the exhaust to launch itself. A hot launch system does not require an ejection mechanism, but does require some way of disposing of the missile's exhaust and heat as it leaves the cell. If the missile ignites in a cell without an ejection mechanism, the cell must withstand the tremendous heat generated without igniting the missiles in the adjacent cells and can cause catastrophic damage to the vessel.

An advantage of a hot-launch system is that the missile propels itself out of the launching cell using its own engine, which eliminates the need for a separate system to eject the missile from the launching tube. This potentially makes a hot-launch system relatively light, small, and economical to develop and produce, particularly when designed around smaller missiles. A potential disadvantage is that a malfunctioning missile could destroy the launch tube. The advantage of the cold-launch system is in its safety, should a missile engine malfunction during launch, the cold-launch system can eject the missile thereby reducing or eliminating the threat. Thus providing a safety check. As missile size grows, the benefits of ejection launching increase. Above a certain size, a missile booster cannot be safely ignited within the confines of a ship's hull. Most modern ICBMs and SLBMs are cold-launched.

c. Dynamic Fluid Body Interaction

The analysis of the motion needs use of fluid solid interaction and since both the platform and fluid are in relative motion a dynamic fluid body interaction had to be modelled. This is done by using the DFBI body object in STAR-CCM+. This object helps in simulating the motion of platform in water.

C. Problem definition

The study of such an evolution involves multiple branches of science involving various levels of interdependency. To develop an understanding of the actual physics behind it is necessary to understand the phenomenon part by part. The study involves rigid body motion, flow around the missile, study of behaviour of exhaust gases, flow dynamics of the gas fluid mixture inside the silo and stability of the platform.

There were many challenges due to the very nature of the problem. Since the research in this particular field is restricted to only some of the superpowers which actually operate such platforms. And the available literature were related to flow dynamics around the missile. There is a hardly any study in open source about the dynamics of the platform. The analysis of the problem is a very costly because the analysis is transient and due to need of the dynamic meshing to capture the motion of the platform, the simulations needed to be run on high performance computers available.

II. METHODOLOGY

A. Setting up of Simulation

a. Selection of Missile System

For the purpose of carrying out the analysis a missile system was needed. A hypothetical system has been selected based on open source realistic data. The main particulars of the selected missile are as follows:

Diameter	:	0.5 m
Length	:	3.0 m
Weight	:	3 tonnes

b. *Design of a Suitable Missile Platform*

For the analysis a simple design was adopted which was a rectangular barge like platform with the dimensions as follows:

Length	:	4m
Breadth	:	4m
Depth	:	4m

The platform is to be kept in neutrally buoyant position at a depth of 4m to do so the weight and buoyancy need to be balanced at the starting of the analysis.

c. *Selection of Analysis Tool*

For analysis of the problem a CFD tool was required STAR-CCM+ was the software used for simulation of the missile launch. The software provides all the required models for setting up the simulation. STAR CCM provides overset mesh for solving problems involving moving bodies. In an overset mesh, cells are grouped into active, inactive, or acceptor cells. Within active cells, discretized governing equations are solved. Within inactive cells, no equation is solved, however, these cells can become active if the overset region is moving. Acceptor cells separate active and inactive cells in the background region and are attached to the overset boundary in the overset region.

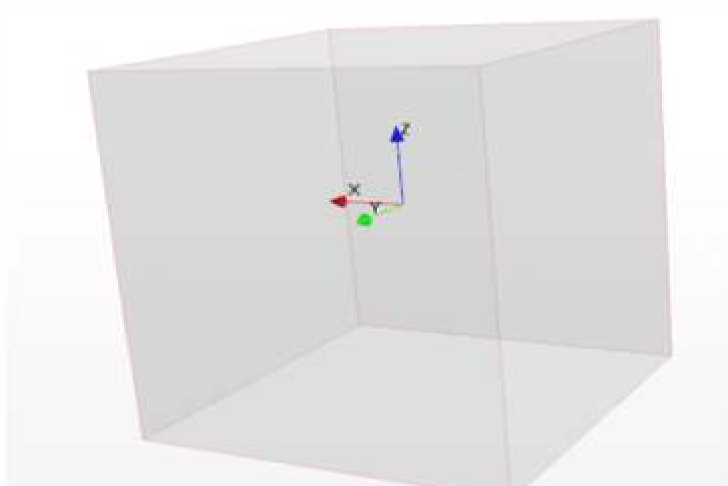

Fig. 4. The Missile Launch Platform

Acceptor cells are used to couple solutions on the two overlapping grids. Variable values at donor cells of one mesh express variable values at acceptor cells in the other mesh, through interpolation. The donor cells are the active cells from the other mesh that are nearest to the acceptor cell.

d. *Setting up the Geometry for the problem*

First we need to create the platform which is a cube with sides of 4 m each. Volume is required which is larger than the platform volume and overlaps the platform this region is called the overset region. The overset region is the dynamic mesh that handles the movement of the platform. The overset region for the problem is a cube of sides 4 each.

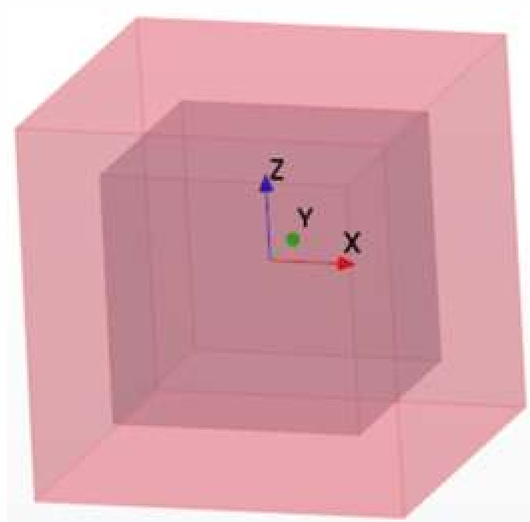

Fig 5 The Overset Region

Another region is to be made which forms the interface between the overset and the background. Background is the complete fluid domain. This interfacing region is called the overlap, the overset region can move in this region only and lastly the background which is the overall fluid domain for the problem. The overlap region has dimension of 8mx8mx20m and background is a cube of sides 20m each.

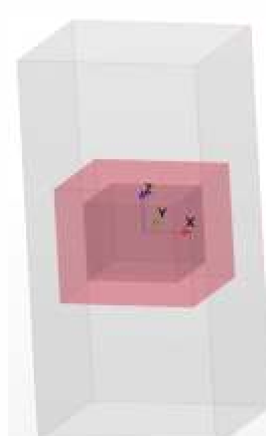

Fig 6 The Overlap Region

The active meshes which participate in the simulation are overset and the background. The overlap region is used for volumetric control of the meshing to allow for the interface between the two meshes.

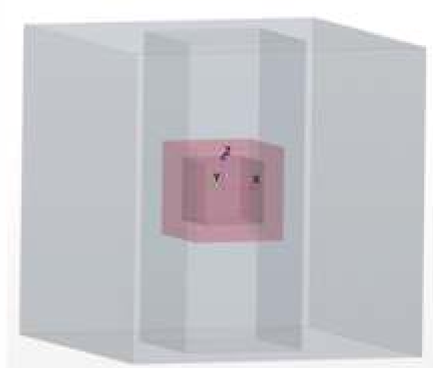

Fig. 4. The Missile Launch Platform

e. Meshing the Domain

The meshing is done in two parts one for the background which is a coarse mesh and another for overset which is a finer mesh. Special volumetric controls are given for overlap in background and platform in overset region.

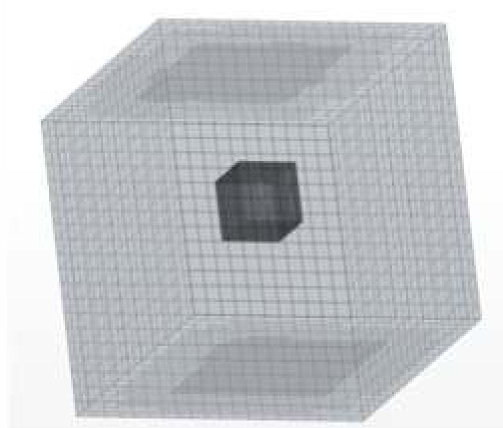

Fig 8 Mesh Generated for the simulation

Meshing details

Background region

Base size	:	1.0 m
Minimum surface size	:	0.1 m
Volume growth rate	:	Slow

Overset region

Base size	:	0.2m
Minimum surface size	:	0.02m
Volume growth rate	:	Fast

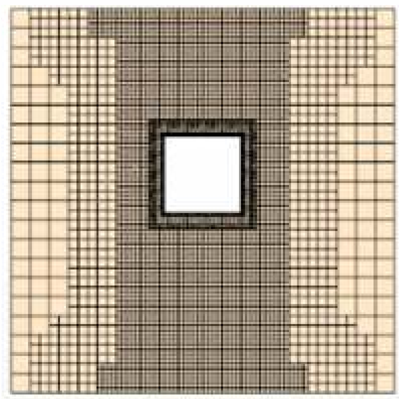

Fig 9 A Section through the mesh

f. Setting up physics models for the setup

The following physics models are selected to capture the phenomenon in the simulation

- Three dimensional
- Implicit unsteady
- Eulerian Multiphase
- Volume of Fluid
- Segregated Flow
- Gravity
- VOF waves
- Turbulent Flow
- Reynolds-Averaged Navier-Stokes
- K-Epsilon turbulence model

g. Setting up a Dynamic Fluid Body Interaction

Dynamic Fluid Body Interaction is used to simulate the motion of a rigid body due to forces on it due to fluid forces. The platform surface is assigned to the DFBI body. The weight and other forces acting on the body are initialized.

Table 1 Forces acting on the platform

Weight of the platform at the start	64 Tonnes (to maintain a neutral equilibrium)
Force acting on the platform	-34973.77N (Due to the missile launch acting for 0.5 seconds).
Weight loss due to missile launch	3 Tonnes
Weight due to water filling into the missile silo	W(t) = 0.75t2 - 0.75t + 0.1875 The quadratic function acts from 0.5 to 2.5 secs.

h. Setting the solvers

The following solvers are used

(i) Implicit Unsteady

(ii) 6 DOF Solver

(iii) 6 DOF motion

(iv) Segregated flow

(v) Segregated VOF

(vi) K-Epsilon Turbulence

(vii) K-Epsilon Turbulent Viscosity

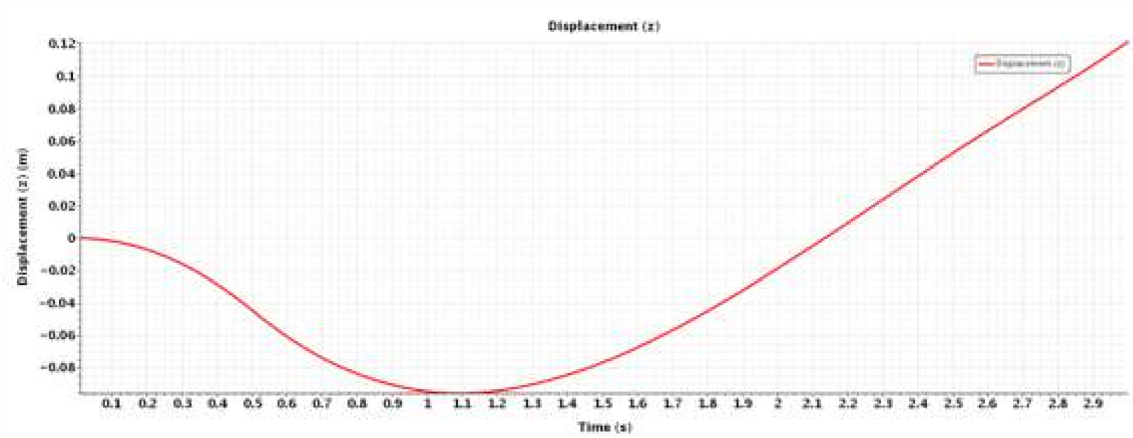

Fig 10 Plot of displacement (z)

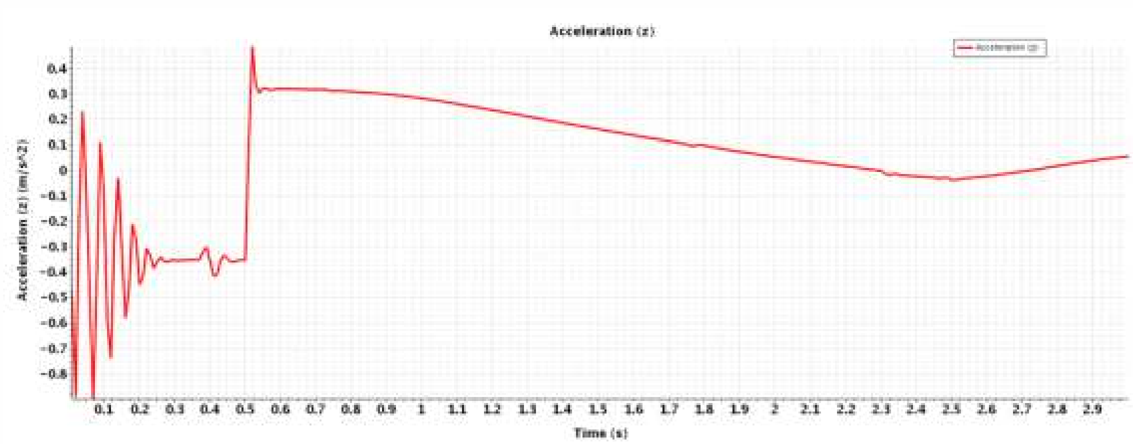

Fig 11 Plot of Acceleration (z)

Table 2 Observed Displacements and Accelerations (z)

Time	Displacement(m)	Acceleration(m/s2)
0.01	-0.00002	-0.4543
0.1	-0.00189	-0.0432
0.2	-0.00723	-0.4388
0.3	-0.01618	-0.3416
0.4	-0.02865	-0.3539
0.5	-0.04466	-0.3516
0.6	-0.06090	0.3213
0.7	-0.07392	0.3183
0.8	-0.08378	0.3101
0.9	-0.09054	0.2990
1	-0.09432	0.2823
1.1	-0.09529	0.2599
1.2	-0.09368	0.2353
1.3	-0.08973	0.2094
1.4	-0.08370	0.1835
1.5	-0.07584	0.1583
1.6	-0.06642	0.1344
1.7	-0.05566	0.1114
1.8	-0.04380	0.0939
1.9	-0.03102	0.0711
2	-0.01755	0.0503
2.1	-0.00357	0.0317
2.2	0.01071	0.0132
2.3	0.02512	-0.0125
2.4	0.03943	-0.0244
2.5	0.05349	-0.0402

IV. CONCLUSIONS

The results from the simulation has given us a head start into the study of analysis of the motion of an underwater missile launch platform. This results can be verified with an experimental setup similar to the one simulated. Thereafter the same can be done for a real missile launch platform. This particular model is a simplified version for the platform the actual one would be a complicated one and would require high computational power and understanding of the physics behind the operation from such platform. Also a highly accurate measurements need to be taken while conducting the experiments.

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14. Star CCM User Manual

CFD Analysis of a Missile Launch from a Static Underwater Platform

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ABSTRACT

Stability of a launch platform is an important aspect for operation of a missile and more so in case of an underwater platform. Availability of a platform dynamics estimation tool for missile launch evolution analysis during initial design stages is critical for designers. In this study a transient numerical analysis has been carried out to study the motion of an underwater platform post launch of a missile. A very simplistic setup was modelled to understand the physics of the problem. The motive of the work was to develop an understanding of the problem and to prepare a foundation for analysis of the actual system – static/mobile platform.

The results from the simulation has given us a head start into the study of analysis of the motion of an underwater missile launch platform. This results can be verified with an experimental setup similar to the one simulated. Thereafter the same can be done for a real missile launch platform. This particular model is a simplified version for the platform the actual one would be a complicated one and would require high computational power and understanding of the physics behind the operation from such platform. Also a highly accurate measurements need to be taken while conducting the experiments.

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FINITE ELEMENT ANALYSIS OF RESIDUAL STRESSES DUE TO WELDING IN SUBMARINE HULL

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Abstract In this paper, Welding of ASTM 36 carbon steel plates was studied numerically. The Finite Element Analysis (FEA) of residual stresses in butt welding of two similar plates is performed with commercial FEsoftware ANSYS®. This analysis includes a finite element model for the transient thermal and mechanical welding simulation. It also includes a moving heat source, material, temperature dependant material properties, metal plasticity and elasticity, transient heat transfer and mechanical analysis. The welding simulation was considered as a sequential coupled thermo-mechanical analysis and the element birth and death technique was employed for the simulation of filler metal deposition. The residual stress distribution, strain and magnitude in the axial direction were obtained. The results were initially validated with open source literature and further analysed for multiple boundary conditions.

Keywords: Welding, welding joint, plate, residual stresses, stress analysis, finite element method

1. Introduction

A. Submarine Welding and Residual Stresses

Submarines have a pressure hull and an outer hull .The pressure hull is designed to withstand the hydrostatic pressures till the required depths. Out of all the loads acting on the submarine, hydrostatic pressure is the major component. Other loads acting are shock loads underwater detonation, longitudinal and transverse loads due to waves.

The shell of the pressure hull absorbs forces in longitudinal direction however, the transverse frame are additionally stiffened to absorb circumferential loads. Such a hull can fail when it is loaded beyond yield point, buckling or overall collapse.Explicit understanding of the residual stress field of primary submarine pressure hull induced during fabrication will improve the fidelity of numerical analysis and experimentation. Hence, supporting operational envelope and design life extension initiatives .The fatigue lifetime of a submarine hull depends on the loads generated by hull contraction under the effect of hydrostatic pressure and the residual stresses. The use of numerical simulation allows a straight forward calculation of the stresses induced by the welding process. It is more intricate to determine the residual stresses resulting from the sheet bending process combined with the sheet assembly using a multipass welding process.

Efforts have been made to establish and improve ultimate submarine design life limits. The residual stresses induced due to manufacturing processes, like rolling and welding, are variables required for analysis of various degradation mechanisms associated with the aggressive loading conditions experienced by a submersible (buckling, fatigue, stress corrosion cracking). In a submarine structure, the hull is essentially composed of rolled plates and T frames welded together. The residual stresses produced by the bending process can be calculated. The resulting through thickness distribution has a typical "Z" shape with tension at the inner surface of the hull and compression at the outer surface. The residual stresses induced in T-butt welds are highly tensile in and around the weld which can have important effects on the mechanisms of crack growth. Consequently, it is very important to predict residual stress and its effect on structural failure analysis through fracture mechanics approach.

The most commonly available residual stressmeasurement techniques that can be applied to cast irons and steels. The techniques can be categorised in terms of penetrationdepth and the degree of material removal required. Only a few techniques are available to measurecomponents thicker than 10mm. Neutron diffraction, centre hole drilling, slitting, deep hole drilling are few techniques, which are destructive and may not give accurate results.

There are many methods adopted during the production and welding to avoid residual stresses. Pre heating, controlled welding using heating pads etc. Inspite of the measures taken residual stresses are unavoidable due to thicknesses involved.

Therefore the paper suggests the significance of numerical studies as a tool to determine the residual stresses that can occur in welding plates of different thicknesses.

II. BACKGROUND

A lot of research has been already done and published on the residual stresses induced during welding. It was largely done on butt welding of thin plates of different materials and for different boundary conditions. FE analysis of welding is essentially a thermo – mechanical simulation. Comparatively there is less research done on FE simulation of submarine hull welding. It is different from other welding processes as the thickness, temperature and other welding variables involved are very different. Therefore there is a large scope for research.

A. Development of Welding Simulation Model

The simulation of welding using FE method can be split into two solution steps: thermal and mechanical analyses. First, the temperature and phase evolution are determined as a function of time in the thermal analysis. Then, the mechanical analysis employs the previous results to get displacements at nodes and stresses at integration points. Since the thermal field has a strong influence on the stress field with little inverse influence, a sequentially coupled analysis predicts quite accurate results. Moreover, a 3-D FE analysis is the optimum method of ascertaining the thermal cycle of welding. Therefore the welding process will be simulated using a sequentially coupled 3-D thermo mechanical FE analysis based on the ANSYS software. For both the thermal and mechanical analyses, temperature dependent thermo-physical and mechanical properties of the materials are used.

Firstly, the computation of the temperature history during welding and subsequent cooling is completed and this temperature field is applied to the mechanical model as a body force to perform the residual stress analysis.

To simulate the moving heat source it is necessary to model the heat source during each time increment. In this analysis the moving heat source is simplified by assuming the welding arc stayed at an element with a constant specific volume heat generation, and then moved to the next element at the end of the load step as the welding is completed. The simulation procedure can be understood from Figure 1.1.

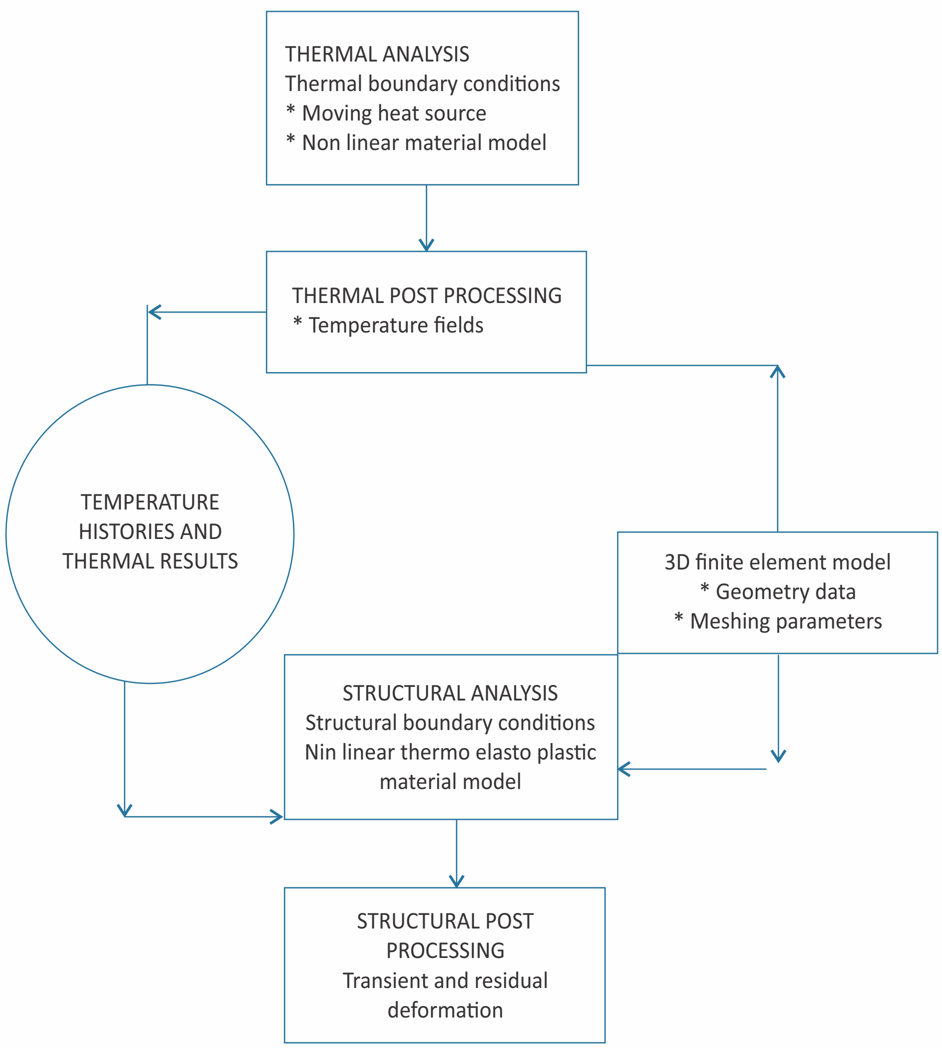

Fig.1.1: Flow chart for simulation [3]

B. Analytical Overview of the Problem

a. Thermal modelling

The principal parameter of the heat source for the temperature field is the heat input into the welding spot in the arc welding, the heat input is the product of current I [A] and voltage U [V] in the case of direct current. Consequently the heat flow is expressed as [1]

$$q=UI\eta h$$

Heat losses e.g. radiation in welding is taken into account by the heat efficiency ηh which depends on the welding process. In computing heat flow in actual weldments, it is often necessary to take into consideration the effect of the size and shape of the heat source. This can be done by treating the heat source as being distributed over an area [J/mm2] or a volume [J/mm3]. Fourier's law of heat conduction describes the heat flow propagation. It states that the heat flow density q [J/mm2] is proportional to the negative temperature gradient ∂T/∂t [°C /mm] by the equation

$$q = -\lambda \frac{\partial T}{\partial t}$$

Where λ [J/(mm°C)] denotes the thermal conductivity and T [°C] the temperature.

In terms of FE modelling of the welding heat source, the heat generation Q can be expressed as [1]

$$Q= Q\ surface+ Q\ volume + Q\ filter$$

where Qsurface is the surface heat flux, Qvolume is the volume heat flux and Qfiller is the heat generated by the addition of the weld filler material at a prescribed initial temperature. One objective with heat transfer analysis in welding is to determine the temperature fields in an object resulting from conditions imposed on its boundaries, the quantity sought being the Temperature distribution. Figure shows a schematic model of the temperature distribution when a surface weld bead is being deposited at a speed v. The coloured bands represent isothermal areas.

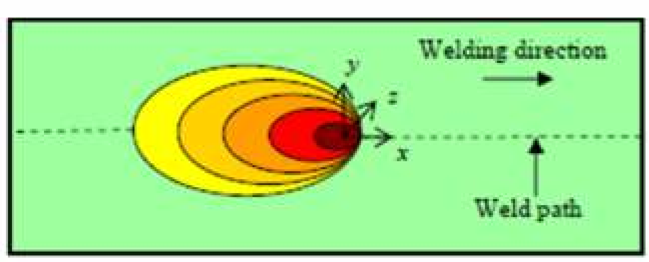

Fig.1.2: Temperature distribution in during welding

The fundamental equation of heat conduction for a homogeneous and isotropic continuum with temperature-independent material characteristic values in a solid is [1]

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c\rho}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+\frac{1}{c\rho}\frac{\partial Q_i}{\partial t}$$

The parameter c [J/g°C] is the mass-specific heat capacity and the parameter ρ [g/mm3] is the density. The parameter Qv [J/mm3] is the rate of temperature change due to heat generated per volume, and λ/cρ is the material-and temperature-dependent coefficient of thermal diffusivity κ [mm2/s]. The temperature field in equation (3) could either be stationary (i.e. steady-state), the temperature field is then time-constant at all points, i.e. $\partial T/\partial t = 0$, or non-stationary (i.e. transient), then the temperature field is determined on the material side by the thermal diffusivity. The characteristic of heat flow during arc welding is that the heat source moves at constant speed on the surface of the work piece, and that the size of the heat source is small compared to the size of the work piece.

b. Welding residual stresses

The residual stresses caused by inhomogeneous temperatures are termed thermal stresses. These elastic thermal stresses disappear after removing the inhomogeneous temperatures which cause them. Where major differences in temperature exist, the thermal stresses give rise to plastic deformation and, after removal of the temperature differences and complete cooling, residual stresses remain. During the welding process the weld area is heated up significantly relative to the surrounding area and fused locally. The material expands as a result of being heated. The heat expansion is restrained by the surrounding colder area, which gives rise to elastic thermal stresses. The thermal stresses partly exceed the yield limit, which is lowered at elevated temperatures. Consequently the weld area is plastically hot-compressed and, after cooling down, it thus displays tensile residual stresses, and the surrounding area compressive residual stresses.

The fundamental equations in the thermo-elastic-plastic analysis of welds are:

(i) A change in temperature, ΔT, causes a volumetric strain $\alpha\Delta T$.

(ii) At each point, the strain increment can be defined as [1].

$$d\varepsilon_{ij}^{Tot} = d\varepsilon_{ij}^{Elastic} + d\varepsilon_{ij}^{Plastic} + d\varepsilon_{ij}^{Thermal}$$

$$d\varepsilon_{ij}^{Elastic} = D_{ijkl}^{-1} d\sigma_{kl}$$

$$d\varepsilon_{ij}^{Plastic} = \lambda \frac{\partial F}{\partial \sigma_{ij}}$$

$$d\varepsilon_{ij}^{Thermal} = \alpha\Delta T \delta_{ij}$$

(iii) The material obeys isotropic/kinematic hardening hypothesis.

(iv)The material properties e.g. the Young's modulus and the yield strength are assumed to be temperature dependent

III. RESEARCH OBJECTIVES

As a part of the research at IIT Delhi, the study of this project is undertaken under following stages.

A. Evolution of Weld Temperature Distribution.

The objective of this project is to model butt welding of two plates and carryout the transient thermal analysis in ANSYS to determine the temperature distribution of the plates after the heat input is simulated.

B. Determination of Residual Stresses.

Consequently to couple the transient thermal analysis with transient structural analysis to determine the residual stresses and to draw conclusions from results.

IV. SIMULATION

A. Transient Thermal analysis

The welding simulation is carried out in ANSYS 15.0 workbench (Finite Element code). Model of butt joint of the two plates is created in ANSYS design modeler. Thermal analysis is carried out in 'transient thermal module'.

a. Geomtry Model

60 mm X 60 mm X 6 mm thick plate is modeled with a 'v' groove of 60 degrees. In Figure 2.1 the weld bead is divided into 4 parts to simulate the moving heat source through the element birth and death technique.

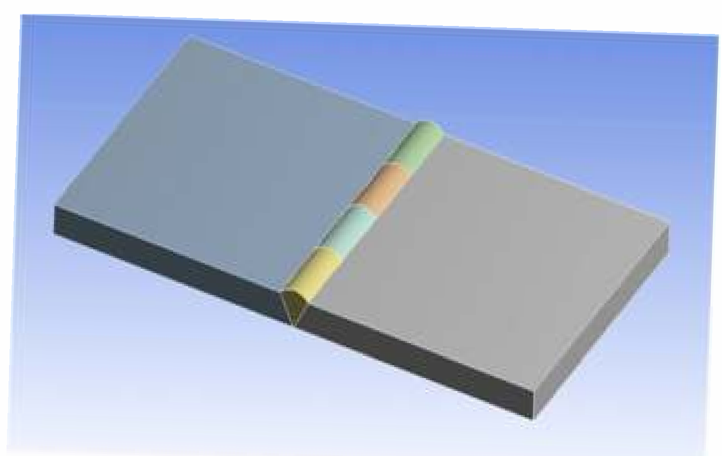

Fig 2.1: Model of the plates with weld bead

b. Material Properties

ASTM 36 steel is chosen for the analysis. The process is a nonlinear elasto plastic deformation and the required temperature dependent mechanical properties are fed into the material library in ANSYS. For plasticity, bi linear isotropic hardening is used with yield strength and tangent modulus varying with temperature. The thermal and mechanical properties of the material are given in Table 2.1

c. Mesh

Fine mesh is used for weld zone and comparatively coarser mesh is used for the weld plates. The size of the fine mesh being 1 mm. This selective meshing is shown in Figure 2.2.

d. Initial condition

Initial temperature of the weld plates is set to 22 °C.

e. Time settings

Simulation time is set to 400 seconds with a time step of 1 second. It is very important to carry the thermal analysis with large time settings in order to facilitate the cooling of the weld bead to room temperature. The results thus obtained will be used as an input for the mechanical analysis further.

Table 2.1: Temperature dependent mechanical and thermal properties [2]

Temperature (°C)	Specific heat (J/kg°C)	Conductivity (W/m°C)	Density (kgm-3)	Yield stress (MPa)	Thermal expansion coefficient (10-5/°C)	Young's modulus (GPa)	Poisson's ratio
0	480	60	7880	380	1.15	210	0.3
100	500	50	7880	340	1.2	200	0.3
200	520	45	7800	315	1.3	200	0.3
400	650	38	7760	230	1.42	170	0.3
600	750	30	7600	110	1.45	80	0.3
800	1000	25	7520	30	1.45	35	0.3
1000	1200	26	7390	25	1.45	20	0.3
1200	1400	28	7300	20	1.45	15	0.3
1400	1600	37	7250	18	1.45	10	0.3
1550	1700	37	7180	15	1.45	10	0.3

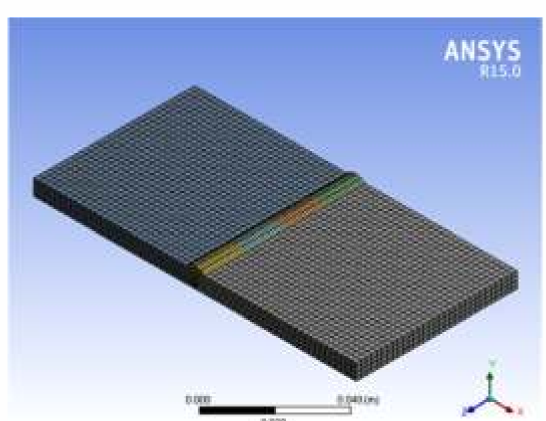

Fig.2.2: Mesh of the welded plates

f. Heat input

A calculated heat generation of 1.8x1010 W/m3 is given as a function of time and coordinate along weld length.

g. Element birth and death technique

The total length of the weld bead 60 mm is divided into 4 regions assuming that the weld speed is 15 mm/sec. The heat input is given in a sequence such that the elements in a particular region element are alive for one second with heat input and dead for the rest 3 seconds. This simulates a moving heat source across the length of the weld. Figures 2.3 to 2.6 show the sequential heat sourceinput.

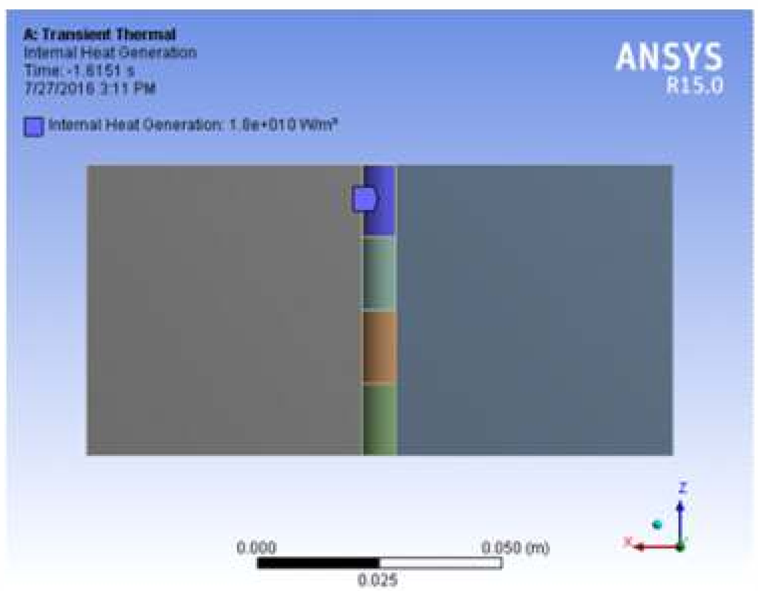

Fig. 2.3: Active element region with heat input from 0 to1 second.

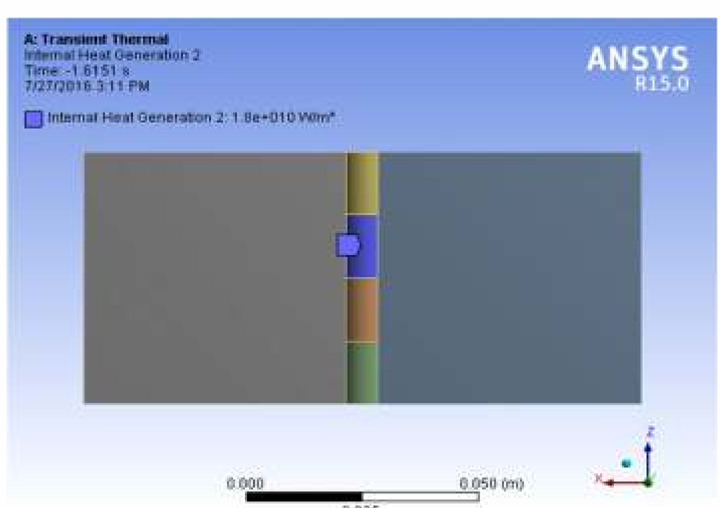

Fig. 2.4: Active element region with heat input from 1 to 2 seconds.

h. Thermal Boundary conditions

The two extreme edges of the plates are maintained at 22 °C. Other2?

i. Radiation and convection

Radiation boundary condition is imposed with an emissivity of 0.3 and convection boundary condition with a convection coefficient of 15 W/m2 °C and surrounding temperature as 22°C

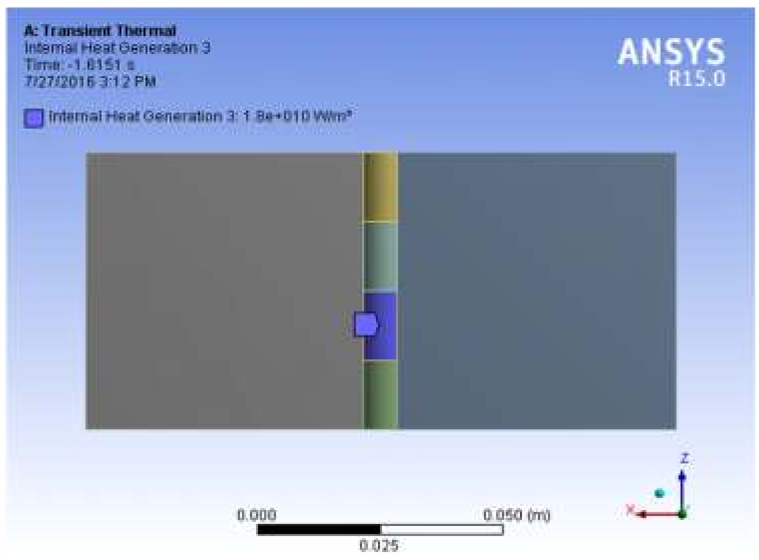

Fig.2.5: Active element region with heat input from 2 to3 seconds.

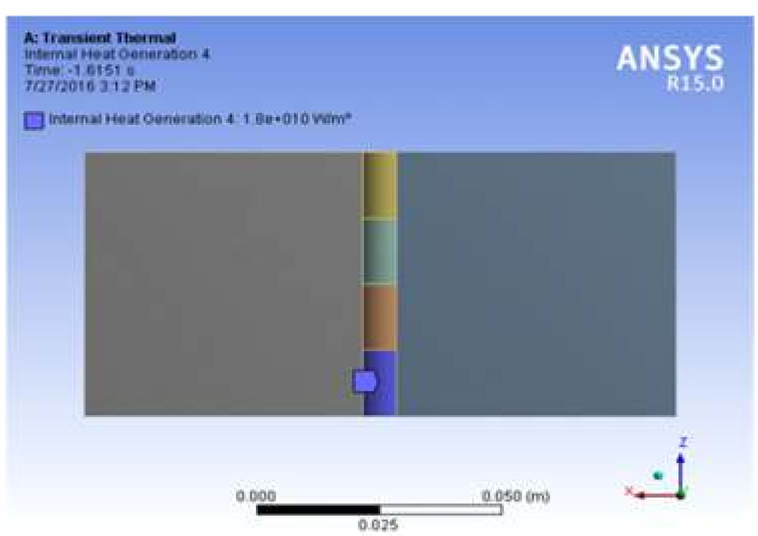

Fig.2.6: Active element region with heat input from 3 to 4 seconds.

B. Results and Discussions: Thermal

The variation of maximum temperature in the weld bead with time is shown in the Figure 2.7. The initial temperature is 22°C and with the heat input, temperature rises to a peak of 1916 °C at the end of first second in region 1, then the maximum temperature appears in the region 2 and so on as the heat source moves. After 4 seconds, it cools down for 396 seconds to attain boundary temperature.

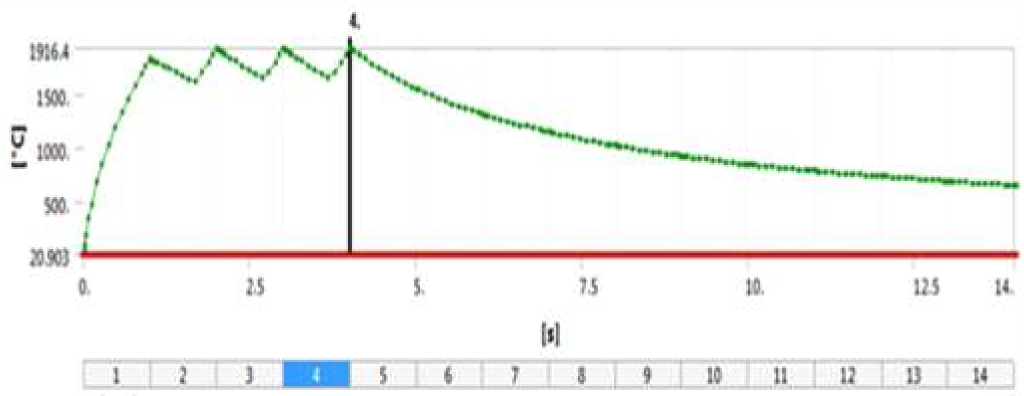

Fig.2.7: Maximum temperature variation with time

The temperature distribution around the weld bead after 400 seconds is shown in Figure 2.8. The weld bead is cooled to 29°C. It can be seen from Figure 2.8 that the temperatures of portions away from weld bead decreases from 29.6 °C at bead to 22°C at the edges

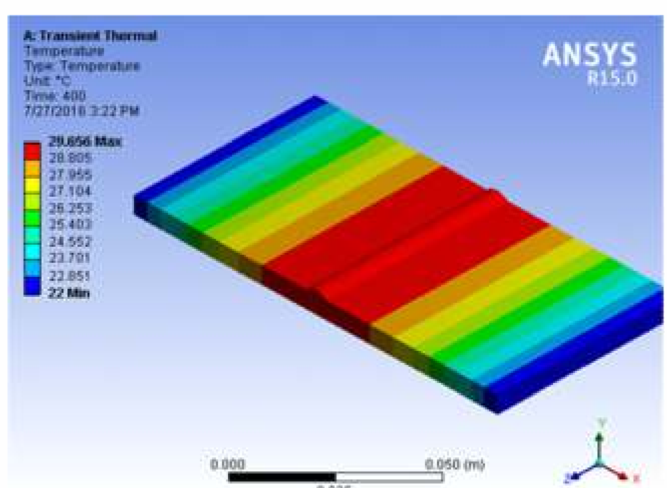

Fig.2.8: Temperature distribution at 400 seconds

C. Transient Structural Analysis with Two Edges Fixed

The transient thermal module is coupled with the transient structural module as shown in the Figure 2.9. The same material properties, geometry and mesh are used for this analysis also. The element for structural analysis is switched

Fixed support at both edges of the plates is shown in the Figure 2.10. Fixed support constrains all the degrees of freedom of the edge.

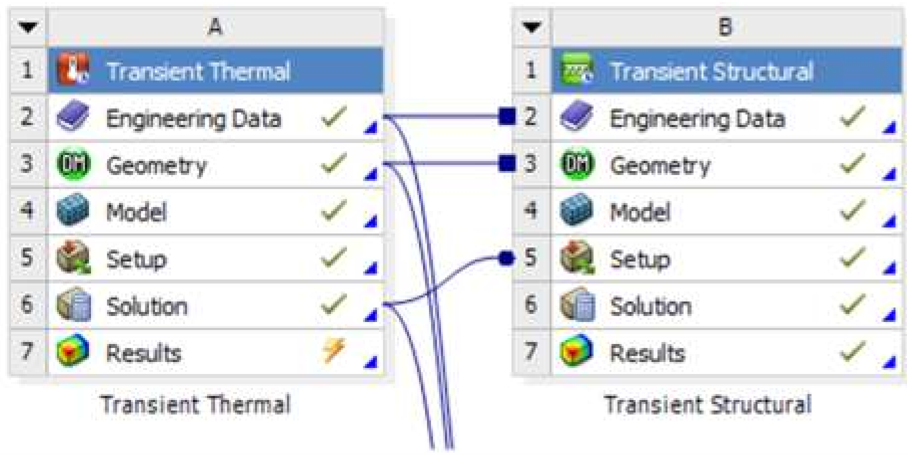

Fig.2.9: coupled analysis.

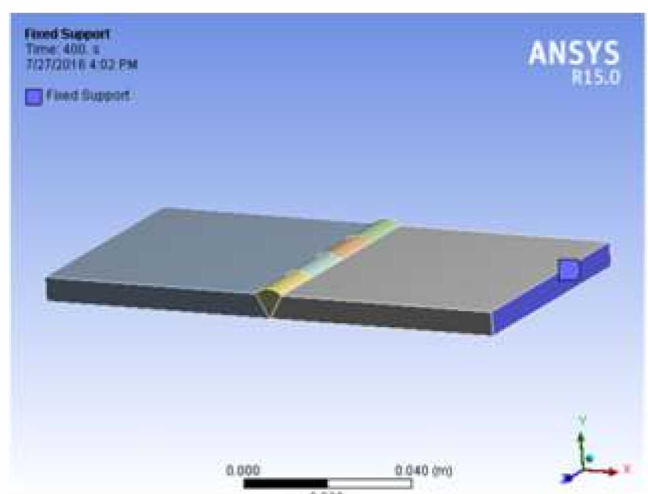

Fig.2.10: Fixed edges of the plate

Thermal load (temperature distribution), output of the thermal analysis is imported into the mechanical simulation for all time steps (400 sec).

D. Results and Discussions: Mechanical

This section discusses the residual stresses and strains induced in the welded plate due to the applied thermal load. Figure 2.11 shows the equivalent stresses (von- Mises) induced in the weld plate. The residual stresses are high at the four corners of the plates which is 322 MPa, which is close to the yield stress of the material (350MPa). But the stresses around the weld bead is 200 to 100 MPa which are smaller than the yield stress of the material.

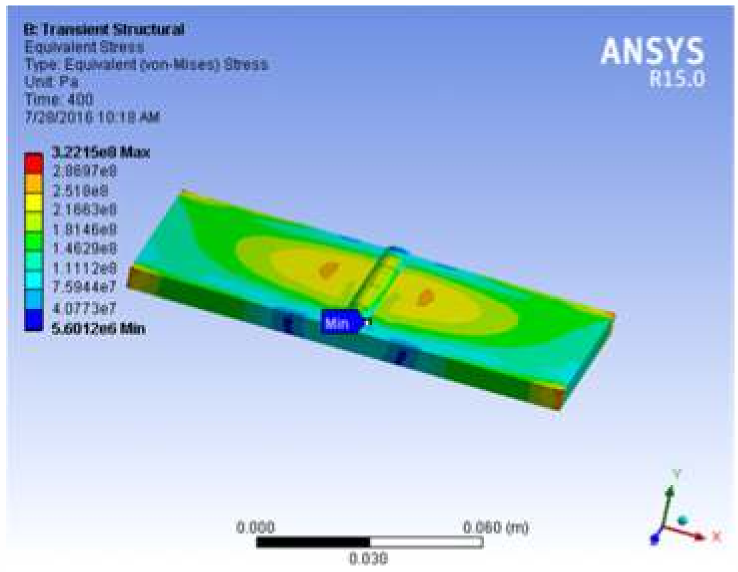

Fig.2.11: Equivalent residual stress distribution in the welded plates

Figure 2.11 shows the plot of residual stresses along X direction mid-way of the welded plates. These stresses are lowest at the weld bead (50MPa) and highest (250MPa) away from the weld zone and decrease gradually as one moves towards the edge of the plate. The transverse stress distribution graph is shown in Figure 2.12 .Red line shows membrane stresses and the blue line shows bending stresses.

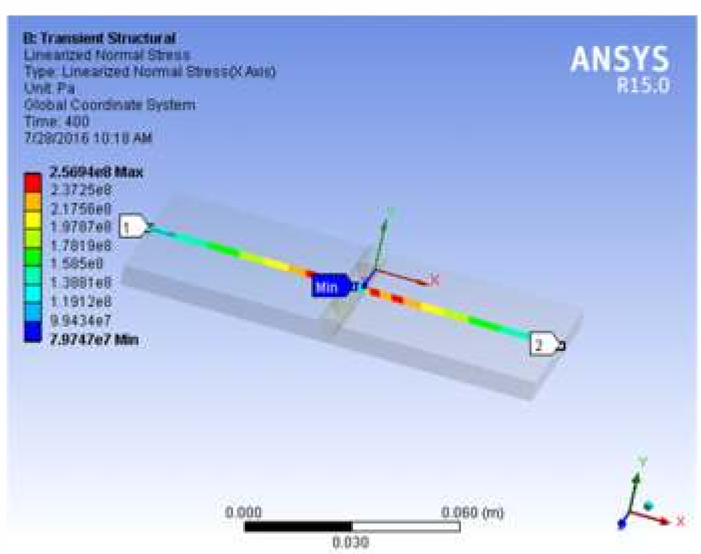

Fig.2.12 contour plot of σxx

Figure 2.14 shows the contour plotted normal stresses in the Y direction i.e. perpendicular to the plate on the outer surface. Maximum stress occurs on the surface of the weld. Figure 2.15 shows the stress distribution graph. Red line shows the membrane stresses and the blue line shows the bending stresses.

Figures 2.16 and 2.17 show the stress distribution in Z direction along the weld bead. The maximum stress is 250 MPa. Compressive stresses are induced at the bottom. Light red plot in the graph depicts membrane stresses and the blue plot shows bending stresses.

Figure 2.18 shows the plastic strain in the welded plates. Maximum strain is at the weld bead which is 0.0356. Minimum strain is 0.

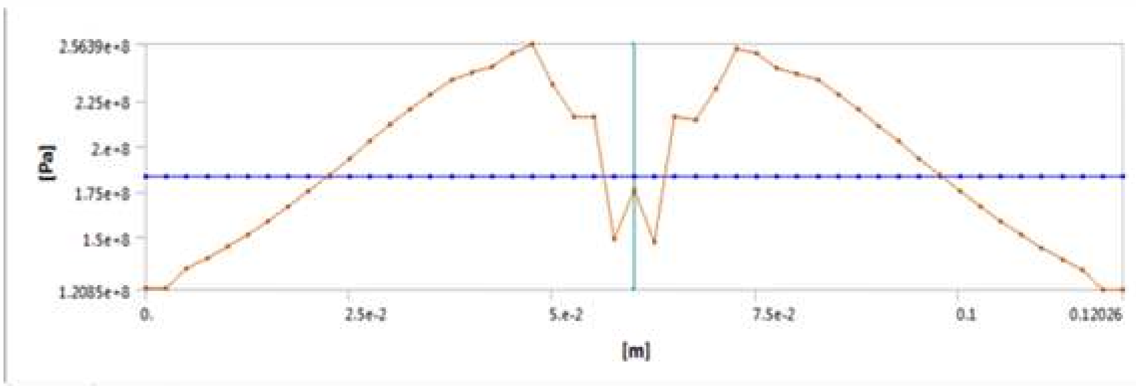

Fig.2.13: Normal stress (σxx) variation along centre line perpendicular to weld bead direction

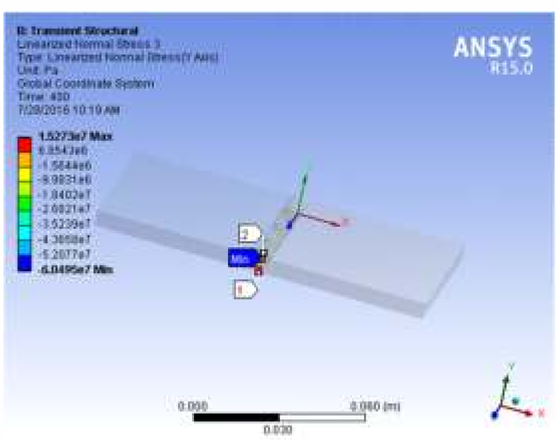

Fig.2.14: contour plot of σyy

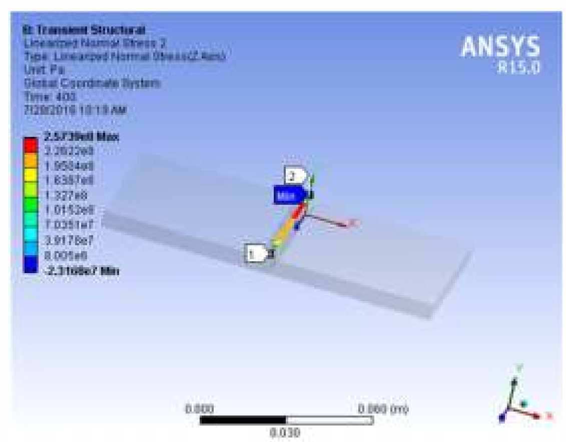

Fig.2.16: contour plot of σzz

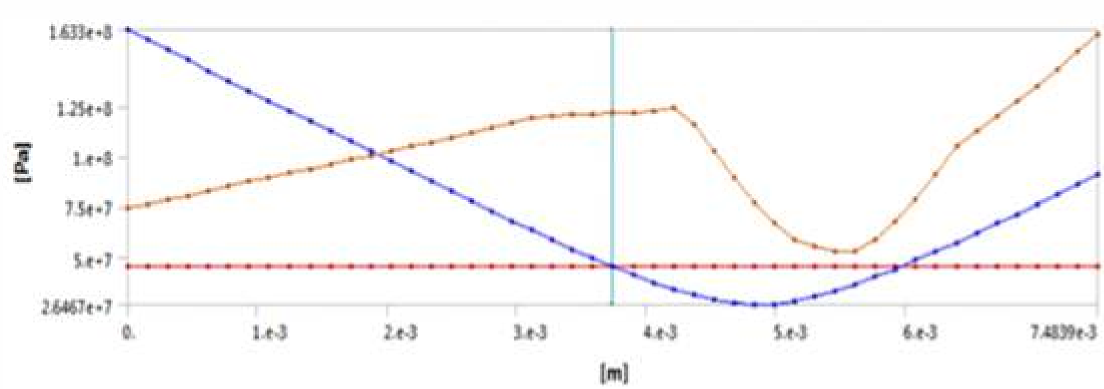

Fig.2.15:Normal stress (σyy) variation along center line perpendicular to weld bead direction.

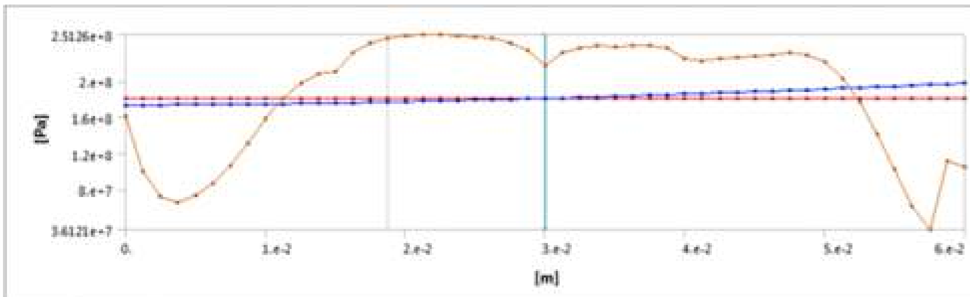

Fig.2.17: Normal stress (σzz) variation along centre line in weld bead direction

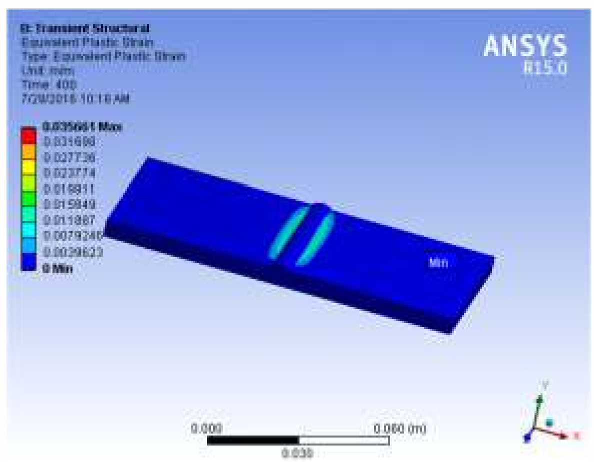

Fig.2.18: Plastic strain.

V SIMULATION 2 – TRANSIENT STRUCTURAL ANALYSIS WITH ONE EDGE FIXED.

A similar analysis as the previous simulation is carried out with the welded plates fixed along only one edge .All other parameters remaining the same.

A. Results

Residual stresses in the plate are maximum at the weld bead with maximum von- Mises stress as 464 MPa. The stresses induced in this simulation are higher than the stresses in the previous simulation (both the edges fixed).

VI CONCLUSION

Numerical results obtained from the FE analysis are in good agreement with the experimental and analytical results available in the open source. The residual stress patterns are also similar, suggesting that FE predictions are reliable for further studies of estimation of fatigue life of the structure.

The maximum temperature of the weld bead after cooling for 400 seconds is 29.6 °C. During the heat input maximum temperatures of 1916 °C occurs at the moving heat source. This temperature is in the range of melting point of the material.

From the simulations carried out, for plate fixed at both the ends maximum von Mises stress is 322 MPa which is very close to the yield strength of the material, it occurs only at the corners of the support.so this maximum stress depends on the type of boundary condition chosen. But the maximum residual stress occurring at the weld bead is 200 to 180 MPa, which is less than the yield strength of the material. Results also show that welding induces plastic deformation which is retained in the material.

While in the simulation with one edge fixed the maximum von - Mises stress obtained is 464 MPa which is very high compared to the yield stress of the material (350 MPa). Which shows serious residual stress is present at a coupon level. The residual stresses obtained in simulation 2 are very high compared to the stresses obtained in simulation 1 when both the edges are fixed.

The plastic strain in both the simulations is nearly equal.

VII WAY AHEAD

The plate thicknesses involved in submarine welding are very high which demands multipass welding. In numerical simulation of a multipass welding, element birth and death technique is used. In this technique, the elements are killed at the beginning of the thermal analysis and then for every load step a cross-sectional “strip” of elements of given pass, are reactivated and loaded to simulate the passage of the heat source and the filling material deposition. Such simulation can be done to find out the residual stresses and stress distribution in submarine hull.

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FINITE ELEMENT ANALYSIS OF RESIDUAL STRESSES DUE TO WELDING IN SUBMARINE HULL

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ABSTRACT

In this paper, welding of ASTM 36 carbon steel plates was studied numerically. The Finite Element Analysis (FEA) of residual stresses in butt welding of two similar plates is performed with commercial FE software ANSYS®. This analysis includes a finite element model for the transient thermal and mechanical welding simulation. It also includes a moving heat source, material, temperature dependant material properties, metal plasticity and elasticity, transient heat transfer and mechanical analysis. The welding simulation was considered as a sequential coupled thermo-mechanical analysis and the element birth and death technique was employed for the simulation of filler metal deposition. The residual stress distribution, strain and magnitude in the axial direction were obtained. The results were initially validated with open source literature and further analyser for multiple boundary conditions

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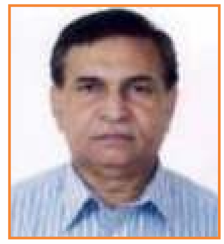

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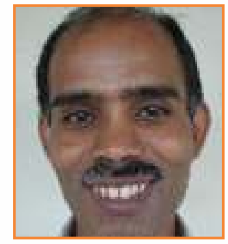

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article 15

DEPENDENCY OF HYDRODYNAMIC COEFFICIENTS ON GEOMETRICAL CONSIDERATIONS FOR AN AXISYMMETRIC SUBMERSIBLE BODY

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Abstract Controlling ship motions at sea has always been a challenge for the ship designers. His or her responsibility has been to ensure not only that the ship can safely ride out the roughest storms but should also be able to proceed on course under severe conditions with a minimum of delay and carry out specific missions successfully. The behaviour of these vessels can be predicted by estimating their hydrodynamic coefficients. In this study the effect of variation of the vehicle length on the hydrodynamic forces and moments is presented. Geometry used in the study is DARPA SUBOFF body. The change in length is accomplished by making a parametric CAD model of an axisymmetric body. The study is confined to bare hull configuration of the vehicle. Hydrodynamic coefficients determined for the various configurations of axisymmetric body are the axial force, normal force and pitching moment coefficients.

I. Introduction

A ship may be very well designed as regards its structure, strength, propulsion, weapons system, survivability etc., but all this excellent work will not bear fruit if the ship does not perform well in seaway. An open ocean is a challenging environment at high sea states where a warship is expected to perform its role to the best of its capabilities.

Sophisticated experimental techniques and modern computer applications in ship motion theories have presented an opportunity for a designer to consider the sea keeping and manoeuvring qualities of the ship at an early stage of design.

The behaviour of these vessels can be predicted by estimating their hydrodynamic coefficients. In this study the effect of variation of the vehicle length on the hydrodynamic forces and moments is presented. The change in length is accomplished by making a parametric CAD model of an axisymmetric body. The study is confined to bare hull configuration of the vehicle.

II. Methodology and Objectives

A. Geometry: A 3D parametric model was developed using PARAMARINE. DARPA SUBOFF model used in the current study is an axisymmetric body developed by DARPA, U.S.

Fig 1. DARPA SUBOFF Model

B. Hydrodynamic Coefficients: To determine hydrodynamic coefficients a Naval Architect package to be used to calculate both linear and non-linear hydrodynamic coefficients.

C. Objective: Study the dependency of HDCs on geometrical considerations.

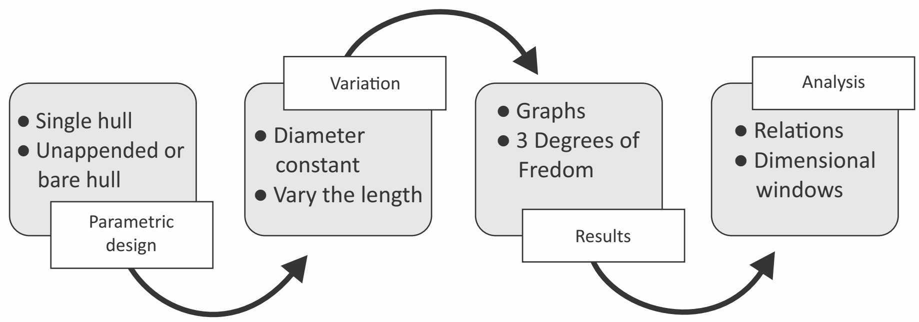

Fig 2. Structure of Study

III. Definition of Hydrodynamic Coefficients

The terms in the equations of motion which represent the hydrodynamic forces and moments acting on the vehicle are often expanded in a Taylor series about some convenient reference condition. For aircraft and surface ships this reference condition is usually taken to be the equilibrium condition of forward motion at constant speed. One approach to determining the hydrodynamic forces and moments on a manoeuvring submarine is to assume that at any point in time these forces and moments are functions of the motions (velocities and accelerations), propeller rpm, and appendage angles, at that point in time. This is a similar approach to that used for surface ships.

As with surface ships, the relationship between each motion variable and the resultant force or moment can be represented by a mathematical model comprising a series of coefficients. The resulting forces and moments due to each of these are then added to give the total force or moment on the submarine at that point in time. The choice of which coefficients, and hence which mathematical model, to use will depend on experience. It is normal for a single mathematical model to be used by a given organization to represent different submarines. Once the mathematical model representing the forces and moments has been selected, different submarines, or changes to the shape of a given submarine, can be represented by changing the values of the individual coefficients.

It is important to recognize that as different organizations may use different mathematical models it is not necessarily possible to compare the values of coefficients between different organizations. Also, as improvements in understanding are achieved, and the mathematical model updated, care needs to be taken to ensure that legacy coefficient sets are retained for past submarines.

For example, Surge Force

$$
\begin{aligned}
X = {} & \tfrac{1}{2}\rho L^4\left[X'_{qq}q^2 + X'_{rr}r^2 + X'_{rp}rp\right] + \\
& \tfrac{1}{2}\rho L^3\left[X'_{\dot{u}} + X'_{vr}vr + X'_{wq}wq\right] + \\
& \tfrac{1}{2}\rho L^2[X'_{uu}u^2 + X'_{vv}v^2 + X'_{ww}w^2 + \\
& X'_{\delta R\delta R}u^2\delta_R^2 + X'_{\delta S\delta S}u^2\delta_S^2 + X'_{\delta B\delta B}u^2\delta_B^2] + \\
& \tfrac{1}{2}\rho L^2[a_i u^2 + b_i u u_c + c_i u_c^2] - \\
& (W - B)\sin\theta + \tfrac{1}{2}\rho L^2\left[X'_{vv\eta}v^2 + \right. \\
& \left. X'_{ww\eta}w^2 + X'_{\delta R\delta R\eta}u^2\delta_R^2 + X'_{\delta S\delta S\eta}u^2\delta_S^2\right](\eta - \\
& 1)
\end{aligned}
$$

Notation, $X'_{\dot{u}} = \frac{\partial X}{\partial \dot{u}}$

IV. Results and Discussion

Using Maneuvering module of Paramarine, both linear and nonlinear hydrodynamic coefficients can be determined. In the current study, only HULL HDCs are calculated, ignoring propulsion and appendages relating HDCs. the length of the body is changed keeping the diameter constant. Set of hydrodynamic coefficients is collated for each model. Dimensional window of L/D is kept as 10-14. Length is varied from 55 m to 80 m. Diameter is constant at 7.8 m.

The following observations were made from the results:

a) Variations in nonlinear HDCs were only observed in Pitch and Yaw motions.

b) Variations were seen in linear HDCs for different length and diameter configuration.

c) By changing the diameter from 6.5 m to 9 m with a step of 0.5 m, another set of hydrodynamic coefficients is evaluated. The length is kept constant at 65 m. No appreciable changes in HDCs, in this case, were observed.

Table 1 HDCs for Yaw, N

Length(m)	55	60	63	70	75	80
N UU	0	0	0	0	0	0
N UV0	-16.157	-17.124	-17.719	-19.109	-20.097	-21.096
N UP	-0.57	-0.57	-0.57	-0.57	-0.57	-0.57
N UR0	-0.446	-0.425	-0.416	-0.398	-0.385	-0.376
N Vnu0	11.1	11.1	11.1	11.1	11.1	11.1
N Rnu	-2.57	-2.57	-2.57	-2.57	-2.57	-2.57
N Vdot	0.42	0.42	0.42	0.42	0.42	0.42
N Rdot	-0.615	-0.663	-0.692	-0.758	-0.804	-0.85

Table 2 HDCs for Pitch, M

Length(m)	55	60	63	70	75	80
M UU	0.1	0.1	0.1	0.1	0.1	0.1
M UV	0	0	0	0	0	0
M UW0	13.116	14.203	14.85	16.343	17.398	18.443
M VV	21.7	21.7	21.7	21.7	21.7	21.7
M VR	-11.2	-11.2	-11.2	-11.2	-11.2	-11.2
M PR	0.78	0.78	0.78	0.78	0.78	0.78
M Qnu	2.3	2.3	2.3	2.3	2.3	2.3

Table 3 Linear HDCs

Length(m)	55	60	63	70	75	80
Mw	13.116	14.203	15.279	16.343	17.398	18.443
Nv	-13.116	-14.203	-15.279	-16.343	-17.398	-18.443

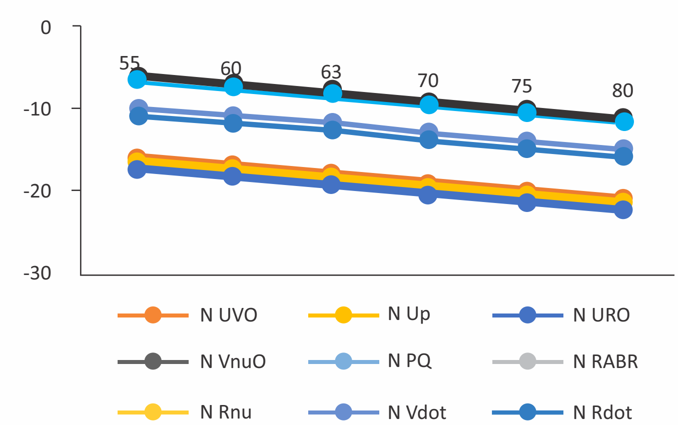

Fig 3. Variation of HDC for Yaw, N

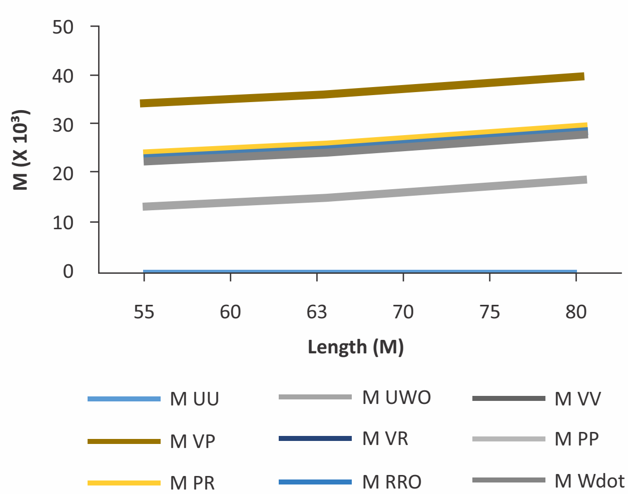

Fig 4. Variation of HDC for Pitch, M

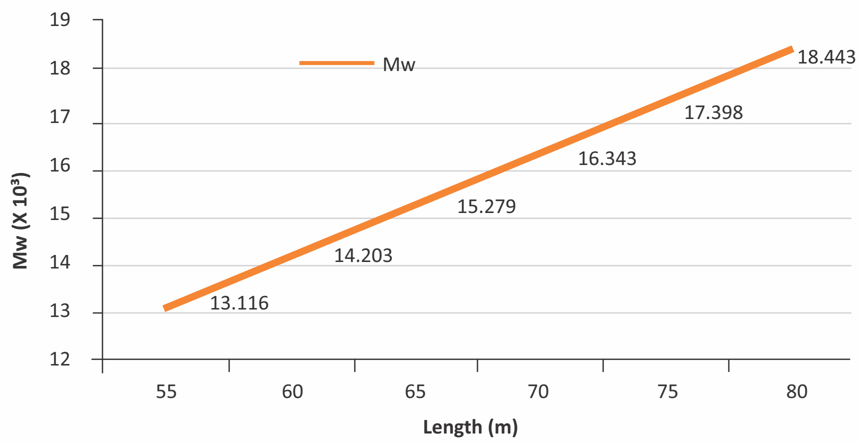

Fig 5. Variation of Linear HDC Mw

This equation shows the relationship between HDC M_w and L/D ratio:

$$M_w = \left[-\left(\frac{L}{D}\right) + 20\right] X\ 10^{-3}$$

Relation for Z_w

Similarly, a relation between Z_w and L/D ratio can be evaluated:

$$Z_w = \left[0.5\left(\frac{L}{D}\right) - 11\right] X\ 10^{-3}$$

Relation for N_v

$$N_v = -\left[-\left(\frac{L}{D}\right) + 20\right] X\ 10^{-3}$$

V. CONCLUSION

Hydrodynamic coefficients for axisymmetric underwater vehicle with different L/D ratio were estimated using a CAD tool. Estimates were found to be in coherence with experimental studies.

The current study shows that the linear hydrodynamic coefficients vary linearly with L/D ratio, while the nonlinear coefficients vary nonlinearly within the range of L/D ratio tested.

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DEPENDENCY OF HYDRODYNAMIC COEFFICIENTS ON GEOMETRICAL CONSIDERATIONS FOR AN AXISYMMETRIC SUBMERSIBLE BODY

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ABSTRACT

Controlling ship motions at sea has always been a challenge for the ship designers. His or her responsibility has been to ensure not only that the ship can safely ride out the roughest storms but should also be able to proceed on course under severe conditions with a minimum of delay and carry out specific missions successfully. The behavior of these vessels can be predicted by estimating their hydrodynamic coefficients. In this study the effect of variation of the vehicle length on the hydrodynamic forces and moments is presented. Geometry used in the study is DARPA SUBOFF body. The change in length is accomplished by making a parametric CAD model of an axisymmetric body. The study is confined to bare hull configuration of the vehicle. Hydrodynamic coefficients determined for the various configurations of axisymmetric body are the axial force, normal force and pitching moment coefficients.

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article

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STRUCTURAL SIMILITUDE AND SCALING OF PRESSURE VESSELS

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ABSTRACT

The study conducted involves the use of structural parameters to develop the similitude theory and is therefore called structural similitude of a thin walled pressure vessel. It gives relationship of prototype and its scaled models in such a way that when the scaled models' responses are multiplied by the scale factor, behaviour of the prototype for which it was developed is predicted.

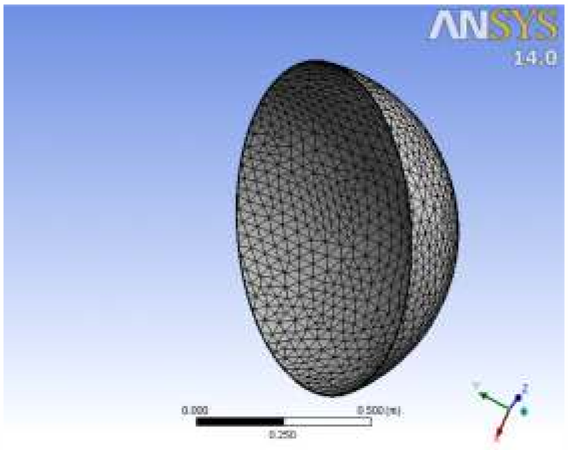
Governing equations and dimensional analysis (Buckingham pi-theorem technique) are two methods which have been used to find scale factors. Buckingham pi-theorem technique was employed for dimensional analysis after studying parameters on which pressure vessel is designed. Complete similarity between prototype and its scaled model exists when pi-products obtained from dimensional analysis are identical for both of them. Pi-products containing ratio of dimensions of pressure vessel can be validated for complete similarity. ANSYS software has been used to validate the pi-products concerning total deformation, equivalent elastic strain and equivalent (von-Mises) stress of externally pressurised thin walled un-stiffened sphere and thin walled un-stiffened cylindrical vessel with ends closed with circular plates. Scaled model results obtained from ANSYS analysis are multiplied by their scale factors (predicted model results) and then compared with the prototype results also obtained from ANSYS. Complete similarity is achieved when predicted prototype results completely map on to prototype results

1. Introduction

1.1 **Thin wall pressure vessels**: Thin wall pressure vessels are widely used in industry for storage and transportation of liquids and gases when configured as tanks. They also appear as components of aerospace and marine vehicles such as rocket and balloon skins and submarine hulls (although in the latter case the vessel is externally pressurized, violating one of the assumptions listed below). Two geometries which are of concern here are:

- Spherical pressure vessels
- Cylindrical pressure vessels

The walls of an ideal thin-wall pressure vessel act as a membrane (that is, they are unaffected by bending stresses over most of their extent).



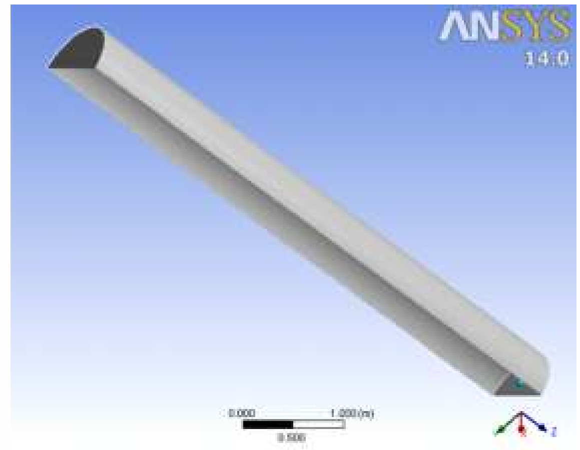


Fig 1: A section of thin wall sphere **Fig 2: A section of thin wall cylinder**

A sphere is the optimal geometry for a closed pressure vessel in the sense of being the most structurally efficient shape. A cylindrical vessel is somewhat less efficient for two reasons: (1) the wall stresses vary with direction, (2) closure by end caps can alter significantly the ideal membrane state, requiring additional local reinforcements. However the cylindrical shape may be more convenient to fabricate and transport. Further, more usable area for a given volume can be obtained from a cylindrical pressure vessel vis-à-vis spherical pressure vessel.

Assumptions:

The followings assumptions were made for carrying out the study:

1. Wall Thinness: The wall is assumed to be very thin compared to the other dimensions of the vessel. If the thickness is t and a characteristic dimension is R (for example, the radius of the cylinder or sphere) we assume that $t/R << 1$, or $R/t >> 1$, Usually $R/t > 10$. As a result, we may assume that the stresses are uniform across the wall.

2. Symmetries: In cylindrical vessels, the geometry and the loading are axi-symmetric. Consequently the stresses may be assumed to be independent of the angular coordinate of the cylindrical coordinate system. In spherical vessels, the geometry and the loading are spherically symmetric. Therefore the stresses may be assumed to be independent of the two angular coordinates of the spherical coordinate system and in fact are the same in all directions.

3. Uniform Internal Pressure. The internal pressure (P) is uniform and everywhere positive. If the vessel is also externally pressurized, for example subject to atmospheric pressure, P is defined by subtracting the external pressure from the internal one, a difference called gage pressure. If the external pressure is higher, as in the case of a submarine hull, the stress formulas should be applied with extreme caution because another failure mode: instability due to wall buckling may come into play.

4. Ignoring End Effects: Features that may invalidate the symmetry assumptions are ignored. This includes supports and cylinder end caps. The assumption is that disturbances of the basic stress

state are confined to local regions and may be ignored in basic design decision such as picking up the thickness away from such regions. The results obtained, are valid for regions away from the discontinuities.

1.2 Similitude Theory: A mathematical model of a system can be made using all the systems variables and parameters. For similar systems these parameters are similar but not identical. The theory of similitude searches for a relationship (transformation) which maps the models parameters onto the prototypes parameters. This means that each model parameter is proportional to its corresponding prototype parameter. This proportional factor is called the scale factor.

The two methods which are used to determine scale factors in this study are:

- governing equations
- dimensional analysis

Further, ANSYS software has been used to validate the scale factors which we obtained from the above mentioned methods.

2. Methods to determine scale factors

In order to find the scale factors, the following methods were used:

a. Direct use of governing equations

b. Dimensional analysis (Buckingham-pi theorem)

c. Use of FEM tool (ANSYS software)

2. 1. Governing equations

2.1.1 Governing equations for sphere:

Following are the deformation, strain and stress equations used for a sphere:

- *Deformation* = $[\frac{1-\vartheta}{E}].[\frac{Pr^2}{2t}]$
- *Strain* = $[\frac{1-\vartheta}{E}].[\frac{Pr}{2t}]$
- *Stress*= $[\frac{Pr}{2t}]$

Where, P = pressure applied (bar)

r = radius of sphere (m)

t = thickness of sphere (m)

E = young's modulus of material (MPa)

ϑ = poisson's ratio of material

Hoop stress and longitudinal stress for the case of sphere are same.

2.1.2 Governing equations for cylinder:

Following are the deformation, strain and stress equations used for a cylinder:

- Deformation = $[\frac{1-\vartheta}{E}].[\frac{Pr^2}{2t}]$
- Strain = $[\frac{1-\vartheta}{E}].[\frac{Pr}{2t}]$
- Hoop Stress= $[\frac{Pr}{t}]$
- Longitudinal Stress= $[\frac{Pr}{2t}]$

Where, P = pressure applied (bar)

r = radius of sphere (m)

t = thickness of sphere (m)

E = young's modulus of material (MPa)

ϑ = poisson's ratio of material

2.2 Dimensional analysis

2.2.1 Dimensional analysis for sphere:

1. $\prod_1 = P^a r^b t$

$= [FL^{-2}]^a [L]^b [L]$

$= F^a L^{-2a+b+1}$

$= P^0 r^{-1} t$

$\prod_1 = \frac{t}{r}$

4. $\prod_4 = P^a r^b \Delta r$

$= [FL^{-2}]^a [L]^b [L]$

$= F^a L^{-2a+b+1}$

$= P^0 r^{-1} \Delta r$

$\prod_4 = \frac{\Delta r}{r}$

2. $\prod_2 = P^a r^b \vartheta$

$$= [FL^{-2}]^a [L]^b [F^0 L^0]$$

$$= F^a L^{-2a+b}$$

$$= P^0 r^0 \vartheta$$

$$\prod_2 = \vartheta$$

3. $\prod_3 = P^a r^b E$

$$= [FL^{-2}]^a [L]^b [FL^{-2}]$$

$$= F^{a+1} L^{-2a+b-2}$$

$$= P^{-1} r^0 E$$

$$\prod_3 = \frac{E}{P}$$

5. $\prod_5 = P^a r^b \sigma$

$$= [FL^{-2}]^a [L]^b [FL^{-2}]$$

$$= F^{a+1} L^{-2a+b-2}$$

$$= P^{-1} r^0 \sigma$$

$$\prod_5 = \frac{\sigma}{P}$$

Dimension group	*Pressure group*
$\prod_1$	$\prod_3$
$\prod_2$	$\prod_5$
$\prod_4$	$\prod_6$

Where, σ = equivalent stress (Pa)

2.2.2 Dimensional analysis for cylinder:

1. $\prod_1 = P^a r^b t$

$$= [FL^{-2}]^a [L]^b [L]$$

$$= F^a L^{-2a+b+1}$$

$$= P^0 r^{-1} t$$

$$\prod_1 = \frac{t}{r}$$

4. $\prod_4 = P^a r^b \Delta r$

$$= [FL^{-2}]^a [L]^b [L]$$

$$= F^a L^{-2a+b+1}$$

$$= P^0 r^{-1} \Delta r$$

$$\prod_4 = \frac{\Delta r}{r}$$

2. $\prod_2 = P^a r^b \vartheta$

$= [FL^{-2}]^a [L]^b [F^0 L^0]$

$= F^a L^{-2a+b}$

$= P^0 r^0 \vartheta$

$\prod_2 = \vartheta$

3. $\prod_3 = P^a r^b E$

$= [FL^{-2}]^a [L]^b [FL^{-2}]$

$= F^{a+1} L^{-2a+b-2}$

$= P^{-1} r^0 E$

$\prod_3 = \frac{E}{P}$

5. $\prod_5 = P^a r^b \sigma$

$= [FL^{-2}]^a [L]^b [FL^{-2}]$

$= F^{a+1} L^{-2a+b-2}$

$= P^{-1} r^0 \sigma$

$\prod_5 = \frac{\sigma}{P}$

6. $\prod_4 = P^a r^b \Delta h$

$= [FL^{-2}]^a [L]^b [L]$

$= F^a L^{-2a+b+1}$

$= P^0 r^{-1} \Delta h$

$\prod_6 = \frac{\Delta h}{h}$

Dimension group	Pressure group
$\prod_1$	$\prod_3$
$\prod_2$	$\prod_5$
$\prod_4$	
$\prod_6$	

Where, σ = equivalent stress (Pa)

h = length of cylinder (m)

2.3 ANSYS software

2.3.1 ANSYS software for sphere:

ANSYS static structural was used to create a prototype and two 1/10th dimensionally scaled down models using the mechanical properties of grade 65 steel. Pressure was scaled down for one of the models. These models were solved to find out total deformation, equivalent elastic strain and equivalent (von-Mises) stress of externally pressurised thin walled un-stiffened sphere.

Dimensions and pressure values for prototype and models is given in the table (table 1) below:

Table 1: Dimensions and pressure values for spherical prototype and models

	Prototype	Model 1	Model 2
Radius(m)	5	0.5	0.5
Thickness(m)	0.05	0.005	0.005
Pressure(bar)	100	10	100

2.3.2 ANSYS software for cylinder:

ANSYS static structural was used to create a prototype and two 1/10th dimensionally scaled down models. Pressure was scaled down for one of the models. These models were solved to find out total deformation, equivalent elastic strain and equivalent (von-Mises) stress of externally pressurised thin walled un-stiffened cylinder.

Dimensions and pressure values for prototype and models which were modelled and analysed using ANSYS software are given in the table below:

Table 2: Dimensions and pressure values for cylindrical prototype and models

	Prototype	Model 1	Model 2
Radius(m)	5	0.5	0.5
Thickness(m)	0.05	0.005	0.005
Length(m)	60	6	6
Pressure(bar)	100	10	100

3. Results and conclusion

3.1. Results

3.1.1 Results for Sphere

3.1.1.1 Total deformation

The results for total deformation for externally pressurized thin wall sphere - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 3:

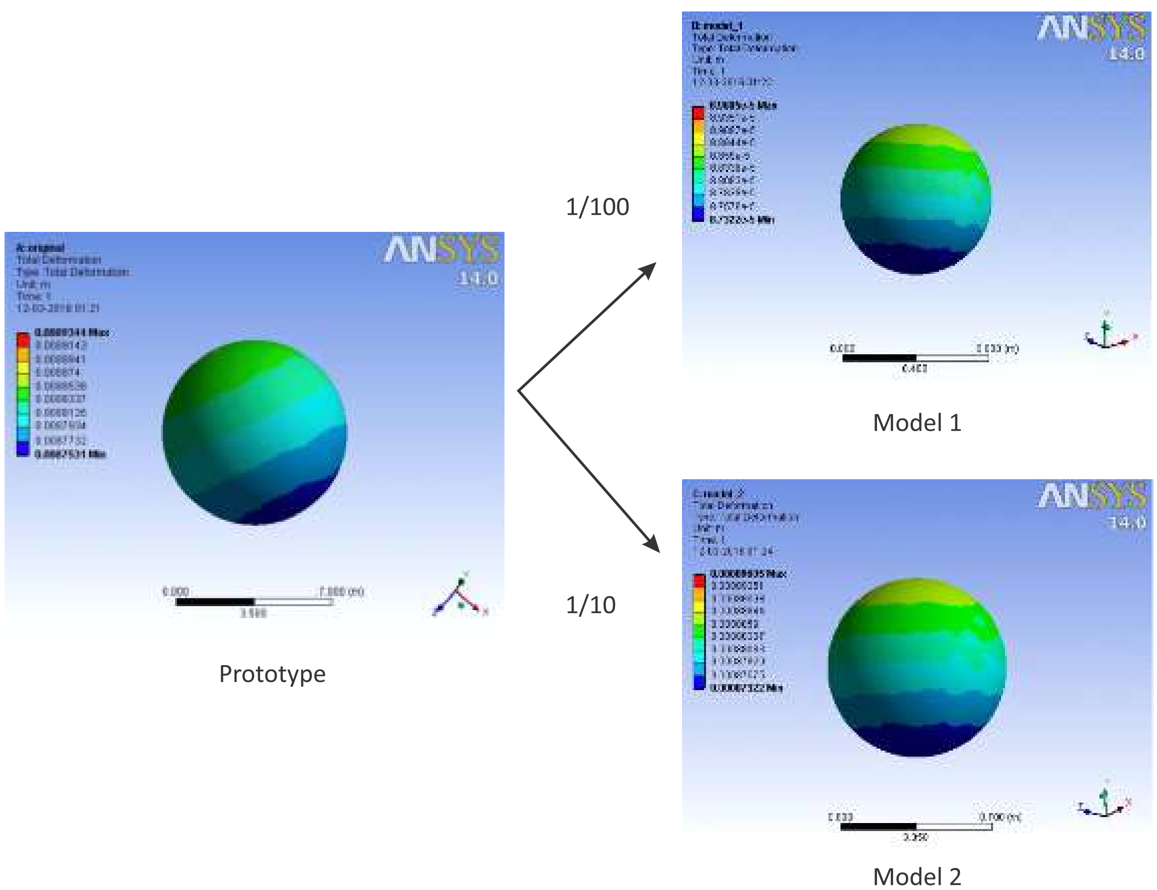


Fig 3: Total deformation in externally pressurized thin wall sphere – prototype and scaled down models

3.1.1.2 Equivalent elastic strain

The results for equivalent elastic strain for externally pressurized thin wall sphere - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 4:

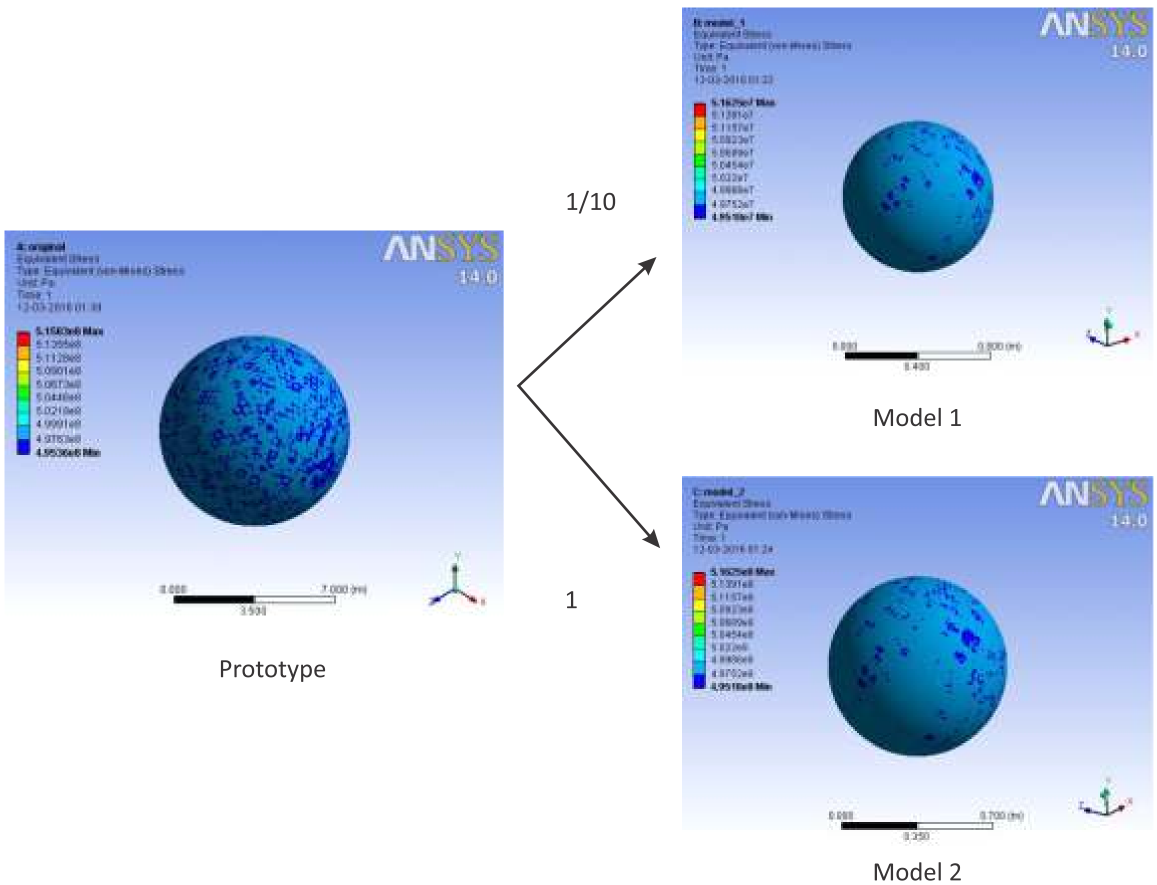


Fig 4: Equivalent strain in externally pressurized thin wall sphere – prototype and scaled down models

3.1.1.3 Equivalent (von-Mises) stress

The results for equivalent (von-Mises) stress for externally pressurized thin wall sphere - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 5:

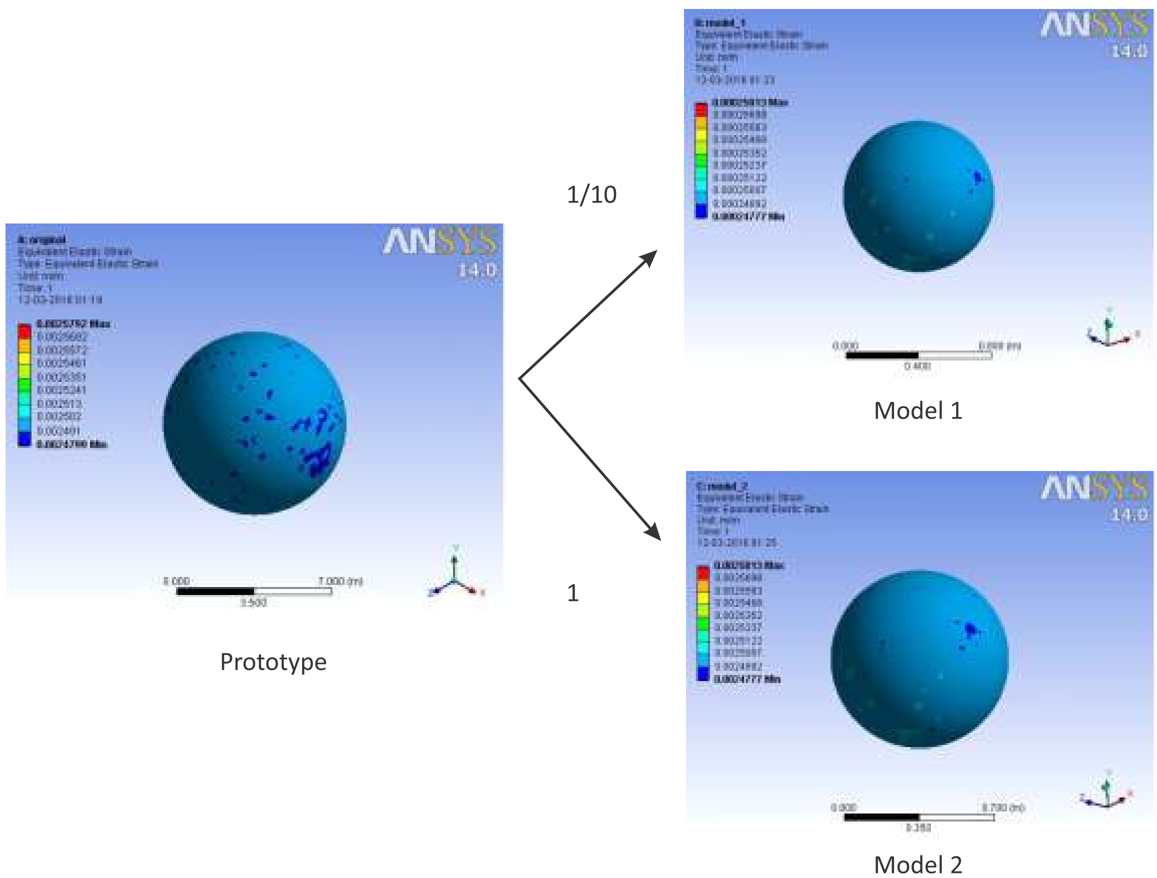


Fig 5: Equivalent (von-Mises) stress in externally pressurized thin wall sphere – prototype and scaled down models

3.1.2 Results for Cylinder

3.1.2.1 Total deformation

The results for total deformation for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 6:

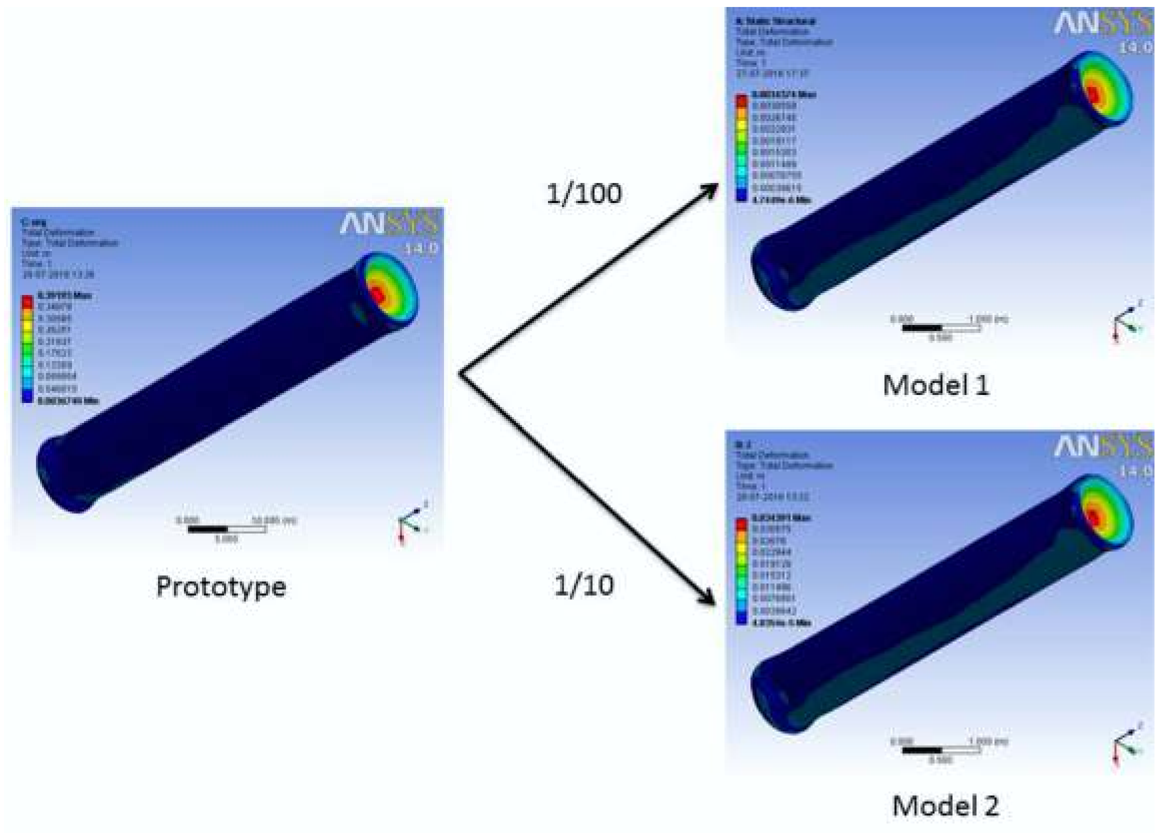


Fig 6: Total deformation in externally pressurized thin wall cylinder – prototype and scaled down models

i: Directional deformation in x-direction -The results for directional deformation in x-direction for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 7

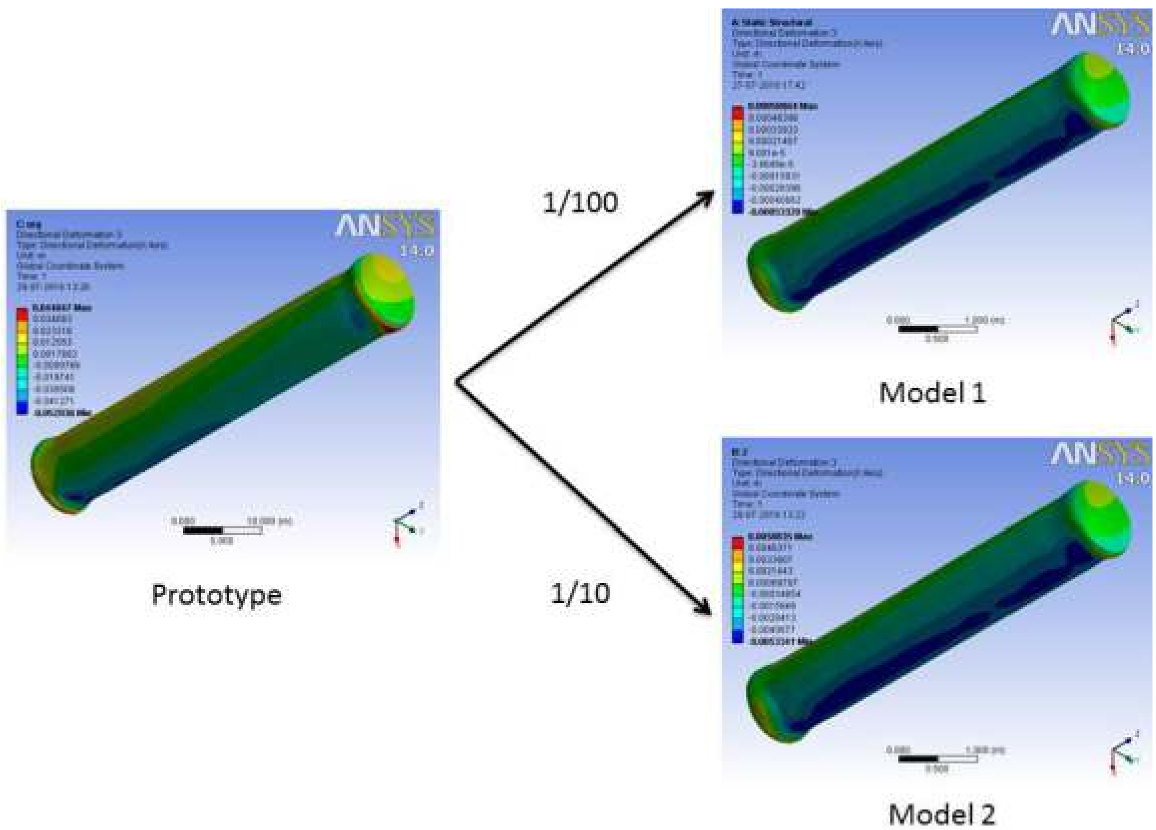


Fig 7: Directional deformation in x-direction in externally pressurized thin wall cylinder – prototype and scaled down models

ii: Directional deformation in y-direction -The result for directional deformation in y-direction for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 8:

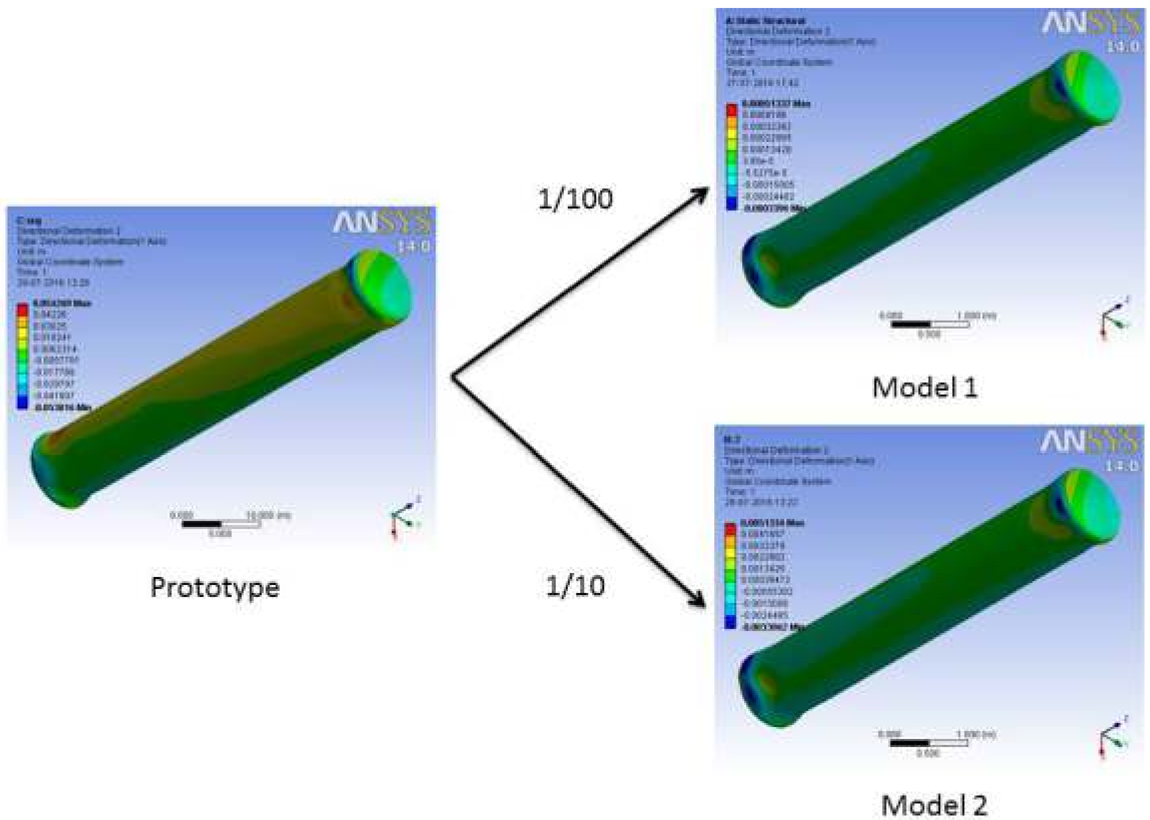


Fig 8: Directional deformation in y-direction in externally pressurized thin wall cylinder – prototype and scaled down models

iii: Directional deformation in z-direction -The result for directional deformation in z-direction for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 9:

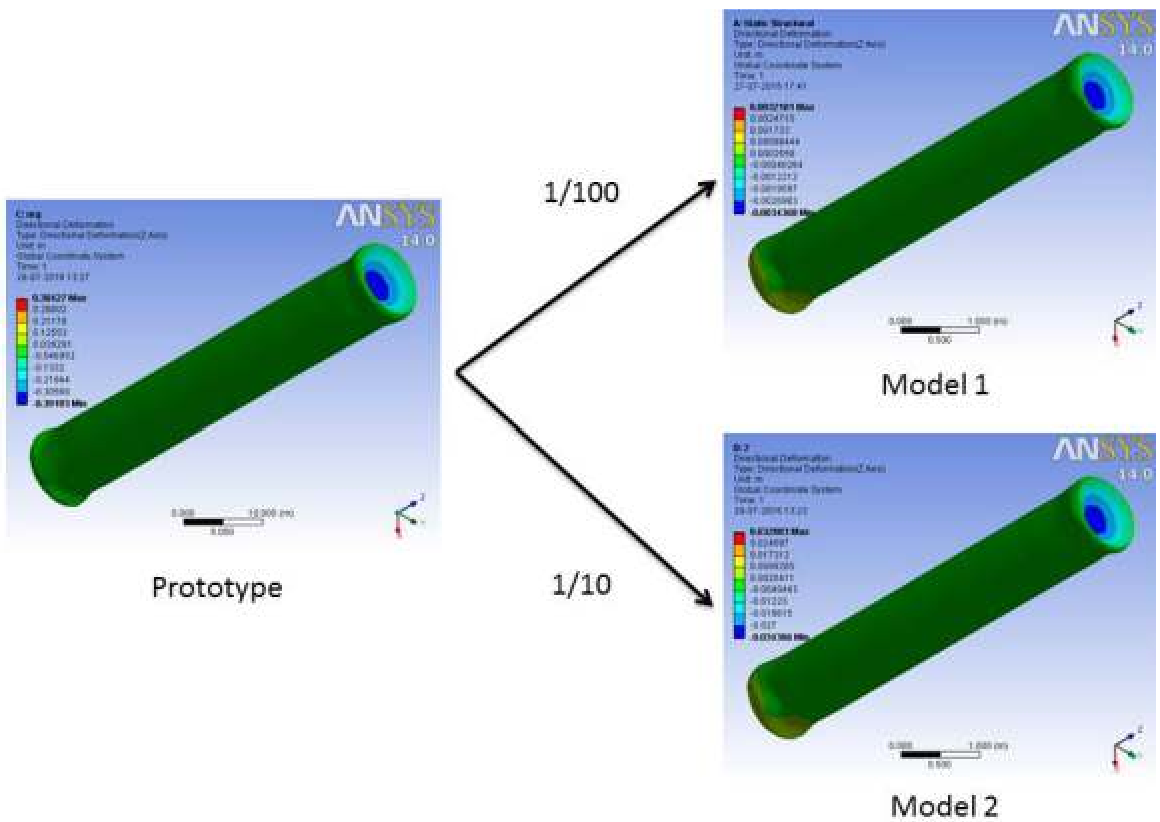


Fig 9: Directional deformation in z-direction in externally pressurized thin wall cylinder – prototype and scaled down models

3.1.2.2 Equivalent elastic strain

The results for equivalent elastic strain for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 10:

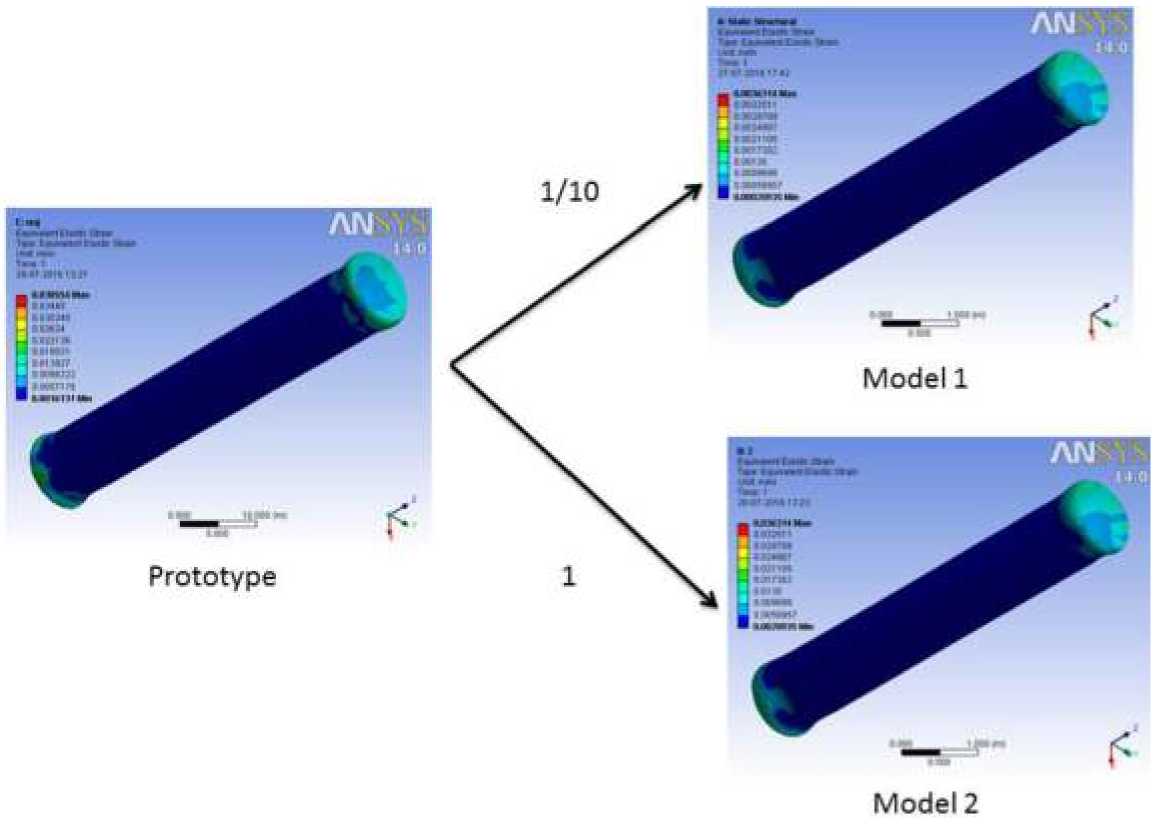


Fig 10: Equivalent strain in externally pressurized thin wall cylinder – prototype and scaled down models

3.1.2.3 Equivalent (von-Mises) stress

The results for equivalent (von-Mises) stress for externally pressurized thin wall cylinder - prototype and its scaled down models, obtained using ANSYS software are shown below in figure 11:

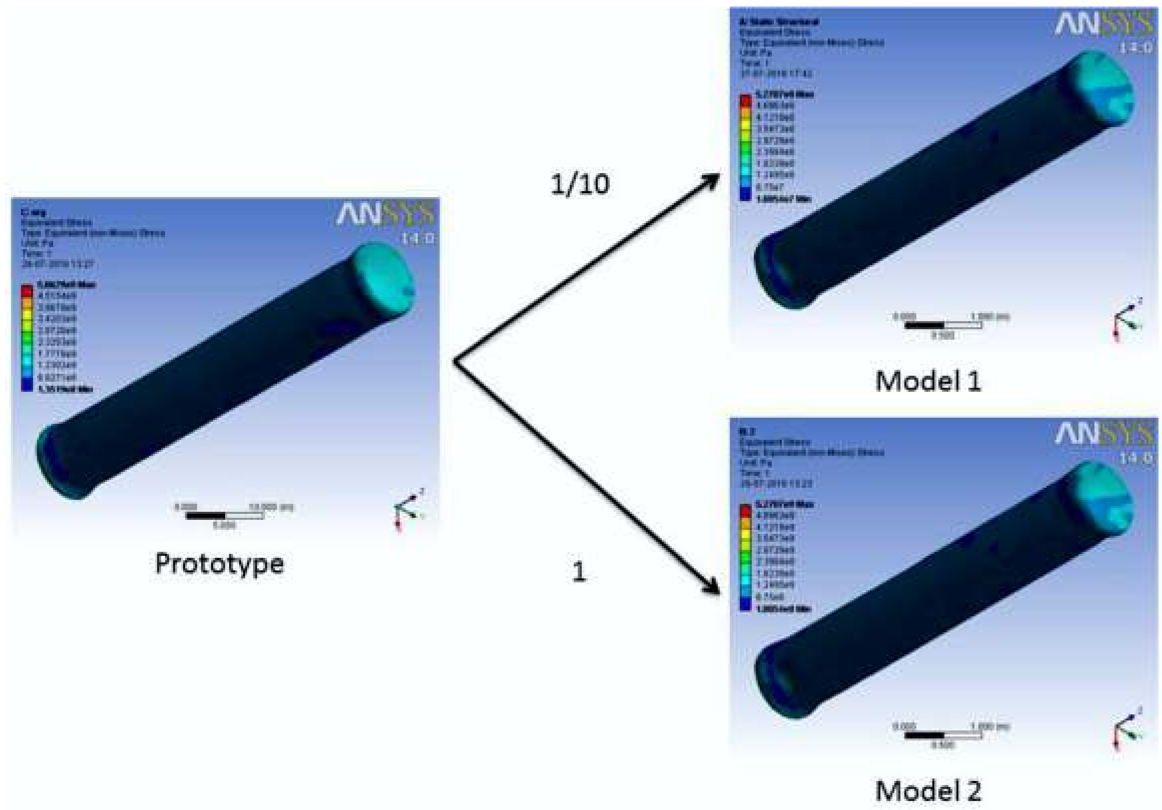


Fig 11: Equivalent (von-Mises) stress in externally pressurized thin wall cylinder – prototype and scaled down models

3.1.3 Tabulated result

3.1.3.1 Tabulated result for sphere

Table 3: Result for sphere

	Prototype		Model 1		Model 2	
Total deformation(m)	8.93e-3	8.75e-3	8.93e-5	8.75e-5	8.93e-4	8.75e-4
Equivalent Strain(m/m)	2.85e-3	2.48e-3	2.85e-4	2.48e-4	2.85e-3	2.48e-3
Equivalent Stress(Pa)	5.18e8	4.95e8	5.18e7	4.95e7	5.18e8	4.95e8

3.1.3.2 Tabulated result for cylinder

Table 4: Result for cylinder

	Prototype		Model 1		Model 2	
Total deformation(m)	3.91e-1	3.67e-3	3.43e-3	4.74e-6	3.43e-24.	74e-5
Deformation in x-dirn (m)	4.48e2	5.20e2	5.88e4	5.33e4	5.88e3	5.33e3
Deformation in y-dirn (m)	5.43e2	5.38e2	5.13e4	3.39e4	5.13e3	3.39e3
Deformation in z-dirn (m)	3.84e1	3.91e1	3.21e3	3.34e3	3.21e2	3.34e2
Equivalent Strain(m/m)	3.85e-2	1.16e-3	3.63e-3	2.09e-4	3.63e-2	2.09e-3
Equivalent Stress(Pa)	5.06e9	1.35e8	5.27e8	1.01e7	5.27e9	1.01e8

3.2 Conclusion

For both sphere and cylinder: deformation is dependent directly on P and r2/t and equivalent elastic strain and equivalent (von-Mises) stress are dependent directly on P and r/t. The scale factors which we obtained as a result of prototype and model analysis using ANSYS software validate the pi-product results and satisfy the governing equations. Hence, the scale factors determined using the established similitude theory, can be used to make a scaled model which accurately predicts prototype response.

Theory of similitude is a very useful tool as it predicts response without developing full scale models. It is very economical where large scale testing is required. It gives us rules that should be followed, if complete prototype results are to be predicted using a scaled model.

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STRUCTURAL SIMILITUDE AND SCALING OF PRESSURE VESSELS

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ABSTRACT

The study conducted involves the use of structural parameters to develop the similitude theory and is therefore called structural similitude of a thin walled pressure vessel. It gives relationship of prototype and its scaled models in such a way that when the scaled models' responses are multiplied by the scale factor, behaviour of the prototype for which it was developed is predicted.

Governing equations and dimensional analysis (Buckingham pi-theorem technique) are two methods which have been used to find scale factors. Buckingham pi-theorem technique was employed for dimensional analysis after studying parameters on which pressure vessel is designed. Complete similarity between prototype and its scaled model exists when pi-products obtained from dimensional analysis are identical for both of them. Pi-products containing ratio of dimensions of pressure vessel can be validated for complete similarity. ANSYS software has been used to validate the pi-products concerning total deformation, equivalent elastic strain and equivalent (von-Mises) stress of externally pressurised thin walled un-stiffened sphere and thin walled un-stiffened cylindrical vessel with ends closed with circular plates. Scaled model results obtained from ANSYS analysis are multiplied by their scale factors (predicted model results) and then compared with the prototype results also obtained from ANSYS. Complete similarity is achieved when predicted prototype results completely map on to prototype results.

Lt Harleen Kaur is a graduate of Metallurgical Engineering from the PEC University of Technology, Chandigarh. She is presently undergoing a PG Diploma course in Naval Construction Wing from Indian Institute of Technology, Delhi. Prior to this, the officer was working in Honda Cars India Ltd, R&D Division as a graduate engineer trainee for a period of nine months. Her fields of interest include – Pressure Vessel Design and Construction, Metallurgical Analysis and Corrosion Science.

article 17

PUMP LESS HYDRAULIC DESIGN FOR STEERING SYSTEM

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1. Introduction.

Submarines are considered one of the most potent war platforms available to date. The underwater platform moves in three dimensions in water i.e it has to steer in a two dimensional plane to maintain course as well as in vertical plane to maintain depth. The precise movement of the submarine is affected by use of control surfaces. These control surfaces need a considerable amount of power to move from one angle to another opposing the hydrodynamic forces that are generated on these planes. Hydraulic power has been used to provide the necessary force to these planes through certain mechanisms for a long time on all forms of marine vessels. However, when it comes to submarines, the design of hydraulic steering system adopts a different design philosophy as compared to surface ships. For example, space constraints and noise from running machinery are critical factors that differentiate the very design philosophy between surface and sub surface platforms. This paper aims to provide a overview of the existing form of steering gear systems being used in submarines and to bring out scope of improvements in the current design.

2. Conventional Hydraulic System

Figure 1 shows a hydraulic steering system consisting of a single rod double acting hydraulic cylinder which acts an actuator to turn the control surfaces. The piston of the cylinder is moved by hydraulic pressure supplied by a pump through a directional control valve. The directional control valve is remotely operated to change the direction of actuator movement based on control logic of the planes. However, in modern day steering systems, use of directional control valve for changing the direction of actuator is replaced by use of variable discharge pumps which are two way positive displacement pumps. These pumps have movable swash plates which can change the flow of fluid as well as the direction of actuator based on control logic. Further improvements in basic design have given way to use of double acting cylinders (fig 2). Double acting cylinders provide better load carrying capacity as compared to single acting cylinders due to use of two bearings for side load support. Also, it is easier to have same speed in extension as well as retraction speed due to equal area on both the cavities of the actuator cylinder.

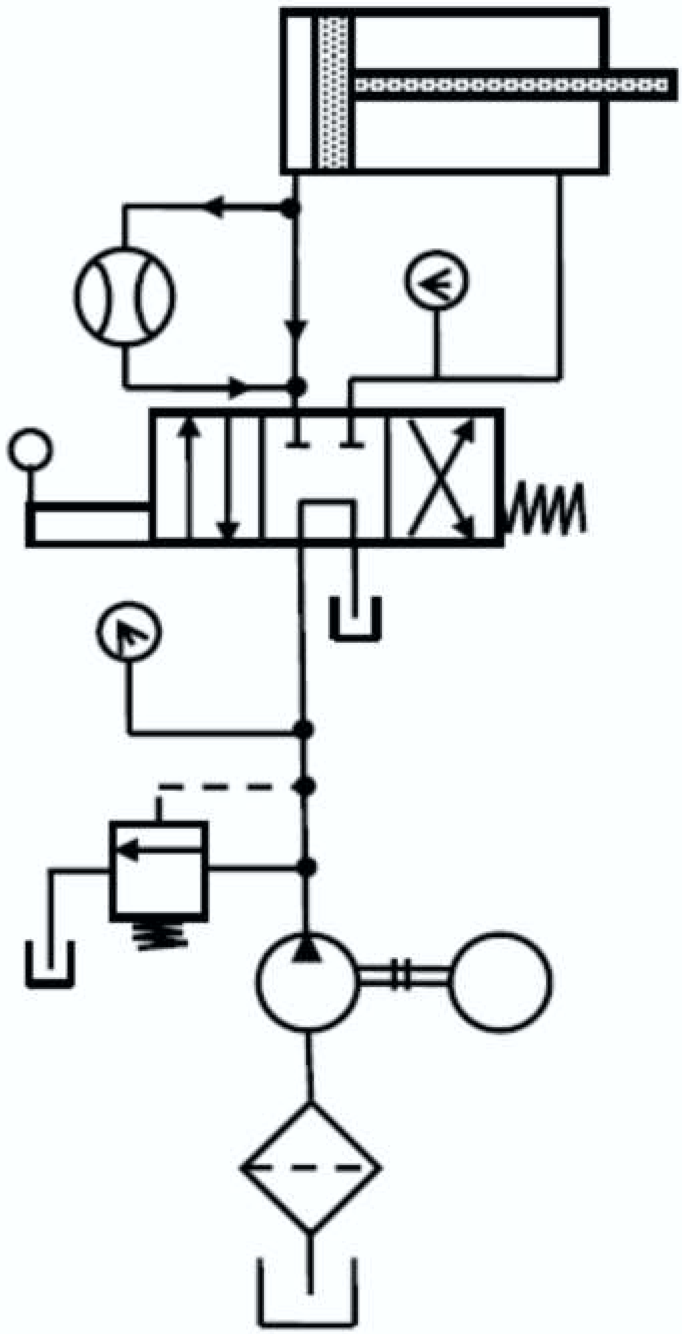

Figure 1. Conventional Hydraulic System with Pump

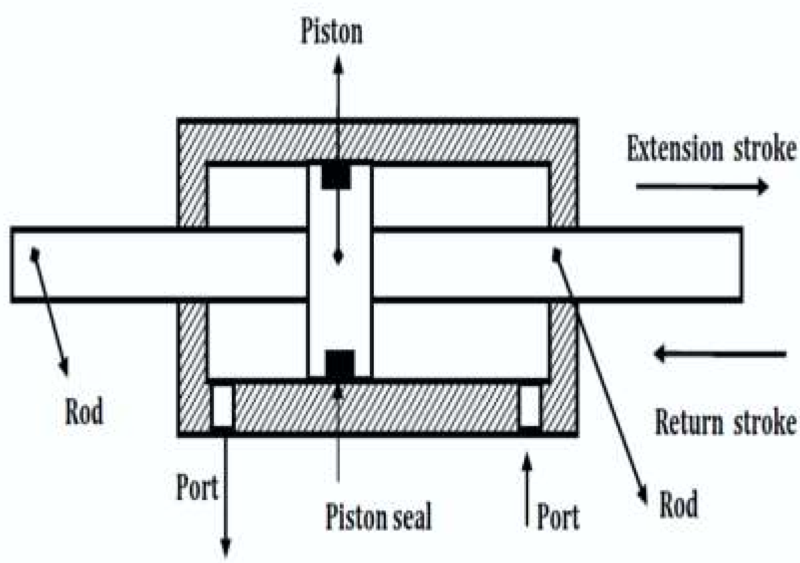

Figure 2. Double Acting Hydraulic Cylinder with two Rods

2.1 Problem Area

In spite of providing a very reliable steering system , the above mentioned arrangement suffers few shortcomings which are detrimental to operation of underwater platforms. Failure of power pack(Pump) is a critical scenario which can leave the submarine without any control on depth or direction. One way to counter this problem is to have redundancy in form of an additional Pump for such situations. However,, it is to be understood that unlike a surface ship, a submarine has little space for such design philosophies. So, a better idea would be to use another hydraulic system which may be existing in the boat for some other purpose in such emergencies. This idea necessarily indicates that Ship's General hydraulic system be used for steering in case of emergencies. The General Hydraulic system on under water platforms is normally a accumulator based hydraulic system in which stored hydraulic energy is used as a power source as and when required. This being a passive system (without any moving parts) is highly reliable. Therefore, a new improvised steering gear system is developed which uses variable discharge pump as main power source and a accumulator system for emergency power source.

2.2 Hydraulic Accumulator

A Hydraulic Accumulator is equipment that stores energy in form of pressurized hydraulic fluid. The hydraulic fluid in the accumulator is pressurized by various means such as spring, dead weight and high pressure air. Submarines use pressurized air for various other purposes and is available stored in numerous air cylinders carried on the platform. It is thus logical to use hydraulic accumulators which are pre charged with high pressure Air. A typical gas/Air charged accumulator is shown in figure 3. The pressure and volume design of accumulators is carried on the basis of system requirement. The pressure and volume variation of such a accumulator is not linear as shown in figure 4. The relation between pressure and volume is defined by universal gas law i.e PV^n = Const., Where n is the Polytropic exponent.

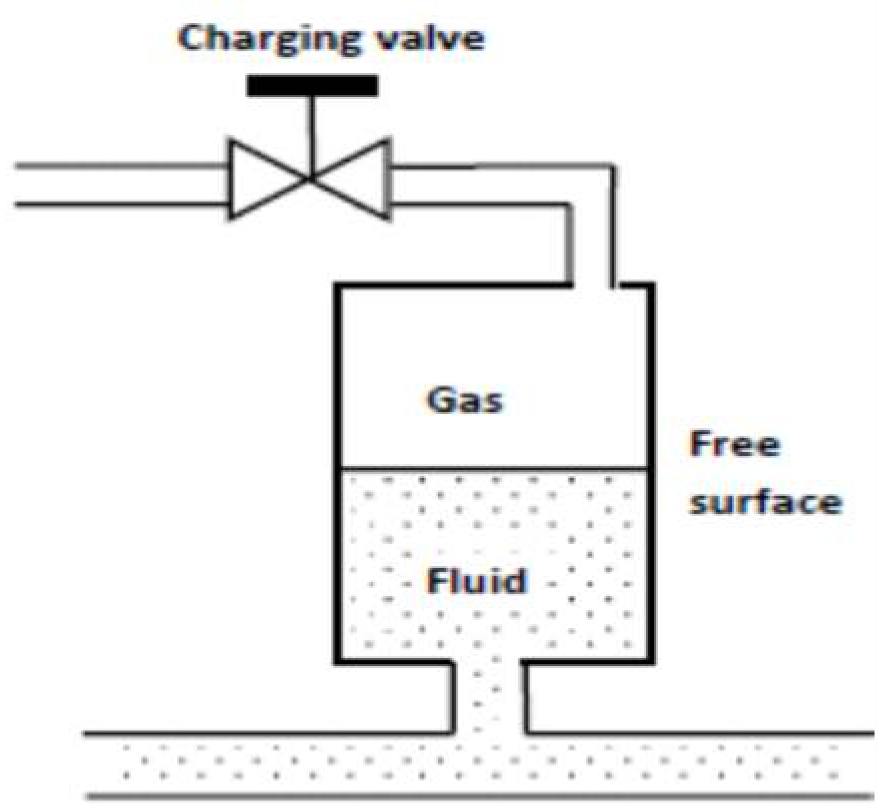

Figure 3. Gas Charged Accumulator

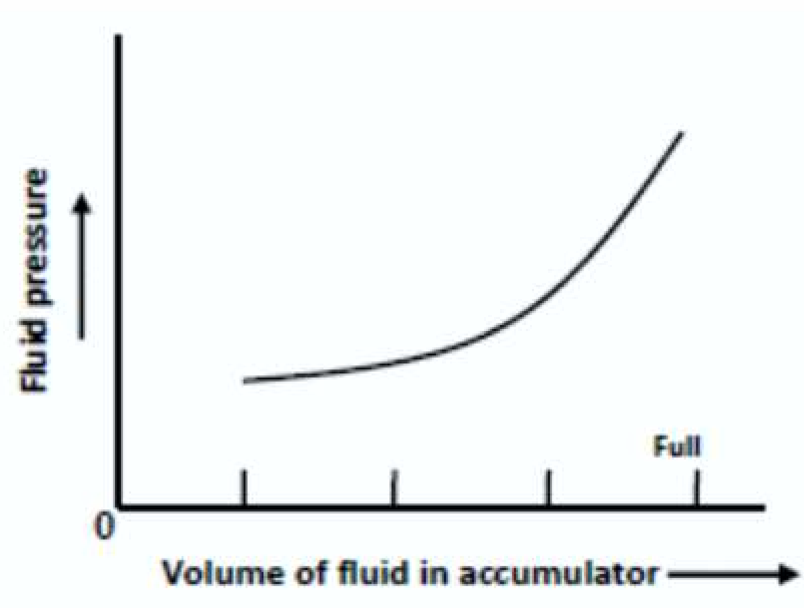

Figure 4. Pressure Volume relation in a Gas Charged Accumulator

3. Steering System with Accumulator as Emergency Power Source

3.1 **Description**. During normal operation this system works with the hydraulic pump supplying pressurized fluid to the actuators through directional control valve. The change in direction of the actuator is obtained either by using a Variable Discharge Pump or a remotely controlled Direction controlled Valve. In case of failure of Pump, hydraulic fluid is made available from the accumulator. This system ensures that hydraulic fluid is available even during failure of pump. However, this system also has certain disadvantages as discussed in succeeding paragraphs.

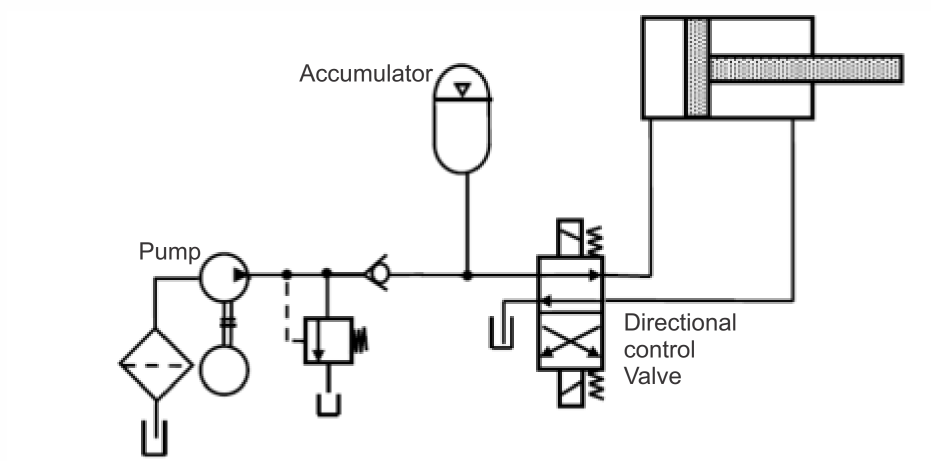

Figure 5. Hydraulic Steering System with Accumulator

3.2 **Problem AreaIn** case of emergency situations, the accumulator provides necessary pressurised fluid to the actuators. However, with every operation, working fluid is drained to tanks through the direction control valve. This will eventually drain the accumulator and also change the operating pressure of the system. If the accumulator has to be charged, then a separate pump needs to be installed and operated continuously in the system. Any increase in the size of the system is against the initial design approach of this paper where space conservation in submarine has been considered as one of the major factors of system design. Also, use of spool type DCVs results in continuous drainage of stored oil from accumulators even when the Steering system is not in use. In subsequent paragraphs a new design has been proposed which aims at minimizing oil transfer from the system to tanks thereby reducing or eliminating use of Hydraulic pump.

4. Proposed New Hydraulic System without Pumps.

4.1 To cater for oil transfer from the accumulator system to tank and subsequent need of using a pump, a modified hydraulic system as indicated in figure 5 has been proposed. The new design does not require continuous running of pump during operation of the system. The system consists of two Actuators and two Accumulators. Each actuator is having two chambers of different effective areas. For example, the Accumulator 1 has left chamber of volume 6 l whereas the right chamber has a volume of 4 L during one complete stroke length. Actuator 1 is used for extension of load and Actuator 2 is used for Retraction of load. Four Non Return Valves(NRVs) have been used in the system as indicated to minimize oil leakage through DCVs. There are two DCVs which connect the Accumulator to the Actuators on remote orders from control system. A third Accumulator has been installed to supplement oil into the system as and when required.

4.2 Functioning of the System.

4.2.1 Piston Movement to Left.To begin with let us assume that the pressure of Accumulator 1 and 2 are set at 100 and 65 bars respectively. Both Actuators are connected to the load which means if the load moves both the Actuators exhibit piston movement. Let us assume that the Piston of both the Accumulators is at the right extreme. A control system command actuates the left envelope of DCV 1 and right envelope of DCV 2 simultaneously. Oil from Accumulator 1 flows into the right chamber of Actuator 1. The Piston moves towards left, thereby moving the Load. Oil from left chamber is forced into Accumulator 2. Whilst the Piston of Actuator 1 is moving, the Actuator 2 Piston also moves towards left. As the piston of Actuator 2 moves left, the Oil in right chamber gets compressed and moves into the left chamber through bypass of DCV 2. It is to be noted that the volume of right chamber is 4 L. So this 4 L oil moves to left chamber whose capacity is 6 L. At this moment additional 2 L oil is filled in the left chamber of Actuator 2 from reserve Accumulator 3. At the end of piston movement from left to right, the pressure in Accumulator 1 and 2 are 69 and 84 bars respectively.

4.2.2 Piston Movement to Right.Control system actuates Left envelope of DCV 2 and right envelope of DCV 1. Accumulator 2 discharges 4 L of oil into the left chamber of Actuator 2 causing Piston movement to right. Pressure in Accumulator 1 drops to initial value of 65 Bar. As the piston moves right, 6 L oil from right chamber moves into Accumulator 1 resulting in pressure rise to initial value of 100 Bar. Simultaneously, piston of Actautor 1 also moves right. Oil from left chamber moves into right chamber through bypass of DCV 1. The left chamber takes in only 4 L of oil , balance 02 L oil moves to a reserve tank. With this one complete cycle of piston movement is affected. Accumulator 1 and 2 attain the initial pressure of 100 and 65 bar respectively. Two liters of Oil is fed into the system form reserve Accumulator and a same volume is discharged to Oil tank. It can be seen that this Hydraulic system requires 02 Liters of Oil charge per cycle of piston movement whilst a conventional system would have required 10 Liters of Oil charge per cycle. This greatly minimizes use of Pump for hydraulic system operation. A pump is however installed to independently charge the reserve Accumulator.

4.2.3.For a similar functioning, a conventional Accumulator based Hydraulic system would consume 10 L of hydraulic oil per cycle of Piston operation. One cycle of Piston operation includes movement of piston from left to right and back to left extreme. When the piston moves from left to right, 4 L of oil will get exhausted to tank while 6 L of oil will be returned to tank as the piston moves from right to left. Whereas, the new system will return only 2 L of oil per cycle of piston operation which is five times less than that of a conventional system.

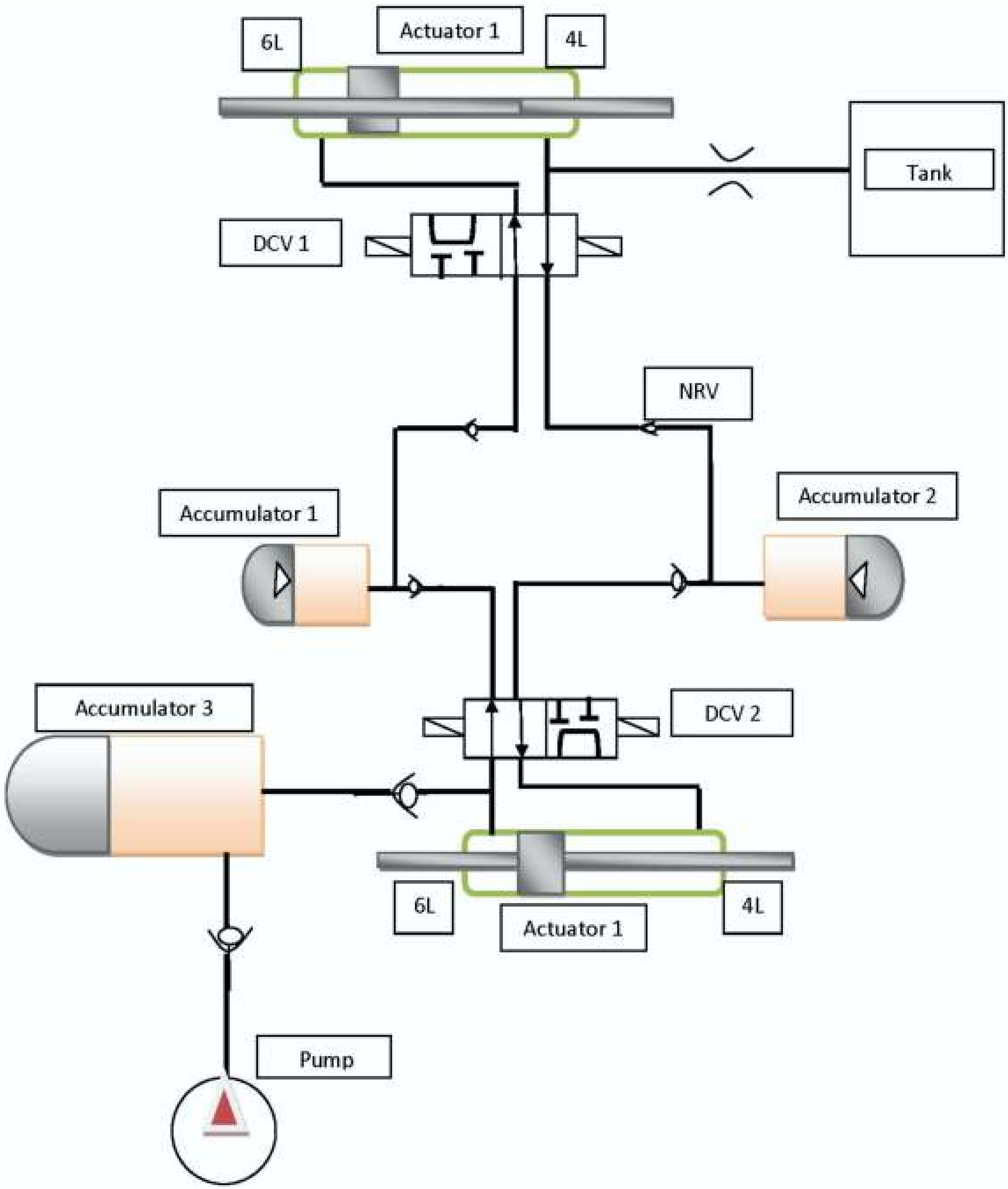

Figure 6. Proposed Hydraulic System without Pump

5.Conclusion.

General Hydraulic System for Steering a Submarine was reviewed in this paper. The limitations and scope for improvement were brought out. An improved Hydraulic system without use of any Hydraulic Pump was proposed to replace the conventional pump operated hydraulic system. The advantages of the proposed system are as indicated below.

(a) A pump less system necessarily means a quiet system which is one of the critical design criteria for under water Platforms.

(b) Use of Accumulators increases the reliability of the system as this is a passive system which works on stored energy in form of pressurized Air.

(c) Hydraulic system with Accumulators have inherent ability to dampen flow related vibrations and minimize ill effects of water hammering effect.

(d) Elimination of large pumps save a lot of space on the Platform.

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ABSTRACT

Hydroplanes are used to steer Submarines to maintain set course and also to maintain depth or a combination of both. These Hydroplanes are subjected to hydrodynamic forces as a Submarine moves in water. Hydroplanes generate opposing forces to that of hydrodynamic forces thus providing necessary moment to maintain course or depth. Traditionally, the motive power for movement of these hydroplanes is obtained from pressurised hydraulic fluids through a set of mechanisms. These mechanisms include Hydraulic Pumps, Rods, Turning Mechanisms etc which occupy space and generate considerable noise. Space conservation and noise reduction are important factors in submarine design. Progressive design improvements in Hydraulic Steering Systems have aimed in minimising both space requirement and noise reduction. This resulted in use of Hydro Pnumatic Accumulators as power source thus reducing the number of large Hydraulic Pumps which generated much of the noise emanated from steering systems. However, conventional Accumulator based Hydraulic Steering System have certain inherent limitations. Pressurised oil from Accumulators is utilised in Hydraulic Cylinders to generate necessary forces and are then exhausted into a drain tank. For a continuously operating system such as steering system, continuous replacement of this oil would be required. This in turn will require a hydraulic Pump that operates continuously as a part of steering system. Thus, a conventional Accumulator based hydraulic system will only reduce the number of Pumps in the system.

This paper aims at proposing a hydraulic system with two Accumulators which operate so that oil from one Accumulator is fed back to another and vise -versa thus reducing the volume of oil exhausted from the system by 80 %. This system will help conserve space and reduce noise due to elimination of continuously operating Pump from the system. Also, the reliability of the system increases as Accumulators are passive devices which work on stored energy in form of pressurised air.

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article 18

DESIGN, FABRICATION AND ANALYSIS OF COMPOSITE DRIVE SHAFT FOR FUTURE UNDERWATER APPLICATION

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Abstract

A Drive Shaft, also known as propeller shaft is a mechanical part, that transmits the Torque generated by engine to propel the vehicle. When concerned to the underwater vehicles, the composite shaft reduces the weight and manufacturing cost. Further, being inherently corrosion resistance the composites are ideally suited for marine application. The physical appearance of the drive shaft resembles like a cylindrical structure of specified diameter. In this project, a scaled down composite drive shaft is considered for lab testing. The concept is validated with Bicycle shaft results. However, the same material can be used to manufacture the shafts for Ships and submarines. The Specimen is made by replacing the existing conventional steel drive shaft with suitable composite materials like E-Glass/Epoxy having high stiffness and high strength to weight ratio in addition of filler materials like 'CO' & General purpose resin, the composite drive shaft is fabricated manually by hand wrapping method. In this paper, an attempt has been made to investigate the characteristics of both conventional and composite drive shaft both theoretically and experimentally. The final results are then compared with each other and the results have marked with optimal characteristics for composite shaft than that of conventional shaft under equal load conditions. The Static and Dynamic analysis was carried out theoretically by using ANSYS Software.

I. INTRODUCTION

The present work aims to design and fabricate a drive shaft made of composite material which could replace the conventionally available steel shaft. The composite drive shaft produced is made to undergo mechanical tests and is analyzed under static and dynamic load conditions with ANSYS tool. The entire work can be divided in to the following steps: (1) Design of conventional and composite drive shaft, (2) Methodology for preparation of test specimen, (3) Experimental analysis of Specimen (4) Finite element analysis of Specimens and (5) Validation of FE results with Experimental results. The material properties are estimated for the e-glass/epoxy composite cloth fibre. The geometric model is modeled in ANSYS platform based on the dimensions of existing shaft. Then the model is fabricated. The aim of this work is to design and fabricate a composite drive shaft which can replace the existing steel drive shaft. A shaft-driven bicycle is a bicycle that uses a drive shaft instead of a chain to transmit power from the pedals to the wheel arrangement.

Functions of the Drive Shaft

- It must transmit torque.
- During the operation, it is necessary to transmit maximum low-gear torque.
- The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle.
- The drive shaft must provide a smooth, uninterrupted flow of power.

II. LITERATURE REVIEW

Shaft drives were introduced over a century ago, but were mostly supplanted by chain-driven bicycles due to the gear ranges. The first shaft drives for cycles appear to have been in United States and England. The Drive shafts are carriers of torque; they are subject to torsion and shear stress, which represents the difference between the input force and the load. They thus need to be strong enough to bear the stress. Most automobiles today use rigid driveshaft to deliver power from a transmission to the wheels. A pair of short driveshaft is commonly used to send power from a central differential, transmission to the wheels. Recently, due to advancements in internal gear technology, a small number of modern shaft-driven bicycles have been introduced and the study is being carried to manufacture the composite shafts on larger vehicles.

III. DESIGN SPECIFICATIONS

The following specifications were assumed suitably, based on the literature and available standards of bicycle drive-shafts:

- Torque transmission capacity of the driveshaft (T) = 900 N-m.
- Minimum bending natural frequency of the shaft ($f_{nb(min)}$) = 50 Hz.
- Outside radius of the driveshaft (r_o)=6mm,length of shaft=295mm.

IV. DESIGN OF CONVENTIONAL STEEL DRIVE-SHAFT

A. Torsional strength

Since the primary load on a driveshaft is torsion, the maximum shear stress (τ_{max}) at the outer radius (r_o) of the shaft is given by:

$$\frac{\tau_{max}}{F.S} = \frac{32Tr_o}{\pi[d_o^4 - d_i^4]}$$

Assuming Tmax =90MPa and a factor of safety (F.S)=3,we get (τ_{max}) =15600MPa.

B. Bending Natural Frequency

According to Bernoulli-Euler beam theory, by neglecting shear deformation and rotational inertia effects, the bending natural frequency of a rotating shaft is given by:

$$f_{nb} = \frac{\pi p^2}{2L^2}\sqrt{\frac{EI_x}{m}}$$

$$m = \rho\left(\frac{\pi}{4}\right)[d_o^2 - d_i^2]$$

'p' is density of EN8 Steel=7800kg/m3

'E' for EN8 steel=290GPa

m=0.88kg/m

$$I_x = \frac{\pi}{64}[d_o^4 - d_i^4]$$

$$= 1.01 \times 10{-}9 \text{ m4}$$

Upon Substitution,

$$f_{nb} = 55.3hz$$

V. DESIGN OF CONVENTIONAL STEEL DRIVE-SHAFT

A. Torsional Strength

Since the nature of loading is pure shear, 70% of the plies can be set at ±45° and the remaining 30% at 0º and 90º orientations.

$$\frac{\tau_{max}}{F.S} = \frac{T}{2\pi r^2 t}$$

Assuming Tmax =210 MPa,and a factor of safety (F.S)=6,we get

τ_{max}=176.6MPa

B. Bending Natural Frequency

$$f_{nb} = \frac{\pi}{2L^2}\sqrt{\frac{EI_x}{m}}$$

'p' is density of e-glass/epoxy=1900kg/m3

'E' for e-glass/epoxy cloth =38700MPa

m=0.25kg/m

Upon Substitution, $f_{nb} = 45.5hz$

VI. METHODOLOGY FOR TEST SPECIMEN PREPARATION

Mild steel threaded rod of specification M8 has been considered. A mixture of general purpose resin with an accelerator which serves as a sticky glue is prepared. Small quantity of hardener like 'CO' is added to the mould. The mixture now serves as a perfect binding agent with the thorough mixture of the above chemical agents. The e-glass epoxy composite cloth is split into long pieces uniformly.

The threaded rod is fixed in the bench-vice and the prepared mixed resin is applied uniformly over the entire length of the rod by changing its position.

The splitted pieces of composite cloth are now wrapped along its entire length so as to assure perfect bonding between the threaded rod and cloth. After wrapping, the resin mixture is again applied onto the cloth which serves a fine layer. Similarly, the whole procedure is repeated with 12 layers of composite cloth with cloth fibre orientation angles as 0o , 90o, +45o, -45o each of three layers so as to produce a uniform solid cylindrical composite rod of 12mm diameter with 295mm length. The thickness of composite cloth fibre is about 0.31mm.

VII. TORSION TEST

A. Composite Drive Shaft

Fig. 1. Minimum Torque output- 42kgm

Fig. 1. Minimum Torque output- 148kgm

B. Conventional Steel Shaft

Fig. 3. Minimum Torque output-22kgm

Fig. 4. Minimum Torque output-85kgm

VIII. SHEAR TEST

Fig. 5. Applied Load 30kN

Fig. 6. Composite Specimen after failure

Fig. 7. Steel Specimen after failure

IX. MODELLING

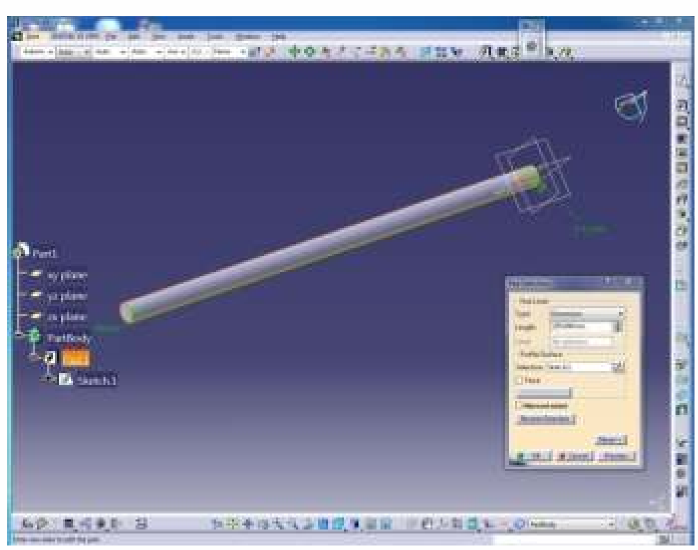


Fig. 8. Catia Model of Specimen

X. FEA ANALYSIS

A. Torsion analysis of composite specimen

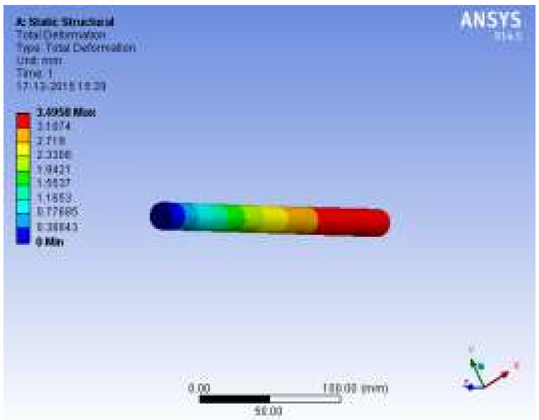


Fig. 9. Model Deformation

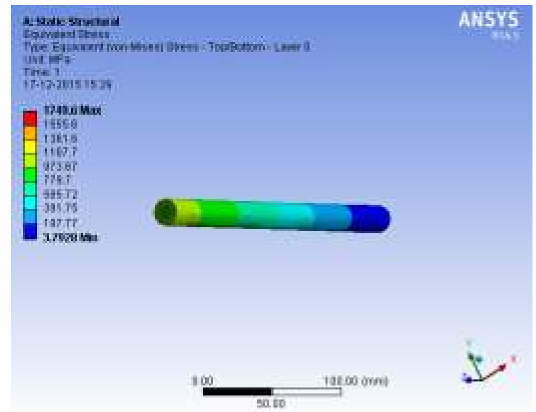


Fig. 10. Von-misses stress

B. Shear analysis of composite specimen

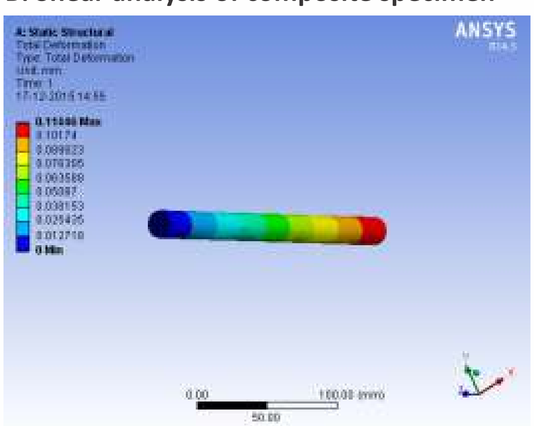


Fig. 11. Maximum Deflection

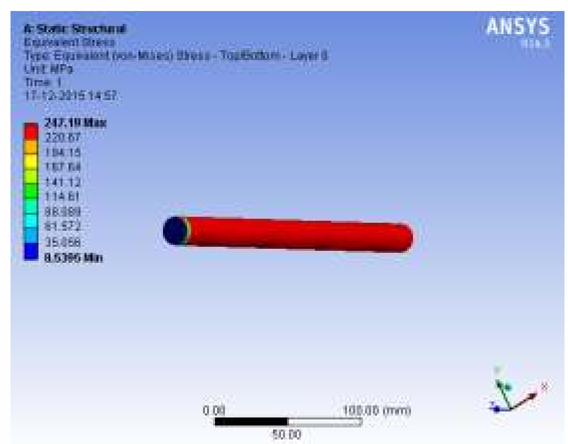


Fig. 12. Von mises Stress

C. Torsional analysis of steel specimen

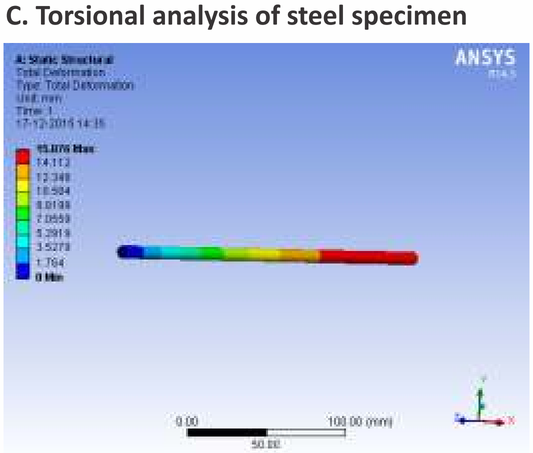


Fig. 13. Maximum Deflection

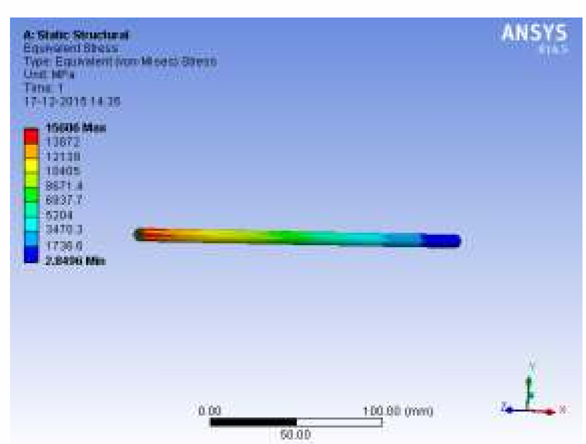


Fig. 14. Von mises Stress

D. Shear analysis of steel specimen

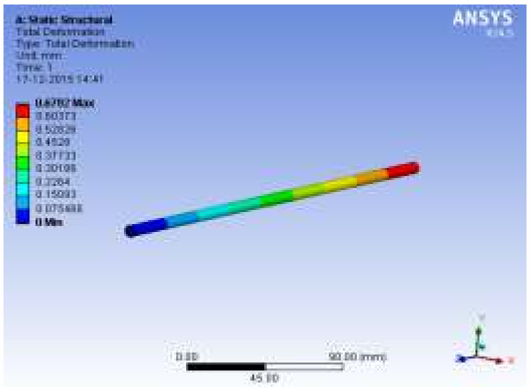


Fig. 15. Maximum Deflection

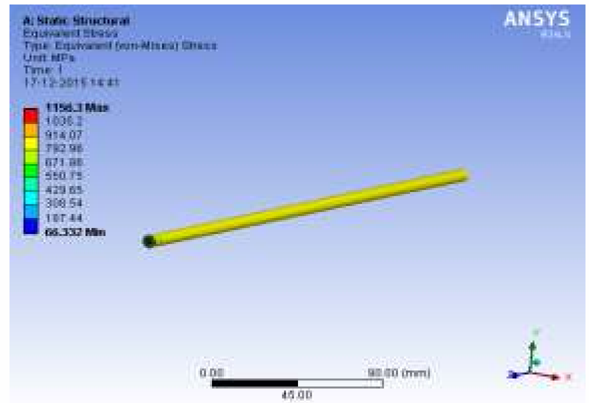


Fig. 16. Von mises Stress

E. Dynamic analysis of composite specimen

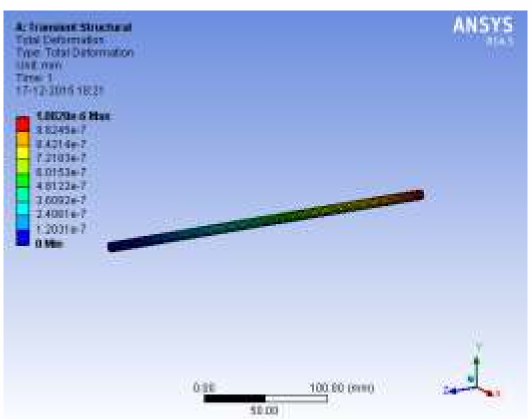


Fig. 17. Maximum Deflection

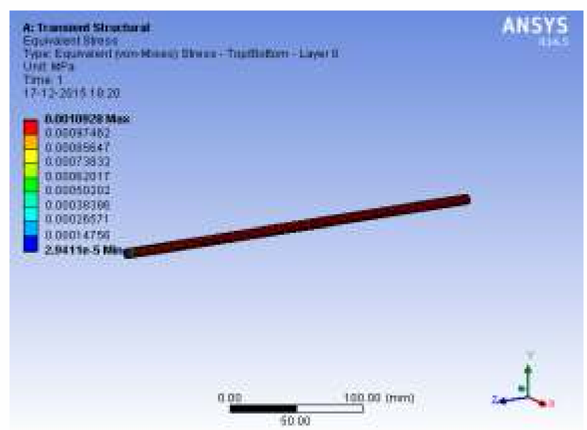


Fig. 18. Equivalent Von-mises Stress

F. Dynamic analysis of steel specimen

For Dynamic analysis a rotational speed of 800-1200 rpm is applied and analyzed for deformation and stresses.

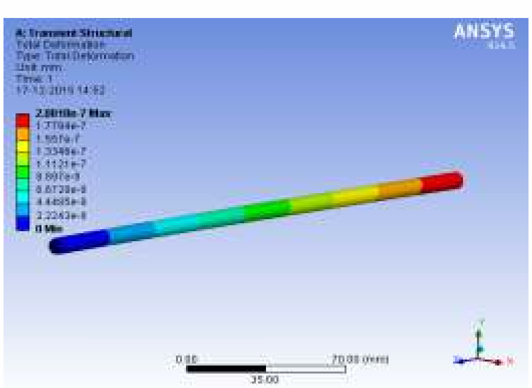


Fig. 19. Maximum Deflection

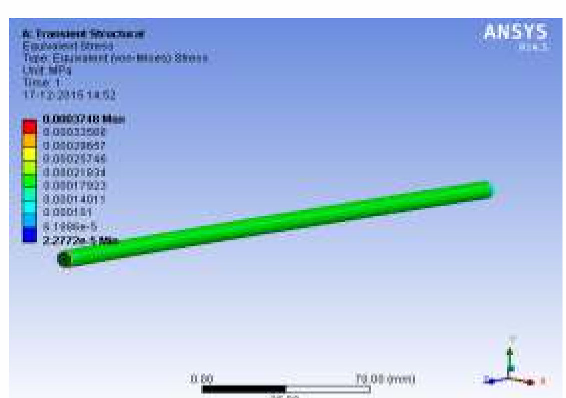
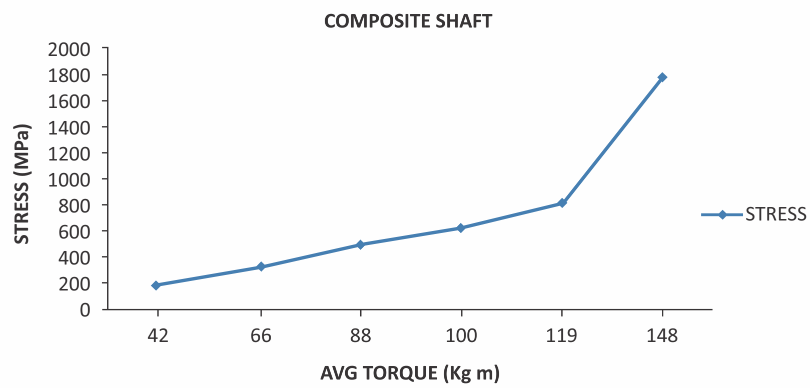
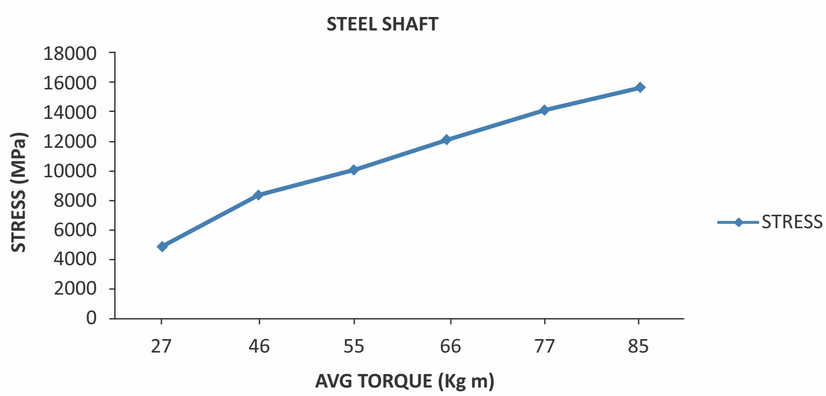


Fig. 20. Equivalent Von-mises Stress

XI. COMPARISION OF RESULTS





GRAPH 1: TORQUE (VS) STRESS

TABLE I. SHEAR TEST RESULTS

Material	Load(kN)		Results	
		Deformation(mm)	Shear Strain	Shear Stress (MPa)
Composite	30	0.1145	0.001527	111.73
Steel	40	0.6792	0.008528	661.09

TABLE II. DYNAMIC TEST RESULTS

Material	Results		
	Deformation(mm)	Shear Strain	Shear Stress (MPa)
Composite	1.0828e-9	6.2497e-9	0.0010928
Steel	2.0 e-7	1.87e-9	0.0003748

XII. CONCLUSION

Composite shaft made from E-Glass/ Epoxy cloth fibre is fabricated and experimentation is done by taking torsion and shear load. For numerical study, the test specimens are modeled using CATIA software and analyzed with FEA. After applying boundary conditions and torque, the torsional deflections are obtained for each torque value. List of the results are plotted. In conclusion, when the Finite Element results are compared with the theoretical results, the observations carried out were successful and yield very small variations from the expected results. From the results, it's clear that the composite rod performs much better than conventional steel rod under torsion loads. The composite also performs almost equally to that of steel shafts. The composite also performs almost equally to that of steel shafts. Properties such as high strength, low weight, corrosion resistance make composite material advantageous over conventional steel for marine applications.

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article
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DESIGN OF NEXT GENERATION ELECTRIC DRIVE SUBMARINES

Captain Arvind Ranganathan (GM Project Varsha)

1. Indian Navy's next-generation submarine should have an **Electric Drive** and advanced **Prime Mover** that would allow it to patrol the seas with near-silence for decades. The **Electric Drive** would replace the existing direct Mechanical connection between the turbines and the Submarine's Propellers. In the new configuration, the Power Source will run Electric motors that propel the Submarine. Electric Drives would prove to be much quieter than the current Direct-Drive method.

2. The Indian Navy has Operated Electric Drives in the 1990s, but found them to be too slow and maintenance needy. Technological advancements over the past few decades provide Electric Propulsion with required hassle-free speeds. Since Submarines rely on Stealth to hide from enemies, a nearly silent engine would make them harder to find.

ABSTRACT

3. Several International Navies are developing or using Electric Drives1 in Naval Ships. The **Electric-drive** development effort centers on the Integrated Power System (IPS) Program. Several Public/Private-sector firms like L&T, BHEL, Siemens etc are now pursuing **Electric Drives** by taking advantage of the strong Power, Technological and Industrial base available in India. Electric Drive offers significant anticipated benefits for Navy Ships & Submarines in terms of reducing Life-cycle cost, increasing stealth, Payload, Survivability, Power available for non-propulsion uses. Potential disadvantages include higher near term costs, increased technical risk, increased system complexity, and less efficiency in full-power operations.

4. Certain risk involved in developing electric-drive technology have been mitigated by the successful development of electric-drive technology for commercial ships. To date developing common electric-drive components is feasible for several kinds of Ships and Submarines and that pursuing electric drive technology in the form of **a common family** of components could have advantages for the Navy.

5. The potential savings associated with a common system are difficult to estimate, but could be substantial. The concept of developing a common system or family of components poses issues for policymakers concerning the extent of commonality across electric-drive-equipped Navy Ships & Submarines and the use of competition in the development and procurement of electric-drive technology.

Long Term Advantages

6. Electric drive is often discussed as a specific system that could be available in the near future program, many elements of electric-drive technology have the potential to evolve and improve

over time. This suggests that policymakers might consider addressing electric drive as not simply a proposal for a specific system that might require a few nearer-term acquisition decisions, but as a broader technology area that might require longer-term management and oversight and a series of research, development, and procurement decisions stretching over the course of several years. If conducting longer-term management and oversight of electric drive is considered appropriate, it might be assisted by developing an electric-drive technology development Road Map or Master Plan extending perhaps 10 to 25 years into the future.

7. The Indian Navy's interest in electric-drive technology is consistent with the decisions of other navies in recent years to move to electric-drive technology for their own ships. The strong interest in electric drive by other navies (particularly the British Navy& US Navy) suggests that electric drive offers a variety of War fighting and Life-Cycle Cost advantages for Naval Ships& Submarines. The interest shown by other navies in electric drive, however, also demonstrates that there are multiple technical approaches to electric drive that should be assessed.

8. Incorporating electric-drive technology into Navy Submarine acquisition programs could add technical or schedule risk to those programs. The potential amount of risk varies, depending on the exact configuration of the system in question. More advanced approaches to electric drive present greater potential technical or schedule risk, but also promise greater potential cost effectiveness. Electric-drive components presenting potential technical or schedule risk include motor drives, motors, generators, electrical distribution system, advanced propeller/stern configurations and overall system design and integration.

9. Issues, Indian Navy needs to address include demonstrating full scale IPS technologies, that to date have been demonstrated at partial scale, improving thermal performance, achieving desired levels of acoustic quieting and shock resistance and designing overall system interfaces, controls, and module specifications. Some of the risks involved in developing electric-drive technology have been mitigated by the successful development of electric-drive technology for commercial ships. Commonality is not an end in itself but rather would be a Strategy for policy makers to consider in seeking the most cost effective path to apply electric-drive technology across the fleet. Pursuing a common electric-drive system or family of components could in theory lead to the emergence of a dominant or monopoly supplier to the Navy of electric-drive technology, components, and systems.

10. One possible approach would be to require the common electric-drive system to be designed to a so-called open architecture. Another possible approach would be to provide continuing funding to firms other than those who supply the current electric drive system to finance continued development of potential competing technologies or components. The issue is highly charged because specific motor types are associated with specific firms competing for a part of the Navy's prospective electric-drive program. The electric motors associated with electric drive systems for large Ships & Submarines could be divided into five basic categories- Synchronous motors, Induction motors, Permanent Magnet (PM) motors, Superconducting Synchronous motors, and Superconducting Homo Polar motors.

11. The Synchronous motor can be considered the most mature technologically in application to large ships. There is a consensus among both naval and industry sources that the synchronous motor, if scaled up to the higher horsepower ratings needed to move surface combatants and Submarines at high speeds (i.e., 30+ knots), would be too large and heavy to be suitable for use on these ships. The induction motor is generally considered the second-most mature motor type for application to large ships, after the synchronous motor. It is the type of motor that could be used in the Navy's full-scale, land-based electric-drive systems.

12. By the same token, however, most sources argue that the induction motor is not sufficiently compact or quiet to be suitable for use on Navy Submarines. Using an electric-drive system with an induction motor(rather than the currently less mature PM motor) might help mitigate the risk of integrating electric-drive technology into the future program, but would preclude achieving motor commonality across surface ships and submarines.

13. The PM motor can be made quieter and significantly more power dense than the induction motor, enough so that it is consequently considered suitable for use on submarines as well as Surface combatants2. The PM motor can be used in a common electric drive system for Navy surface ships and submarines. We should focus on the PM motor as the motor available in the nearer term that would be suitable for a common electric-drive system. Sources differ regarding the amount of technical risk involved in scaling up the PM motor to full size. The Superconducting Synchronous motor, if successfully developed, could be more power-dense and quieter than a PM motor. The Superconducting Synchronous motor is less mature technologically than the PM motor. The term Homo polar (i.e., unipolar) refers to the fact that this motor uses Direct Current (rather than Alternating Current) electricity and does not require either a reversal of current or electrical commutation. As a result, the magnetic field and the electrical current in the armature of a homo polar motor are constant over time and space (i.e. Unvarying). The superconducting Homo polar motor, if successfully developed, could similarly be more power-dense and quieter than a PM motor. Homo polar motor, like the Superconducting Synchronous motor, is less mature technologically than the PM motor.

Electric Drive vs. Mechanical Drive.

14. In a Submarine/Ship with a Mechanical-drive system, the power-producing capability of the Propulsion engines typically represents 75 percent to 85 percent of the total power-producing capability2. This power-producing capability is devoted exclusively to Submarine propulsion and is not available for non-propulsion uses, even when the submarine/ship is stationary or traveling at low speed. Submarines/Ships with an electric-drive system, in contrast, can be designed so that a single set of engines produces a common pool of electricity that is used for both Propulsion and the non-propulsion electrical loads. Such a system is known as an Integrated Electric-Drive (IED) system or IPS. With an IED even when the Submarine/Ship is traveling at high speed, power can be momentarily diverted away from the propulsion system to a non-propulsion system that needs a short burst of high strength power without appreciably slowing the Submarine.

15. Life Cycle Cost. Submarines with IED/IPS would have reduced Life-Cycle Cost. Future Submarines would use Podded Propulsor (PP). The pod, which contains the electric motor driving the propeller, can be designed to swivel in a circle so as to direct the propeller's thrust in any direction and thereby steer the Submarine. A PP eliminates the need at the stern for a lengthy, exposed horizontal shaft leading to the propeller and a rudder for steering. With a PP, there are fewer exposed components to create drag, and the propeller encounters a more uniform (i.e., less disturbed) water flow, increasing its efficiency (i.e., its ability to use its RPMs to create thrust). Using PP could improve a Submarine's maneuverability by permitting a tighter turning radius and by giving it the ability to change the direction of movement or its orientation even at very low speeds. A PP might also offer certain advantages in terms of maintenance and repair, since the pod can be over the life of the Submarine, the savings from reduced fuel consumption promise to significantly outweigh the potential increase in initial procurement cost associated with electric drive, thus significantly reducing the Submarine/ship's total life-cycle cost, also known as Total Ownership Cost (TOC).

16. The Indian Navy is now placing increased emphasis on Life-Cycle Cost in the acquisition process so as to more effectively capture the long-term cost consequences of its acquisition decisions. In addition to savings on fuel, it is anticipated that electric-drive systems may require less maintenance and fewer crew members to operate than mechanical-drive systems. Electric-drive systems can be designed to be highly automated and self monitoring. Reductions in maintenance and crew size would further reduce Ship Life Cycle Cost.

17. Increased Stealth. Electric drive promises to be significantly quieter acoustically than mechanical drive. Since acoustic noise is an important component of a Submarine/Ship's overall detectability, Submarine's equipped with electric drive are designed to be less detectable (i.e., more stealthy) than equipped with mechanical-drive technology. Potential revised propeller/stern arrangement with rotating PP and no rudder motor compared to conventional propeller/stern arrangement with horizontal shaft, strut, propeller and rudder.

18. Alternatively, if fuel storage capacity is held constant, electric drive can permit an increase in Submarine/Ship operating endurance (range). The significantly improved quieting promised by electric drive may be the single most important benefit of electric drive to the Navy's Submarine community. Stealthiness is fundamental to a Submarine's survivability and effectiveness and acoustic noise remains the most reliable method by which submarines can be detected and tracked at longer ranges. The Navy has expended significant resources over the last few decades on making its submarines increasingly quiet (so as to stay ahead of increasingly capable adversary submarine-detection equipment). Electric drive would provide the next significant improvement in acoustic quieting on Submarines. New propeller/stern configurations made possible by electric drive might reduce the wake signature of Submarines/Surface ships, which could reduce their detectability by remote overhead sensors and improve their chances of defeating much-feared wake homing torpedoes.

19. Increased Payload. Electric Drives would permit the Turbines to be located higher in the Submarines, reducing the amount of interior space required for the ducts that are needed to take air down into the engines and to carry exhaust gases away .Electric drive would free up space aboard the Submarine/Ship that can be used to carry additional payload (e.g., Weapons

&Sensors). Freed-up space can also be used for other purposes, such as increasing the size of staterooms for members of the ship's crew so as to improve their quality of life aboard ship, which has recently emerged as Indian Navy's priority.

20. Increased Survivability. Electric-drive can improve Submarine/Ship survivability in several ways. Eliminating mechanical drive's tyranny of the shaft line can improve ship survivability by eliminating the possibility that one or more of the Submarine's long shaft lines will be thrown out of alignment and rendered useless by a nearby weapon explosion.

21. Electric drive in the future could also facilitate the replacement of today's Prime Movers (e.g., Steam turbines or Diesel engines or Gas turbines) and Generators with more efficient power-producing technologies, including direct energy-conversion devices such as Fuel cells. It is possible to place them in locations where they may be better protected from attack by certain weapons (e.g., mines). Electric drive makes it possible to more widely distribute elements of the propulsion system around the ship, making it less likely that a single weapon might disable the entire drive system. With an IPS, the flow of power from distributed power sources can be rapidly reconfigured in the event of damage to the ship to ensure a continued supply of electricity to vital systems. This could be a very significant benefit, during battle damage to naval ships .In addition, electric drive permits smaller propulsion machinery spaces, which could facilitate better damage control and permit greater use of automated damage-control technologies.

22. Increased Power Available for Non-Propulsion Systems. As mentioned earlier, electric drive makes large amounts of power available for non-propulsion uses such as powerful Radar, Sonar, laser Weapons, High-Power Microwave weapons, Electro Magnetic rail guns, Electro Thermal guns or rapidly charging the Batteries of Unmanned Air Vehicles (UAVs), Unmanned Underwater Vehicles (UUVs), and High-energy undersea sensor networks. Some of these functions, particularly the weapons, may require Peak power levels measured in tens of megawatts and adding this much electrical-generating capacity to a mechanical drive ship would incur substantial additional costs.

23. Indian Navy's current Mechanical-drive systems, particularly reduction gears that have been specially engineered for quiet operations, are generally not found in commercial applications, limiting economies of scale in their production and support. In, contrast, electric-drive propulsion will benefit from increasing production and support economies of scale, and will also be able to take advantage of rapid technological advances in the large and vibrant commercial electrical-power and electronics industries.

24. Disadvantages. Electric drive has potential disadvantages in terms of higher near-term costs, increased program risk, increased system complexity, and less efficiency in full-power operations or schedule risk to those programs, since electric-drive technology is less mature than mechanical-drive technology for application to naval ships. However as seen from above the potential advantages of Electric Drive propulsion significantly, outweigh the few disadvantages.

CONCLUSION

25. The next generation Submarines for Indian Navy with Electric Drive Propulsion Systems would have significant advantages over the Mechanical Drive Propulsion System. Electric-Drive technology offers benefits for design of future submarines in terms of reducing Ship Life-Cycle Cost, increasing Stealth, Payload, Survivability and Power available for Non-Propulsion uses.

26. Even though, Electric-Drive Submarine Systems would initially be more expensive to procure than Mechanical-Drive systems, the procurement cost of Electric-Drive systems would come down over time, and the higher initial costs of Electric-Drive systems would be more than offset over the longer run by reduced Submarine/Ship Life-Cycle operating and support costs.

27. The Cost-effectiveness of Electric Drive for future Submarines should be examined not by focusing on the Electric Drive System or any of its components in isolation, but holistically by examining the effect that Electric Drive has on overall Submarine Cost and Capability. With availability of advanced Electric Drive Technology and Industry in India waiting to Develop technologically advanced Ships/Submarines, this opportunity to design next generation Submarines with Electric Drive Propulsion should be best utilised by Indian Navy.

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2. The officer has written and published over 18 Technical papers in National/International Journals. The paper does not contain any classified information.

article 20

FEASIBILITY OF USING LITHIUM TITANATE BATTERIES FOR EXPLOITATION ON BOARD CONVENTIONAL SUBMARINES AND RAPID CHARGING WITH MARINE GAS TURBINE GENERATOR

Cdr RS Ramesh (51501-Y) *Cdr Ramesh Kumar Lakra (51502-Z)*

Synopsis

The lead acid batteries have been traditionally used on board conventional submarines and the usage of lithium ion batteries has been limited due to heavy discharge limitations, Thermal runaway and fire hazard. The advances in lithium based battery chemistries have resulted in a number of high performance compositions. Amongst them, Lithium titanate batteries have been found to be safer with rapid charging and discharging capabilities which are particularly suitable for submarine applications. The paper attempts to bring out the features of a commercially available battery, performance comparison with the existing batteries, the tactical and technical advantages accrued, practical implementation and how wide spread use of this technology aligns with the nation's energy security. The paper also attempts to study the use of a marine gas turbine generator to take advantage of the rapid charging capabilities of the battery thereby considerably lowering the indiscretion rate. Combined use of these technologies would provide such a submarine a considerable edge over its conventional counter parts and better survivability in a hostile scenario.

1. Introduction

The type 877 EKM Russian, Type 209 German submarines currently forms the backbone of Indian Navy Submarine Arm. The New Scorpene submarines are also being inducted in a phased manner. All these platforms rely on the conventional Lead acid batteries. The paper aims to study the feasibility of using Lithium Titanate batteries for propulsion and study the tactical/ technical advantages as well as the challenges faced in implementation onboard. To focus on the subject the study is constrained to the comparison with an EKM battery which is a representative battery for all the conventional submarines. Also for the ease of study on the available data, a commercially available SCiB TM (Super Charge ion battery from Toshiba) is used for comparative studies. The paper also attempts to study the use of a marine gas turbine generator to take advantage of the rapid charging capabilities of the battery thereby considerably lowering the indiscretion rate.

2. Lithium ion Batteries

The conventional Lithium ion does not have a defined unique chemistry like lead acid, nickel metal hydride or Nickel Cadmium batteries. It has a number of different possible combinations, providing a number of possibilities to variety application requirements. A lithium ion cell has three main components: positive electrode (cathode), negative electrode (anode) and separator. This has both advantages and disadvantages. On the one hand, various cathode and anode materials provide flexibility to design batteries for specific application needs, but on the other hand the large number of possible chemistries creates confusion to the customers until a particular chemistry is fully developed and successfully tested in the field.[1] The gravimetric and volumetric energy density with competing technologies are as shown below:

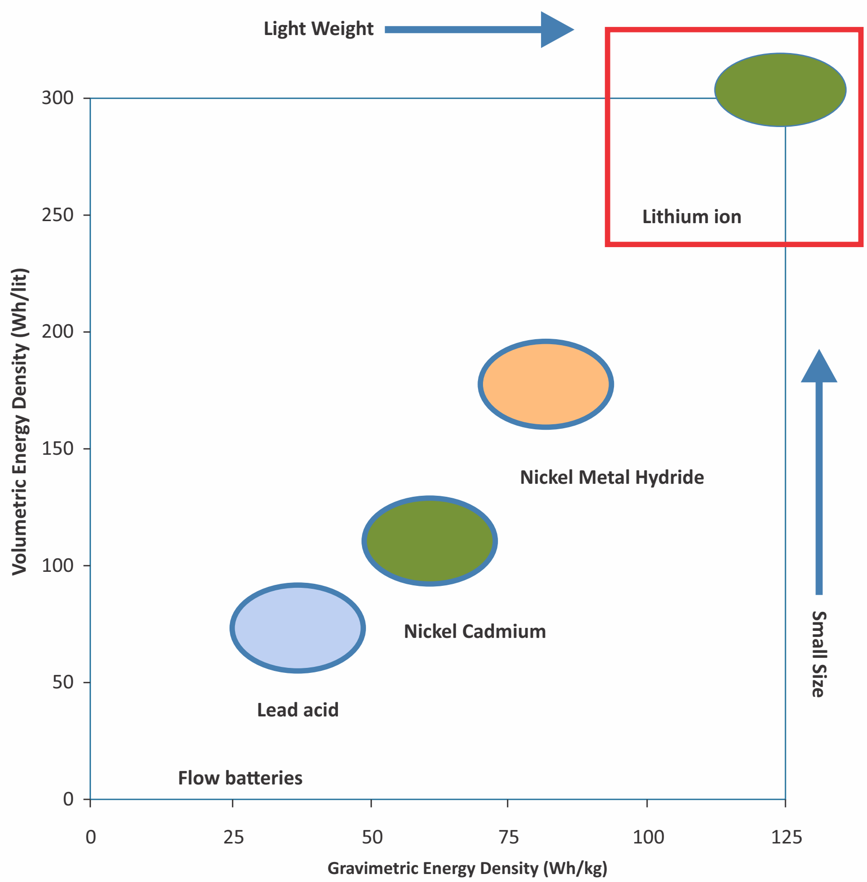


Fig 1. Comparison of Li ion technologies with competing technologies[2]

It can be seen that Lithium ion technologies out run competing technologies in terms of both volumetric and gravimetric densities. However, as the energy density keeps increasing, the failure in case of a thermal runaway for lithium ion batteries leads to catastrophic discharge of energy leading to fire and explosion, making them unsuitable for high power, mobile applications. With the advancement in technologies, Li-ion battery based high torque Electric Vehicle (EV) like Tesla &BYD are revolutionizing the Car industry. Germans are operating Li-ion battery based submarines and USA, Australia and Japan are in the process of constructing a few. Germany has set up a test bed for lithium based submarine battery. The most commonly used and available Li ion technology are Lithium Cobalt Oxide (LCO) ,Lithium Manganese Oxide (LMO) Lithium Nickel Manganese Cobalt Oxide (NMC) Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum Oxide, (NCA) and the Lithium Titanate (LTO).The table 1 gives a comparison of Various available Li ion chemistries:

Table 1: Comparison of Various Lithium Ion Technologies[3]

SNo	Attribute	LCO	LMO	NMC	LFP	NCA	LTO
1	**Voltage**	3.60V nominal; typical operating range 3.0-4.2 V/cell	3.70V (3.80V) nominal; typical operating range 3.0-4.2 V/cell	3.60V, 3.70V nominal; typical operating range 3.0-4.2V/cell, or higher	3.20, 3.30V nominal; typical operating range 2.5-3.65V/cell	3.60V nominal; typical operating range 3.0-4.2V/cell	2.40V nominal; typical operating range 1.8-2.85V/cell
2	**Specific energy (capacity)**	150-200Wh/kg. Specialty cells provide up to 240Wh /kg.	100-150Wh/kg	150-220Wh/kg	90-120Wh/kg	200-260Wh/kg; 300Wh/kg predictable	70-80Wh/kg
3	**Charge (C-rate)**	0.7-1C, charges to 4.20V (most cells); 3h charge typical. Charge current above 1C shortens battery life.	0.7-1C typical, 3C maximum, charges to 4.20V (most cells)	0.7-1C, charges to 4.20V, some go to 4.30V; 3h charge typical. Charge current above 1C shortens battery life.	1C typical, charges to 3.65V; 3h charge time typical	0.7C, charges to 4.20V (most cells), 3h charge typical, fast charge possible with some cells	1C typical; 5C maximum, charges to 2.85V
4	**Discharge (C-rate)**	1C; 2.50V cut off. Discharge current above 1C shortens battery life.	1C; 10C possible with some cells, 30C pulse (5s), 2.50V cut-off	1C; 2C possible on some cells; 2.50V cut-off	1C, 25C on some cells; 40A pulse (2s); 2.50V cut-off (lower that 2V causes damage)	1C typical; 3.00V cut-off; high discharge rate shortens battery life	10C possible, 30C 5s pulse; 1.80V cut-off on LCO/LTO
5	**Cycle life**	500-1000, related to depth of discharge, load, temperature	300-700 (related to depth of discharge, temperature)	1000-2000 (related to depth of discharge, temperature)	1000-2000 (related to depth of discharge, temperature)	500 (related to depth of discharge, temperature)	3,000-7,000
6	**Thermal runaway**	150°C (302°F). Full charge promotes thermal runaway	250°C (482°F) typical. High charge promotes thermal runaway	210°C (410°F) typical. High charge promotes thermal runaway	270°C (518°F) Very safe battery even if fully charged	150°C (302°F) typical, High charge promotes thermal runaway	One of safest Li-ion batteries
7	**Applica tions**	Mobile phones, tablets, laptops, cameras	Power tools, medical devices, electric powertrains	E-bikes, medical devices, EVs, industrial	Portable and stationary needing high load currents and endurance	Medical devices, industrial, electric powertrain (Tesla)	UPS, electric powertrain (Mitsubishi i-MiEV, Honda Fit EV), solar powered street lighting
8	**Remarks**	Very high specific energy, limited specific power. Cobalt is expensive. Serves as Energy Cell. Market share has stabilized.	High power but less capacity; safer than Li-cobalt; commonly mixed with NMC to improve performance.	Provides high capacity and high power. Serves as Hybrid Cell. Favorite chemistry for many uses; market share is increasing.	Very flat voltage discharge curve but low capacity. One of safest Li-ions. Used for special markets. Elevated self-discharge.	Shares similarities with Li-cobalt. Serves as Energy Cell.	Long life, fast charge, wide temperature range but low specific energy and expensive. Among safest Li-ion batteries.

The radar charts of the Li ion batteries based on variables such as Specific energy, Specific power, Safety, Performance, Life Span, Cost are as shown below[4].

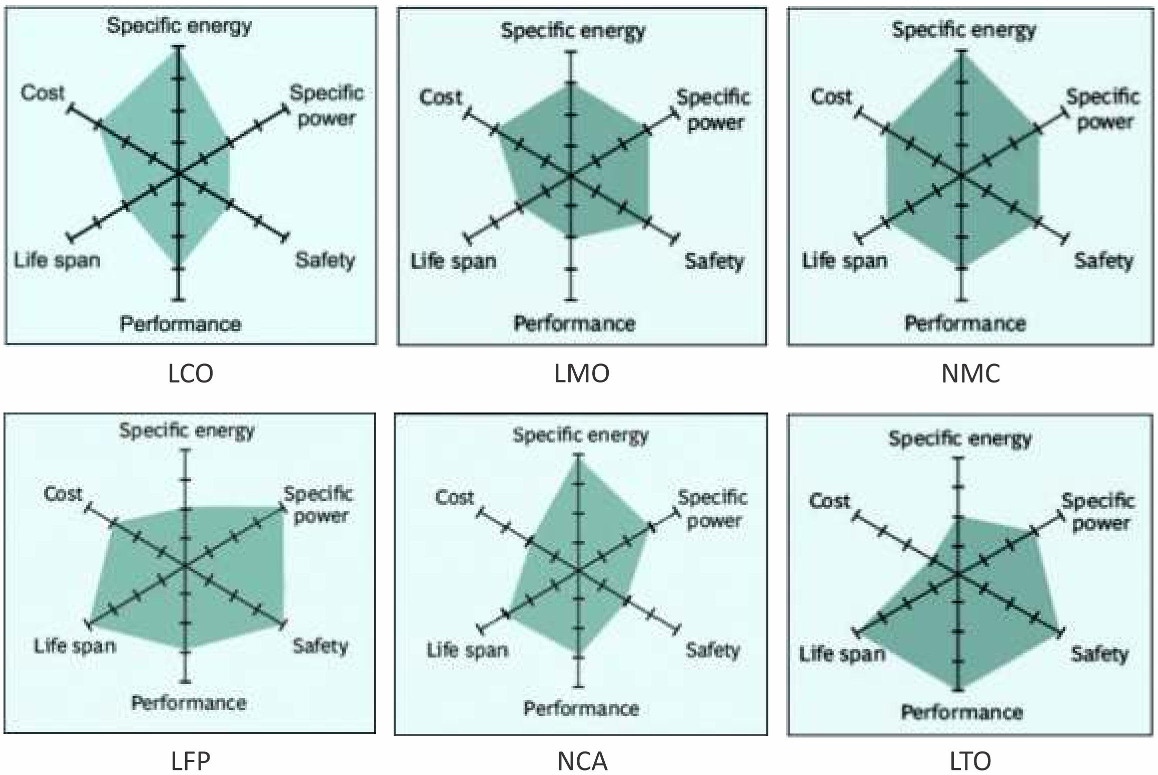


Fig 2. Radar chart of different of Li ion technologies

3. LiTe/LTO Batteries

Lithium titanate[5] (full name lithium metatitanate) is a compound containing lithium and titanium. It is an off-white powder at room temperature and has the chemical formula Li2TiO3. It is the anode component of the fast recharging lithium-titanate battery. A lithium-titanate battery is a rechargeable modified lithium-ion battery that uses lithium-titanate nano crystals on the surface of its anode instead of carbon. This gives the anode a surface area of about 100 square meters per gram, compared with 3 square meters per gram for carbon, allowing electrons to enter and leave the anode quickly. This makes fast recharging possible and provides high currents when needed[6]. It differs from other lithium-ion batteries because it uses lithium-titanate on the anode surface rather than carbon. This is advantageous because it does not create an SEI layer (Solid Electrolyte Interface), which acts as a barrier to the ingress and egress of Li-ion to and from the anode.[7]

4. Primary considerations while using Li ion batteries for submarine applications:

There are a number of factors that needs to be considered while selecting the energy source primarily due to the adverse conditions at which the submarine batteries operate, the space considerations, and safety issues.

(a) **Safety**.The most important aspect that needs to be taken into consideration while choosing a battery for submarine application is the safety of the power source. The enclosed nature and the closed cycle ventilation of the battery make it difficult to manage the gas evolution of Hydrogen, a highly flammable gas and release of highly corrosive sulphuric acid mist while charging and agitation. Special layers of anti corrosive coating are required in the battery pit which needs to be meticulously maintained using periodic pit washing using mild alkaline agents to prevent the electrolyte from eating into the pressure hull of the submarine. Lithium Tiatnate batteries are considered one of the safest batteries among the lithium ion batteries and compares very favorably with respect to the lead acid batteries since the chemical reactions inside the cells does not cause the release of hydrogen gas into the atmosphere. This provides an opportunity to distribute the batteries across machinery spaces since no hydrogen evolution happens during the battery exploitation. This also increases the redundancy for critical submarine systems. Use of these additional batteries can also increase the submerged endurance of the submarine. The safety of these batteries was demonstrated by puncturing a fully charged Lithium Titanate battery and has not resulted in fire or explosion and the temperature rise was limited to $99^{0}C$[8]. Lithium titanate chemistry is not prone to fire or explosion even if an internal short-circuits is forced[9]. The crush test and the penetration test also yielded similar results. Such robustness to shocks, vibrations and explosions make it an ideal candidate for submarine applications.

(b) **High rate of charge and discharge**.To decrease the indiscretion rate, the battery shall be capable of rapid charging using the minimum time. By ensuring that the submarine spends minimum time doing snorting, increases its survivability as well as its tactical advantage in terms of stealth. The battery shall also be able to sustain heavy discharge rates in tactical situations or in emergencies. Such high charge /discharge cycles shall not cause thermal runaway of the cell leading to fire onboard. Conventional Lithium ion batteries do possess a risk of fire and smoke while undergoing rapid charge and discharge cycles. The lithium titanate batteries posses a very light risk compared to other Lithium ion or Lead acid battery technologies. Lithium titanate batteries are designed to sustain high current deep discharges.

(c) **Wide effective state of charge range (SOC).** The deep discharging capability of its batteries shall permit a submarine to stay underwater for longer duration before it comes up for charging again. A deep discharge of the Lead acid batteries shortens its life and in worst case scenario leads to polarity reversal and permanent damage. Even though the lead acid batteries can sustain deep discharges up to 80% such a provision is resorted to only in case of an emergency or tactical situation since it reduces the life of a battery. Lithium Titanate batteries on the other hand are capable of sustained deep discharges of 0-100% discharge , thereby providing an exciting opportunity of to reduce the nominal battery capacity or amount of batteries necessary for a system[10]. Alternately, this wide range SOC shall be used to augment the power storing capacity of the submarines inside the battery pits to increase its endurance.

5. Advantages

The Lithium Titanate battery chosen for the study was the Toshiba SCiB ™ (Super Charge ion battery from Toshiba) since it is widely available and used for various applications including applications within India. Advantages are as follows:

(a) **Safety**. There is a very low risk of fire or explosion from internal short circuit caused by external pressure or other factors. Lithium metal plating does not occur when operated in the normal operational envelope unlike the other Lithium ion technologies. Therefore, SCiB™ is suitable for various applications requiring high levels of safety and reliability, such as automobiles, industrial equipment and stationary systems[11].

(b) **Long Life**. Only a small degree of capacity degradation occurs even after more than 15,000 cycles (for a 20 Ah Cell)* of 60A charging and discharging. SCiB™ also requires low maintenance even when it is used in applications that perform frequent charging/discharging such as large-scale storage battery systems, hence being environment-friendly[12]. It can be seen that the life of the SCiB™ battery exceeds the life of conventional batteries by a factor of 50.

(c) **Increased operational availability.** Due to the advantages enumerated above, for a life cycle of 20 years, there would not be a situation where in the submarine battery needs a change. Taken over a period of 20 years, this would result in increased operational availability of a minimum of 450 days saved due to the absence of battery replacement time. Additionally at least 3 days per month could be saved in Intermediate charge, full charge and equalizing charge. This would lead to a saving of 36 days per year and 720 days during the 20 year cycle. Thus a minimum operational availability of at least 2-2.5 years of the submarine over a period of 20 years effectively provides an additional submarine for a squadron of eight submarines fitted with SCiB™ batteries. This in itself could be a justification for a switchover to these batteries on the existing platforms.

(d) **Rapid Charging and increased endurance**. SCiB™ can be charged with large current, enabling it to be used in automobiles, buses and other vehicles that require quick charging similar to refilling a gasoline car. Also, frequent rapid charging does not cause significant deterioration in the SCiB™ performance[13]. This assumes special significance with respect to the tactical advantage it offers to the submarine commanders. Currently, a minimum of 4-6 hours are spent by the submarine per day to undertake charging. The rapid charging makes it possible to partially charge the battery under 20 minutes and fully charge under one hour. This coupled with the near 100 % discharge capability of the battery enables a submarine to remain submerged for a prolonged duration which would be a revolutionary in terms of range advantage, submerged endurance and indiscretion rate of a submarine.

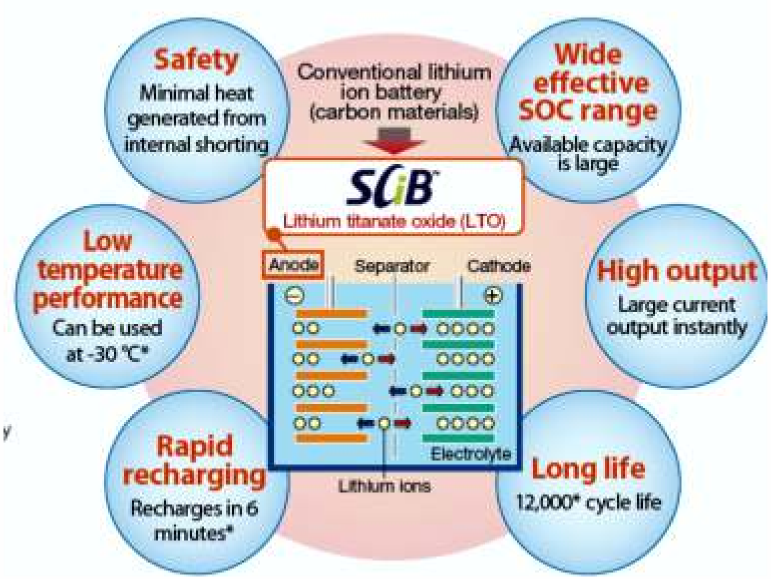
(e) **Lower maintenance**. The absence of prolonged charging cycle and the maintenance free nature of the battery, frees the electrical crew to focus on other maintenance activities. Currently a lot of efforts are put by the Electrical department in carrying out the maintenance which include daily inspection of the battery pit, topping up, Battery pit washing and cell measurements. This battery system also puts lesser long term health issues on the personnel dealing with the battery maintenance compared to the lead acid battery maintenance.

(f) **High Input/Output.** SCiB™ can be charged and discharged at high current rate. Therefore, SCiB™ can accept a large amount of regenerative energy in a short time as produced by a train or an automobile when the brake is being applied, and supply a large current to the motor during vehicle start-up/acceleration[14].

(g) **Wide effective SOC Range14**. SCiB™ exhibits excellent input/output characteristics over a wide SOC* range of 0-100%. This makes it possible to reduce the nominal battery capacity or amount of batteries necessary for a system.

(h) **Low Temperatrure performance**[15]. SCiB™ exhibits low degradation even when it is charged and discharged at -30°C. Thus, SCiB™ can be used for applications that are exposed to low temperatures, such as home battery storage systems and street lamps and high altitude remote locations. This has special significance in cold water operations.

The summary of the performance characteristics are as shown below*:



* Under specified test conditions

Fig 3. Advantages of Lithium Titanate ScIBTM batteries[16]

6. Technical specifications of the basic SCiB™ Cell.

This cell forms the basic prismatic unit or the building block on which the larger power modules are designed. The cells are arranged in series combinations with parallel strings to achieve the desired voltage and current ratings to obtain power output for a particular application. The small size enables the cell to minimize the energy losses due to the ion travel. The cell is encapsulated in a metallic shell that provides robust protection against shock, deformation or damage due to ballistic projectiles. The figure 4 provides the technical specifications of the basic cell unit which is a 2.3 V 20 Ah battery.

20 Amp Hour Cell

Cell Specifications

Nominal Capacity	20 Ah
Nominal Voltage	2.3 V
Weight	510 g
Energy / Weight	90 Wh/kg
Energy / Volume	177 Wh/L
Impedance (AC, 1kHz)	0.53 mΩ
Operating Voltage	1.5 to 2.7 V
Operating Temperature	–30° to 55°C
Charging Method	CC-CV

Fig 4 Technical specifications of the basic cell[17]

The performance parameters of a 1.1 kW Battery Module made from 24 Basic cells for Automobile Applications is as shown in Table 2:

Table 2: Performance parameters of 1.1 kW Battery Module[18]

Sl No	Parameter		Value
(a)	Cell configuration		2 parallel strings of 12 in series
(b)	Nominal capacity		1.1 kWh
(c)	Nominal voltage		DC27.6 V
(d)	Range of battery voltage		DC18.0 to 32.4 V
(e)	Maximum charge current conditions		160 A 100 seconds (not exceeding a cell temperature of 55 °C)
(f)	Maximum discharge current		160 A 100 seconds (not exceeding a cell temperature of 55 °C)
(g)	Humidity		15 to 85%RH
(h)	Cell configuration 2 parallel strings of 12 in series		Nominal capacity
(j)	Environment conditions	Ambient temperature	-20 to 45°C
		Range of battery voltage DC18.0 to 32.4 V	
		Altitude	Under 1000 m
(k)	Weight		About 14 kg
(l)	**Exterior Dimensions**		W187.2 × D358.5(419.3)* × H126.6 mm * Figures inside ( ) include moving parts of terminal cap
(m)	CMU function Cell voltage *(CMU=Cell Monitoring Unit BMU=Battery Monitoring Unit CAN=Controller Area Network)		Temperature monitoring, Cell balance operation, CAN* between BMU* and CMU*

The graphs at Fig 4, 5, 6,7,8,9 depict the following characteristics of a 1.1 kW Module respectively:

(a) Discharge characteristics (rate characteristics)

(b) Discharge characteristics (temperature characteristics)

(c) Float characteristics

(d) Cycle characteristics of 20Ah cell

(e) Storage characteristics (self discharge characteristics)

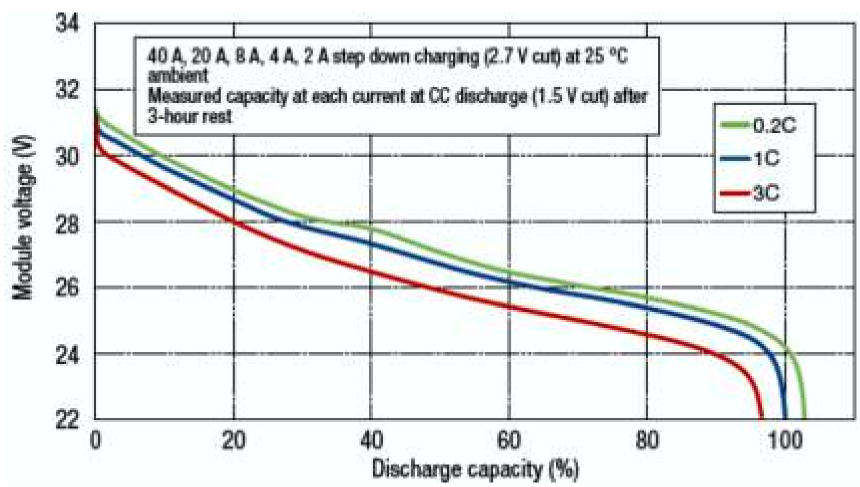


Fig 4. Discharge characteristics (rate characteristics)

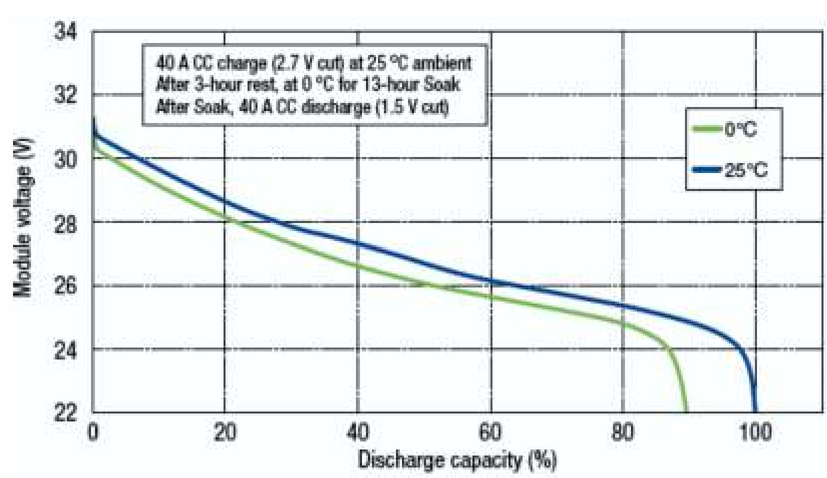


Fig 5. Discharge characteristics (temperature characteristics)

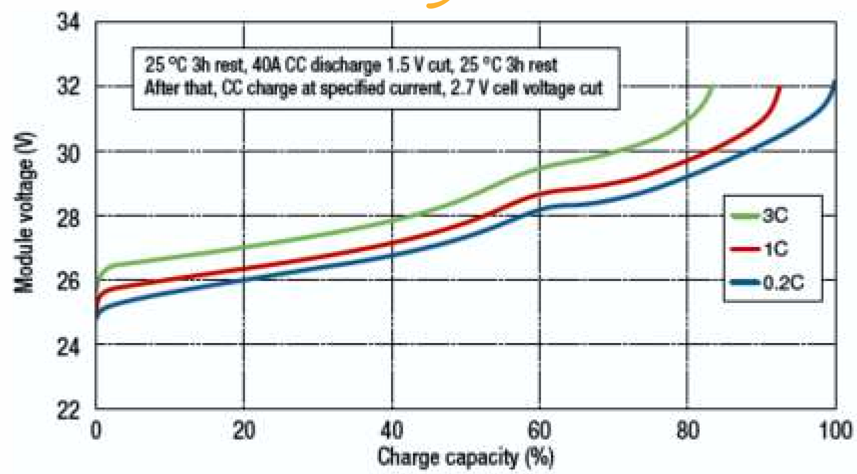


Fig 6. Charging characteristics

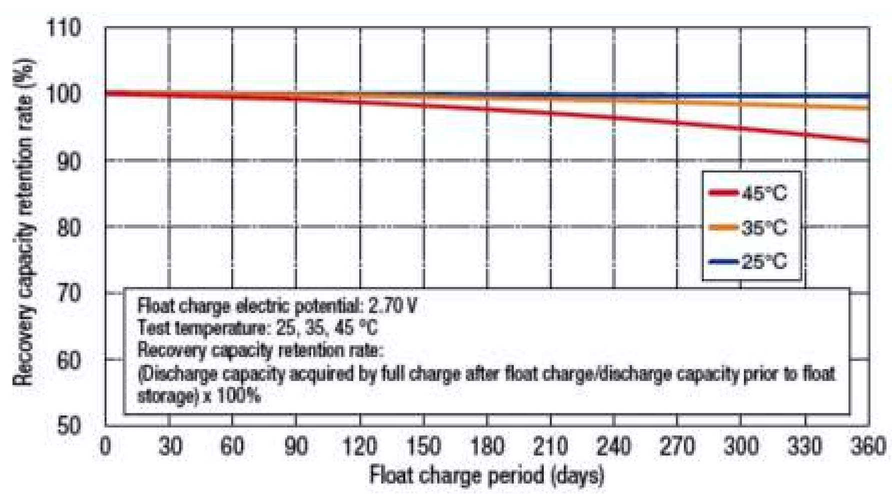


Fig 7. Float characteristics

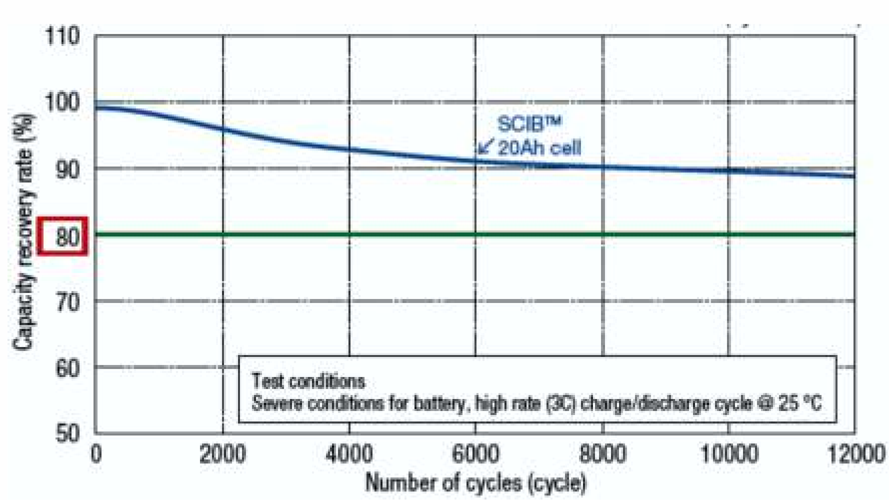


Fig 8.Cycle characteristics of 20Ah cell

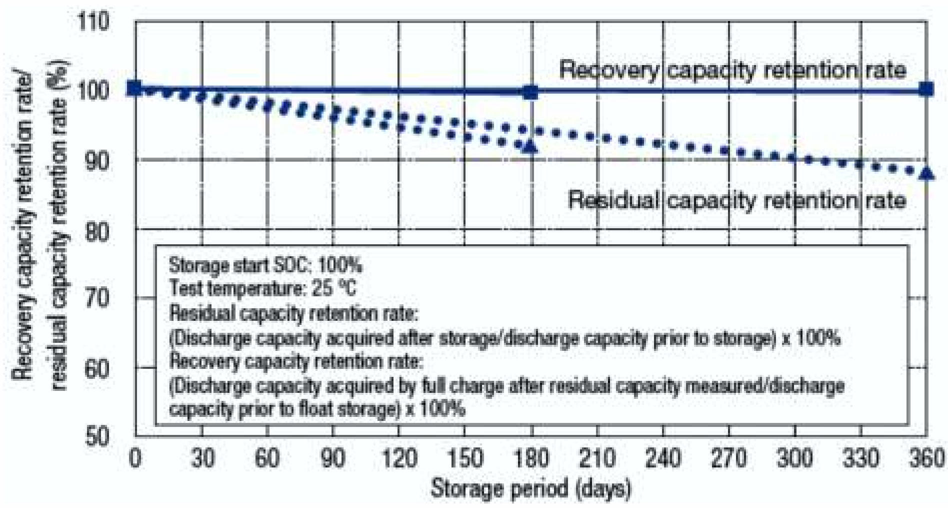


Fig 9.Storage characteristics (self discharge characteristics)

7. Practical Implementation on board a submarine

The volume of Lithium titanate battery for the same power output is 95M^3 after catering additional 25 % for cabling and ventilation. The small footprint of the individual battery module allows for more packing within the given space since there is no requirement for a trolley or even an enclosure where these batteries are kept. This enables of packing of at least 30% more Lithium titanate batteries in the given volume, leading to an additional capacity of approx 2600 kWh thereby enhancing the submerged endurance by 1/3rd.Since the dimension of the 1.1 kW module permits even to pack the modules in the space earlier meant for the gratings, more capacity could be derived from the same battery pit volume. Additionally these batteries could be mounted in the machinery spaces, thereby further increasing the power available to the submarine. Since these batteries weigh only nearly one third the weight of the existing lead acid batteries, weight compensation also will not be a problem and can be easily overcome by placing some dead weights inside the battery pit. Alternatively the 52 Ton weight gained by using the new batteries could be used to store additional stores or fuel to extend the present range. The most important aspect of such a load out is that the submerged endurance of the submarine is effectively doubled which provides a near 100% increase in submerged range and much lower indiscretion rate. Since these batteries are already proven to operate in megawatt scale range, scaling these modules as per the user requirements is not an obstacle. The Figure 10 depicts the scales at which the power modules could be utilized:

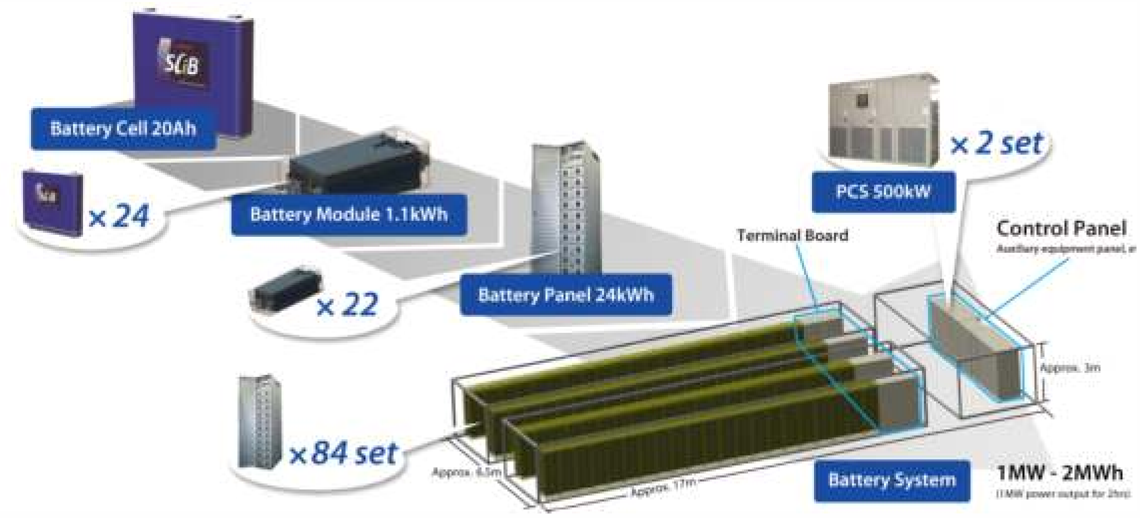


Figure 10: The range and scalability of the Lithium titanate Batteries[19]

8. Power plant considerations.

(a) Existing Diesel generators.The current diesel generators are grossly inadequate to take the advantage of the rapid charging capability of the Lithium titanate batteries. Even in such a scenario, the two/three stage charging for partial charge that is being resorted at sea could be done away to pump in more energy in unit time. This means the battery could be continuously charged for 6 hours at 3600 Amperes to allow 100 % charge from 90% discharged battery. With the Lithium Titanate battery, a single battery could be charged up to 21600 A in 6 hours or alternately reach C1 capacity under 2 hours, since it can use constant current only mode of charging.

(b) Using a Gas Turbine generator for Rapid charging Under 30 Minutes.The use of gas turbine generators is a radical approach compared to the conventional approaches towards battery charging. The following are the difficulties encountered while using a gas turbine generator.

(a) Very High Aspiration and exhaust rate.

(b) High specific fuel consumption.

(c) Possibility of surging and FOD.

(d) Requirement of specialized operators and maintainers.

However the benefit of having a reliable very high power to weight ratio gas turbine generator provides an immense tactical advantage and redundancy. The high power to weight ratio of the generator enables the submarine crew to rapidly charge the batteries under 30 minutes, to avoid detection and increased submerged endurance. The modular acoustic enclosed GTs provides a compact and maintenance free option. For the configuration envisaged, a 4.2 MW LM 500 marine gas turbine generator was considered for implementation onboard. The following are the technical specifications of the LM 500 diesel generators:

Table 3: Details of LM 500 TG set

Sl No	Parameter		LM 500 TG set[20]	Remarks
(a)	Dimensions	Base plate Width	2.36 M	Addl .5 M
		Base plate Length	7.14 M	Addl 1.14M
		Base plate Height	2.39 M	
(b)	Weight including the generator		27.3T	
(c)	Duct flow Area	Inlet	1.12M^2(600mm)	Increased dimensions
		Outlet	0.65 M^2(455mm)	
(d)	Output		4.2MW	
(e)	Heat Rate		11.6KBtu/kWh	
(f)	SFC		269.5g/kWh	
(g)	Exhaust gas Flow		16.4 Kg/Sec	
(h)	Exhaust gas temperature		565?C	
(j)	RPM		7000	
(k)	Inlet Exhaust Losses at		0.1/0.15 M	Higher losses to be catered for GT

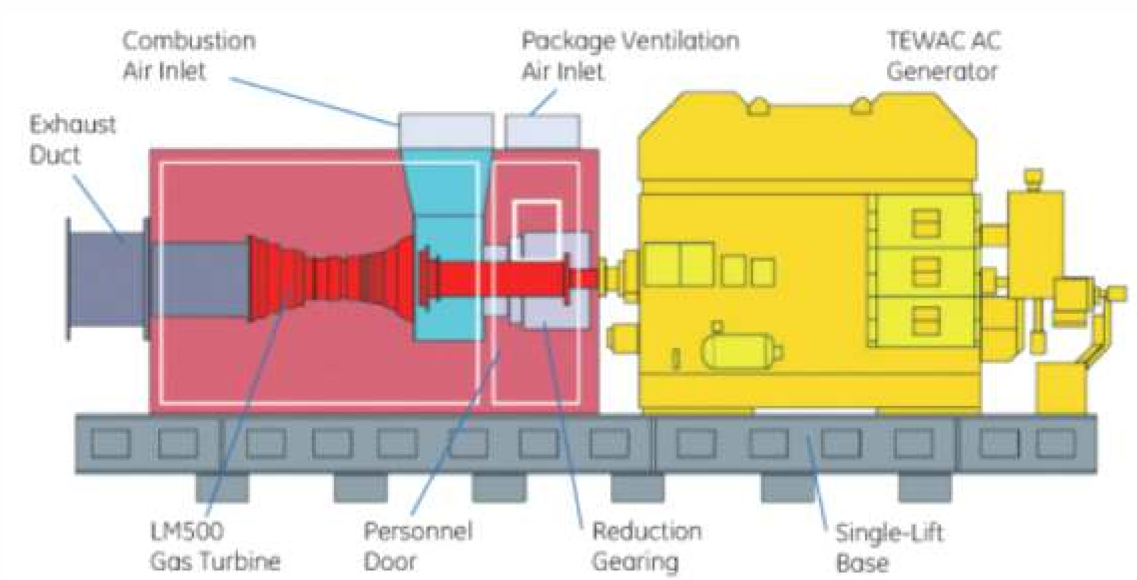


Fig 11 LM 500 TG set[21] mounted on a skid

It can be seen from table 5 that the LM 500 TG set outperforms the existing power plant in almost all parameters except the Air intake and exhaust trunkings and the dimensional difference in Width and Length. It has to be borne in mind that the TG unit is a complete unit in itself with minimum accessories. The additional 1 meter in width requirement and 1.14 M in length requirement can be utilised by moving the Sulzer compressor to the upper deck and extending the skid to the additional 2 metres available in length before the end of the bulkhead. Modification of the Trunking would entail enlarging the dimensions of the inlet and exhaust trunkings by 150 mm. Alternately the TG may be run at 80 % of its full power to obviate the requirement of modification of the Air induction system. Two TG sets would be fitted in the available real estate or a single TG with a smaller 500 kW emergency diesel generator could be used to manage the space constraints. In the proposed configuration only one TG will be running at a time with the other being standby. Assuming 200 kW losses for water column back pressure and air inlet constraints, the TG producing 4000kW would produce about 15500A output after taking the conversion losses from AC to DC conversion. This means the TG could charge the existing batteries under three hours or makes it possible to charge the Lithium Titanate batteries under one hour.

9. Surge prevention

Preventing of surging especially during rough seas is an important aspect to be considered while operation of the TG. A surge occurs when there is disruption of the airflow due to shutting of the snort mast due to a wave splash. This momentary shutting could be managed by the full authority digital control system. To overcome surge issues it is proposed to provide an additional air bottles along with starting air bottles which could provide up to 15 kgs of air for 30 seconds. Shallow planning also provides better protection against surging. Augmentation of Snort mast with a radar transparent Teflon shroud of 30 cm also could be considered to minimise the water ingress.

10. Cost

Lithium titanate batteries are expensive compared to the conventional Lead acid batteries. To get an approximate comparison a commercially available 12 V tubular Gel VRLA battery of 200 AH was considered. To get the same power output, 5 Lithium Titanate cells of 2.3 V was connected in series and two parallel strings to give the similar performance. It s to be taken into consideration that LTO battery capacity is calculated at C1 rate compared to C10 rate by 12 V tubular Gel VRLA battery . This in itself provides it a clear power density advantage. The cost comparison of both the batteries is as follows:

Table 4: Comparison of Cost of VRLA battery and LTO batteries.

Sl No	Cell type	Cost (Rs)	Remarks
(a)	12 V tubular Gel VRLA battery of 200 AH15	22500/-	
(b)	2.3V Lithium Titanate battery of 20 Ah (10 Nos, 5 in series 2 strings in parallel)16	31500/-	29.6% expensive

It can be seen that the LTO battery is 30% more expensive that a conventional Lead acid Gel type VRLA battery. The LTO battery systems will be at least 60 % more expensive once we take the battery monitoring system and the cell monitoring systems that comes along with it after offsetting the need of separate battery monitoring systems in the new configuration. When considering the same for a submarine application a ball park figure of Rs 35 crore (3150* 415*240) including the accessories was reached for the same capacity as that of the EKM battery which costs only about Rs15 crore. The cost of charging the battery weekly from shore facilities may also taken into consideration while arriving at the TCO (total cost of ownership). Even discounting those factors and neglecting the inflation rate, a minimum of 8 set of lead acid batteries are required to be purchased and put over a period of twenty years whereas the LTO battery is a one time investment. That provides a cost advantage factor of at least 3 over twenty years.

11.National Objectives

The nations struggle to achieve energy independence with the National solar Mission and increasing the manufacturing base under Make in India are two important government initiatives that can propel ahead our nation amongst other nations. Adopting LTO batteries as storage solution for solar farms and household could drastically bring down the cost of LTO batteries. A maintenance free nature and 20 year Lifespan of LTO battery marries well with the 20-25 year life span of solar cells. Adoption of LTO in storage of energy can save the nation, need of replacing the lead acid batteries every 6-7 years and the costs incurred along the loss of revenue during the replacement. If the demand is in sufficient numbers, the nation could reach an agreement with the foreign LTO manufacturers to setup production facilities in India, which would lead to further drop in cost of the batteries. Such a move would be akin to reaping the fruits of benefit similar to the LED installation revolution in the nation which saves power thereby indirectly avoiding the requirement of more power plants for lighting requirements.

12.Diplomatic Initiatives

Japan and India share a lot of common interests as well as the challenge posed by its neighbouring nations. The current government dispensation at both these countries share friendly relationship and personal bonhomie at the leadership levels. A large number of Japanese investments are in the pipeline for implementation including the High-speed bullet trains in which a lot of Japanese companies including Toshiba are stake holders. These interests of the stake holders in Indian economy could be leveraged to encourage LTO manufacturers to set up production facilities under Make in India initiative along with suitable concessions. Additionally favourable financing conditions could be obtained from Japanese banks companies to Japanese firms to set up facilities overseas. Suitable Military Corporation along with the diplomatic initiatives could address these concerns. India's proposal to buy Amphibious Aircraft from JMDSF (Japanese Maritime Self Defence Forces) is a case in point.

13.Recommendations

The following are the recommendations towards implementation of the proposal.

(a) Set up an expert committee to study the proposal in detail.

(b) Procurement of the batteries and power plants from the OEM.

(c) Trials of the system and modifications that are required to be undertaken.

14.Conclusion

The LTO batteries provide significant tactical, cost and maintenance advantage over the conventional batteries. These batteries coupled with a gas turbine generator provides significant lower indiscretion rate. These batteries are proven, safe and used over numerous stationary and mobile applications. Reduced maintenance leads to lesser crew fatigue and better performance. The roll out of LTO technology in the national solar mission could provide the twin benefits of energy independence and Make in India. Environmental impact of LTO batteries are much lesser compared to the conventional batteries.

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NON-MAGNETIC PRESSURE HULL – FUTURE CONCEPTS FOR SUBMARINE DESIGN

(Lt Cdr Vikram Singh)

***Abstract**- The submarine is a unique platform that is capable of dealing with conventional as well as asymmetric threats from the littorals. As a stealthy platform that possesses a robust capability for conventional open water anti-surface and antisubmarine warfare, a submarine is also increasingly called upon to undertake intelligence gathering, counter terrorism and special force operations. The need for stealth, range and flexibility while controlling the size and cost of the submarine has resulted in innovative submarine designs. These innovations in the fields of propulsion, structure, construction methodology and battery design are driving submarine design to a new dimension. This paper presents concepts of magnetic stealth, submarine structural design aspects and prospects of using of non-magnetic steel for submarine structural design.*

1. Introduction

1.1 Stealth technology, also known as low observable technology (LOT), is a sub-discipline of military tactics and passive electronic countermeasures, which covers a range of techniques used not just for aircraft, but includes ships, submarines, missiles and satellite in order to make them less visible (ideally invisible) to radar, infra-red and other detection methods. The concept of stealth is to operate or hide without giving enemy forces any indications of the presence.[1]

1.2 An important detection risk for ships and submarines at sea is the magnetic distortion they create in the earth's own magnetic field. Ships and submarines can be thought of as large metal objects which concentrate the earth's relatively weak magnetic field within them, creating stronger distortions or magnetic anomalies which potentially have the ability to trigger the release or detonation of magnetic mines. Warships are now able to reduce these magnetic distortions to sufficiently low levels so that magnetically triggered mines cannot detect them. This can be achieved by magnetising the ship's hull in the opposite direction to the earth's magnetic field, cancelling out the effect. Reverse magnetisation is normally achieved using hull-embedded electromagnets. However, it is sometimes considered preferable to reduce the magnetic signature by constructing the ship's hull from nonmagnetic materials.

1.3 Presently, there is multi-year service experience with both GRP and stainless steel hulls for mine countermeasure vessels. Sedriks in his article has [2] summarized that the performance of the German mine countermeasure vessels indicates that the first German stainless steel vessel has fulfilled all expectations after eight years of service. It also reveals that the anticipated eddy current problem was easily managed by the vessel's degaussing system. There were no changes in the nonmagnetic characteristics of the hull material during the eight year service period.

1.4 The possibility of building warships with nonmagnetic advanced double hulls much larger than mine countermeasure vessels has generated considerable interest in the performance of austenitic stainless steels since the limited stiffness (lower modulus) of GRP has traditionally restricted its use to ship hulls of 60 m or less in length.

1.5 Austenitic non-magnetic stainless steels being used for marine structures are AISI Type 316, Nitronic 50 and AL 6XN. The German stainless steel 1.3964.9 was selected as the nonmagnetic hull material for the Type 206/ 212 class of submarines and the mine countermeasure vessels of the Frankenthal and Hameln classes.

1.6 In the Indian context, INS Kalvari was the first submarine to be commissioned into the Navy on 08 Dec 1967. Till very recent times our navy has been operating submarines procured from foreign navies. Foxtrot class single hull submarines, Kilo class EKM double hull submarines and SSK class attack submarines have been inducted and are still in the service. With the upgradation of expertise in submarine construction, SSK, and Scorpene class submarines are now being constructed in the Indian shipyards. However, there exists a great amount of self sustenance in terms of material, equipment and operations, which needs to be attained by this expanding navy.

1.7 Time has come for us to explore and experiment for newer materials which can provide non-magnetic properties to the pressure hull of a submarine. This paper presents examples of navies that have employed non magnetic steels for submarine construction and urges on the need for development of indigenous materials which can fulfill the requirements.

2. Concept

2.1 For many years, it has been known that magnetite or lodestone if suspended by a thread will come to rest in approximate north–south geographical direction This is an example of a natural magnetic material used by both the Chinese and Scandinavian Vikings for navigation purposes. It is also known that a piece of non-magnetic iron can be converted into a magnet by stroking it in one direction repeatedly using an existing magnet. Certain materials like iron and steel can be magnetised by moving them through the earth's magnetic field, whilst other common metallic materials, such as copper or aluminium, cannot be magnetised.

2.2 The region of space influenced by a magnet can be visualised by considering the concept of the magnetic field. For example, if a bar magnet is covered by a sheet of paper and iron filings then sprinkled onto paper, the iron filings will reveal lines that can be traced from the magnet's North Pole to its South Pole (Figure 1). These 'lines of force' or 'lines of flux' show clearly the direction of the magnetic force at that point. Several key findings can be made about these lines of flux as follows:-

(a) Lines of flux never cross.

(b) Lines of flux are always continuous.

(c) Lines of flux will always take the shortest possible path.

(d) Lines of flux which are parallel and in the same directions repel each other, for example, when two magnets are brought together with north poles adjacent.

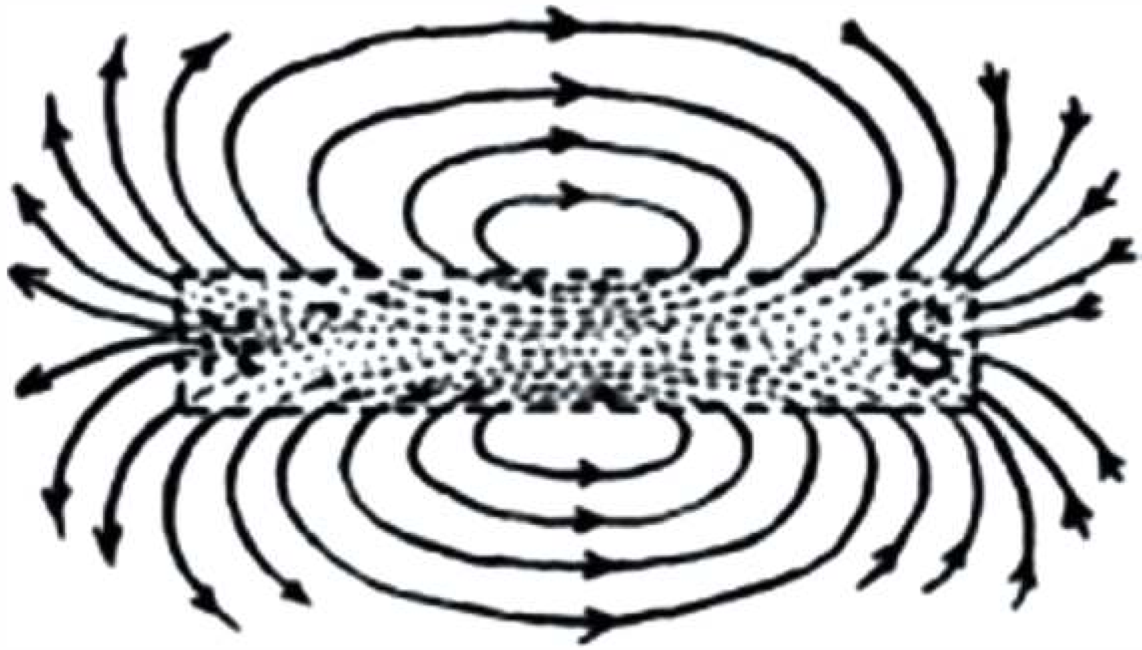

Figure 1 - Magnetic field of bar magnet [1]

2.3 Quantitatively, if a unit area at right angles to the lines of flux is considered, practical numerical definitions and terms can be elaborated. Lines of flux collectively can be said to constitute a magnetic flux, Φ which passes through the area. 'Flux density' is the value of the magnetic field at any point, and is obtained from the following expression:-

$$\text{Flux density} = \frac{\text{Flux}}{\text{Area}}$$

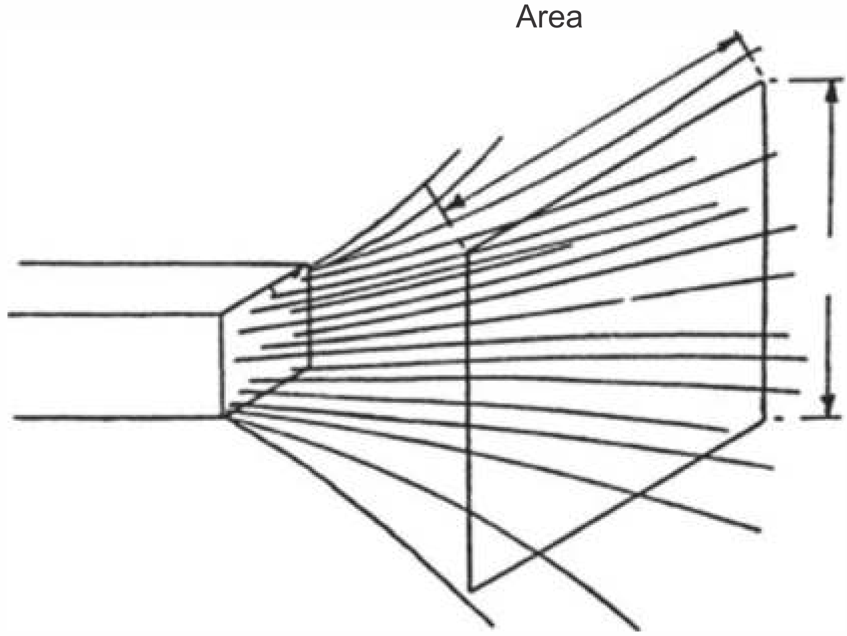

Figure 2 –Spreading lines of flux exiting a magnet [1]

2.4 Figure 2, illustrates the lines of flux exiting a magnet and passing through an area of 1 m2 at 90° to the magnetic flux. The symbol for flux density is B and its unit is the tesla. The following expression links flux, measured in weber, with the flux density, measured in tesla.

$$\text{Flux} = \text{flux density} \times \text{area or } \Phi\ (\text{Wb}) = B\ (\text{T}) \times A\ (\text{m2})$$

2.5 In magnetic materials, a magnetizing force (H) will produce a flux density (B), the magnitude of which depends upon the type of material in the magnetic circuit (e.g. air, steel, soft iron etc.). In free space, for most non-magnetic materials, the ratio between H and B is a constant value, such that the ratio B/H for free space is as follows:-

$$\mu 0 = 4\pi \times 10{-}7\ \text{H m}{-}1$$

2.6 For any material, the ratio of flux density to magnetizing force is called the 'absolute permeability' (μ) and is also measured in Henry per metre (H m−1). Thus,

$$\mu = \frac{B}{H}$$

2.7 However, the 'relative permeability' μR is the ratio of the flux density produced in a magnetic material to the flux density which would be produced in air by the same force, that is,

$$\text{Relative permeability} = \frac{\text{Absolute Permeability}}{\text{Permeability of free space}}$$

$$\mu R = \frac{\mu}{\mu 0}$$

or

$$\mu = \mu 0 \mu R$$

2.8 The result of this is that the permeability differences in magnetic materials will tend to concentrate any magnetic field lines present such that these field lines might be described as 'preferring' to stay and be drawn into the magnetic media rather than in any non-magnetic media. This is not so dissimilar to the way in which light 'prefers' to travel within a high-refractive index media such as glass rather than propagate or travel in a low-refractive index media such as air when it is incident above the critical angle. This concentrating of the magnetic field lines can be described as a magnetic 'lens' whose concentrating ability is determined by the relative permeability of the material in question. For example, for some materials such as iron, nickel and cobalt, this value can be extremely large (ranging between 1,000 and 2,000). For some special materials, the value of the relative permeability can be even higher. Two specialist materials 'nanoperm' (a cobalt-based magnetic alloy 2714 A) and 'metglas' have relative permeability values of 80,000 and 1,000,000 respectively. Interestingly, pure metals such as nickel, cobalt and magnesium exhibit very slight magnetic properties, but when alloyed with iron, very strong magnetic properties result. The consequence of this concentration of magnetic field lines is seen in the relationship between moving conductors and the generation of an electric field.

2.9 The earth can be considered as a relatively simple dipole magnetic with magnetic lines of force running from north to south. Magnetic lines of forces at the earth's surface have two key components, a vertical component (Z) and a horizontal component (H), which is itself divided into two components: a longitudinal component along the ship and an athwartship component across the beam of the ship. The medium through which the field lines pass, with its specific permeability, affects the field strength (the lines of force per unit area). For example, metal is more permeable than water. So the field intensity increases in the ship, creating anomalies or localised concentrations in the magnetic field around it, as illustrated with visualised lines of force in Figure 3.

2.10 In reality, the ship will have a composite permeability of differing metal components and structures with a three-dimensional spatial distribution. A further complication is that all ships are built within the earth's magnetic field, hence they become permanently magnetised, at least partially. However, the level of permanent magnetisation depends on the earth's field where the ship was built, its orientation when it was built and the materials used.

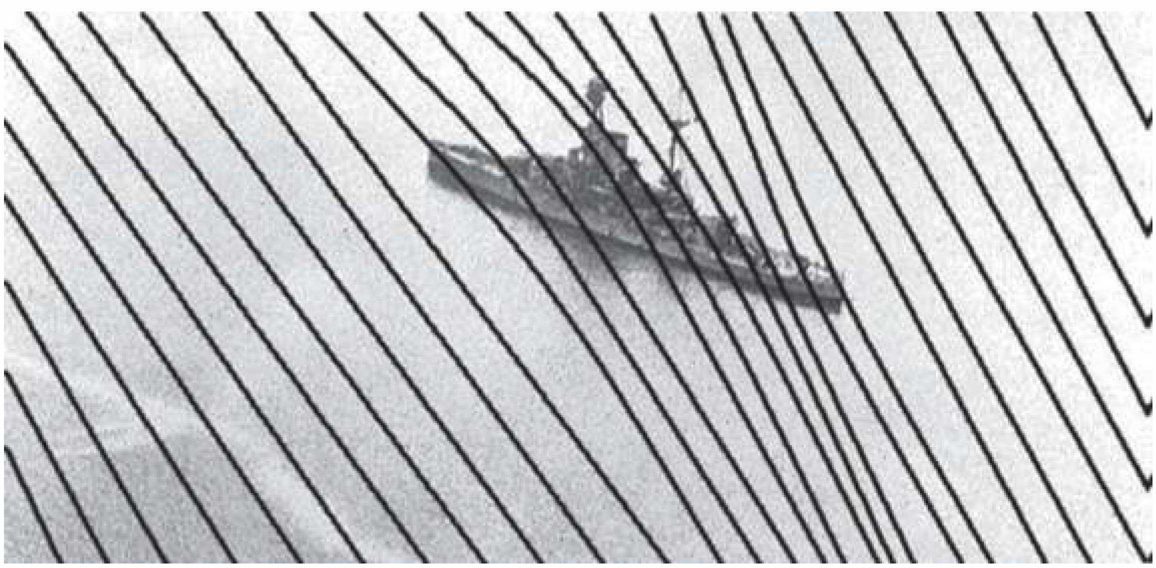

Figure 3 – Magnetic field lines concentrated in the steel hull of the ship [1]

2.11 The induced magnetic field from the ship's magnetic materials when moving in the earth's magnetic field will depend upon the earth's magnetic field strength and the ship's orientation. The components are 'longitudinal' (affected by latitude, heading and pitch), 'athwartship' (affected by latitude, heading and roll) and 'vertical' (affected by latitude, pitch and roll). One solution to this problem is the practical engineering technique of degaussing or, its more modern version, deperming.

2.12 A ship made of ferromagnetic materials such as steel, which concentrate lines of magnetic flux, will constrain them to follow a 'preferred' path to the water surface. Consequently the local magnetic field of the earth, as stated, can become quite distorted. As the ship moves, it will have a potential difference (p.d.) or voltage induced across its hull plates and superstructure, with differing voltages over the entire ship due to the non-uniformities in its original construction and/or subsequent modifications. Variations in current flowing inside the ship will induce magnetic fields around it. This voltage or potential difference across the ends of the conductor will cause a current to flow, which in turn produces an induced magnetic field (Figure 4).

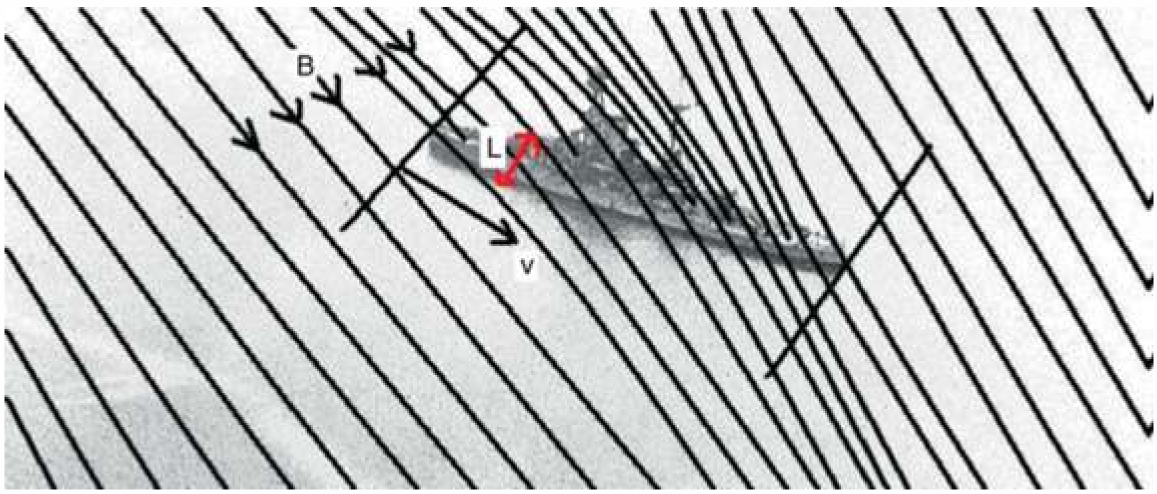

Figure 4 – Origin of induced voltage, V [1]

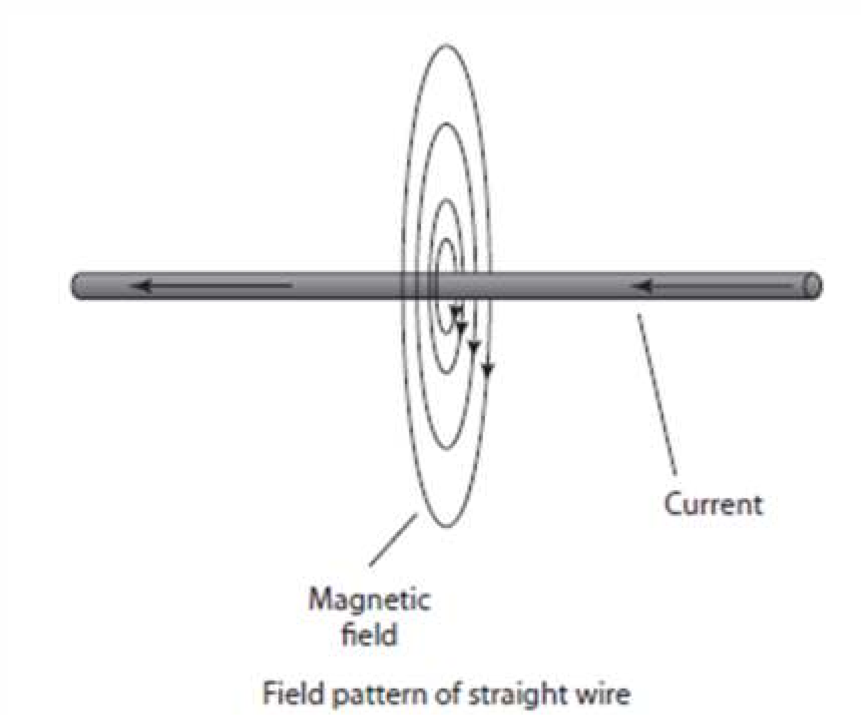

Figure 5 – Magnetic field around current-carrying wire [15]

2.13 A conductor which carries a current (I) has a decreasing radial magnetic field of flux density (B) with increasing distance from the wire. Hence a current is applied which creates a magnetic field in the opposite direction to that which has been induced by this motion (Figure 5).There is a simpler solution than having to remove the permanent and induced fields, and that is to avoid the use of ferromagnetic materials in modern ship/ submarine construction entirely.

3. Basics of Submarine Structural Design

3.1 Before designing any material for a structure, it is important to understand the philosophy and methodology of structural design in detail. A brief introduction of typical structural design of submarines is presented in this section. Conventional submarines are normally designed with single or double hull structure. Single hulled submarines are the boats which do not have any outer hull along her length. Ballast tanks for such types of submarines are placed either at the ends or inside the pressure hull. A double hull submarine has an outer hull enclosing the pressure hull along her length. The volume between the two hulls is used as main ballast tanks. [3-8]

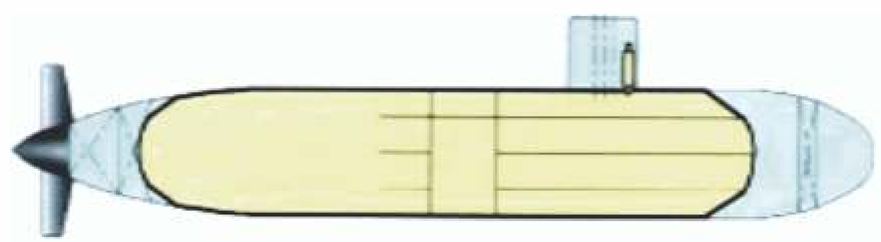

Figure 6 – Single hull construction submarine [14]

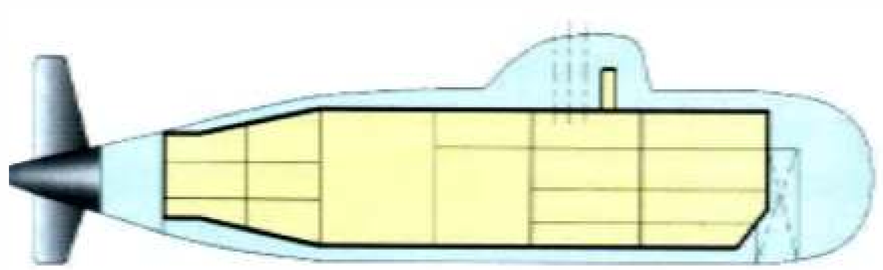

Figure 7 – Double hull construction submarine [14]

3.2 The following are the main parameters to be considered for structural design of a submarine:-

(a) Maximum diving depth and safety factor

(b) Pressure resisting volume

(c) Shape of hull

(d) Internal and external layout

(e) Architecture

(f) Material

(g) Fabrication technology/code

(h) Design methodology/code

3.3 The following are the main loads which are to be considered for a submarine structural design:-

(a) Maximum operating depth (pd)

(b) Occasional overshoots beyond pd due to accident or mal-operation, depending upon:-

(i) Nature of incident

(ii) Submarine length

(iii) Maximum speed

(iv) Control systems characteristics

(v) Emergency deballasting capability

(c) Reserve of strength to survive underwater attack when at pd (Δpr)

3.4 The entire submarine structure is divided into primary and secondary structure. For a submarine, the following are the primary and secondary weight bearing structures:-

(a) Primary

(i) Pressure hull,

(ii) Main transverse bulkheads

(iii) Pressure hull penetrations

(b) Secondary

(i) Outer hull

(ii) Superstructure and appendages

(iii) Internal structures – decks, tanks, platforms, minor bulkheads

(iv) Foundations.

3.5 Typically primary and secondary structures amount to 43-45% of total weight. The challenge of efficient design involves optimum utilisation of strength of material throughout the mass of material while minimising the structural weight. Considering that the hydrostatic pressure is the main design pressure, the spherical submarine hull form would be ideal. But this hull form poses the difficulty of space utilisation, manufacturing and streamlining for the designer.

3.6 The next most efficient hull form for submarines would be right circular cylinder with domed ends. This hull configuration gives the designer geometric freedom to vary L/D ratio, has better volumetric efficiency than sphere and is easier to manufacture due to single curvature. However, this configuration is not so structurally efficient as it has 2:1 stress ratio between circumferential and longitudinal directions. Also, this is not the ideal hydrodynamic shape as a combination of cones & cylindrical sections used.

3.7 Other pressure hull shapes which can be used are:-

(a) Central circular cylinder with canted conical sections rising at either end

(b) Aft end as a flattened horizontal oval shape to suit twin shafts and fore end being a vertical oval section for weapons

(c) Figure-of-8 cross-section.

3.8 The following are the typical modes of failure for a submarine:-

(a) Interframe shell yielding

(b) Interframe buckling

(c) Overall collapse

(d) Frame buckling and tripping

(e) Dome buckling

3.9 The minimum buckling pressure (pm) is estimated using the equation [8]:-

$$p_m = \frac{0.919E(t/R)^2}{L/(Rt)^{1/2} - 0.636}$$

Where, t = shell thickness
R = mean radius of shell
L = unsupported length of shell

3.10 For the pressure hull design, the pressure hull is considered as a whole and each component ensures that no component fails prematurely before rest of the structure. Design is undertaken such that the material should reach its yield stress before failure. Also, the pressure required for buckling should be greater than for yield failure. It is imperative for a designer to account for imperfections in the geometry during the design stage itself. These shape imperfections introduce bending stresses in addition to existing shell membrane stresses in the frames. These shape imperfections can be Out-of-Circularity (OOC) shape which maybe 6 mm on 4.5 m radius at a frame. Typically OOC can be 0.001 to 0.0025 times the radius of pressure hull. The submarine structural design procedure has been elaborated in detail in BS5500:1976. [9-13]

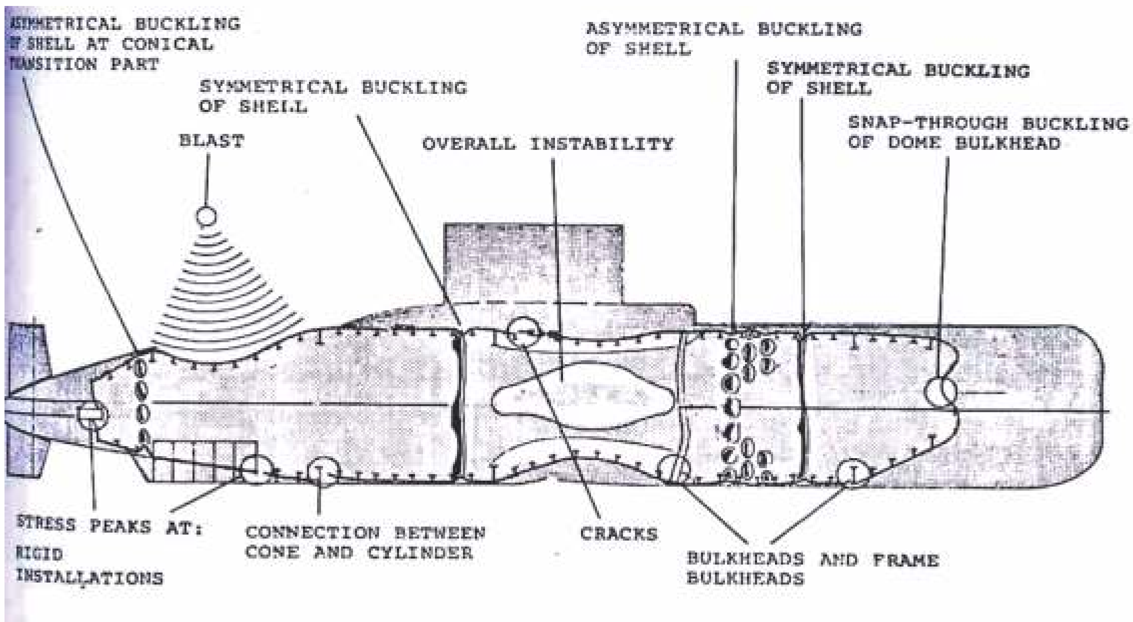

Figure 8 – Modes of structural failures for submarine [8]

4. Materials for submarine hulls

4.1 Material selection for hulls is one of the most important tasks during the submarine design stage. It is required to survey and ascertain the materials available for hull construction and assess their suitability for design based on several factors including availability, reliability and maintenance (ARM). Broadly the following design considerations are made for submarine hull material selection:-

(a) High Strength to Density Ratio.

(b) High Yield Strength

(c) Modulus of Elasticity

(d) High Impact Strength/ Fracture Toughness

(e) Ductility

(f) Low Magnetic Properties (desirable)

(g) Good Weldability

(h) Corrosion Resistance

(j) Fatigue Strength

(k) Availability

(l) Cost

Table 1 – A comparison of material properties [10]

Material	σ_{UTS}(MPa)	E (Gpa)	ρ kg/m	σ_{UTS}/ρ m/s	E/ρ $(m/s)^2$
Medium strength mild steel	370	200	7840	$47x10^3$	$26x10^6$
High-strength mild steel	1550	200	7840	$198x10^3$	$26x10^6$
Aluminium alloy	430	70	2800	$154x10^3$	$25x10^6$
Titanium alloy	690	120	4500	$153x10^3$	$27x10^6$
High-strength GFRP	1600	60	2000	$800x10^3$	$30x10^6$
CFRP	1400	170	1600	$875x10^3$	$105x10^6$

4.2 Most commonly used steel for submarine design is high strength alloy steel with yield strength, σy = 500-700 MPa. The steel alloys are primarily chosen for construction due to their high modulus of elasticity and it is possible to design on basis of yield rather than buckling load. But, for very high yield strength, buckling stiffness may become a criterion. Different types of steels used for submarine construction are High Yield 80 (HY80), AK 25 and 10XSND.

4.3 Newer construction materials like Aluminium, FRP have been considered and employed in submarine hull construction with limitations. These materials have been used partially for constructing upper casings, fins, masts and sonar domes of submarines. They primarily pose limitation in exploitation as structural materials due to lower yield strengths and limitations in fabrication.

4.4 Titanium alloys for pressure hull have been used only by Russia. This alloy is very expensive and difficult to fabricate, but has very high strength to weight ratio (approximately 288). Titanium alloys are used for making sonar domes in submarines due to their non-magnetic properties.

4.5 While the submarines have become more silent and almost non-detectable with advanced technological designs, hull material is an area which still can be explored for reducing the magnetic signature and enhancing stealth. The use of non-magnetic variants of steel can be used for pressure hull for minimizing the magnetic signatures. This philosophy has already been employed in the Soviet minesweepers wherein, non magnetic U3 steel was used as the hull material. This special type of steel used for minesweepers reduced their vulnerability to magnetic mines, torpedoes and magnetic anomaly detection. However, the experience of working on U3 steel has revealed the following concerns:-

(a) Welding process has preheating requirements.

(b) Reverse polarity is to be used for minimizing heat affected zone (HAZ).

(c) Frequent cracking of the HAZ and weldment post hot work.

(d) Gas cutting using oxy-acetylene torch cannot be used.

4.6 In view of the above problems encountered during fabrication and repairs of U3 steel, serious limitations exist in its use as material for pressure hull construction. Presently, U3 steel has been employed in fabricating parts of outer hull of Russian submarines but not yet selected for pressure hull of a submarine. Accordingly, a need for material exists which should have adequate strength, good non-magnetic properties, corrosion resistance and ease of fabrication and repairs. Considering these requirements, austenitic steels with non magnetic properties and yield strength of 500-700 MPa seem a possible material option for pressure hull of a submarine. After surveying the materials available for magnetic stealth design, AISI Type 316, Nitronic 50, AL 6XN and the German stainless steel 1.3964.9 were found to meet the criteria for building a submarine with non-magnetic pressure hull.

Table 2 – Austenitic stainless steel options for pressure hull construction [2]

Steel	1.3964.9	Type 316	Nitronic 50	6XN
wt%				
Carbon	0.04 max.	0.08 max.	0.06 max.	0.03 max.
Chromium	20 to 21.5	16 to 18	20.5 to 23.5	20 to 22
Nickel	15 to 17	10 to 14	11.5 to 13.5	23.5 to 25.5
Silicon	1.0 max.	1.0 max.	1.0 max.	1.0 max.
Manganese	4 to 6	2.0 max.	4 to 6	2.0 max.
Molybdenum	3.0 to 3.5	2 to 3	1.5 to 3.0	6 to 7
Nitrogen	0.20 to 0.35	0.05	0.20 to 0.40	0.18 to 0.25
Niobium	0.25 max.	—	0.10 to 0.30	—
Vanadium	—	—	0.10 to 0.30	—
Copper	—	—	—	0.75 max.
Sulfur	0.010 max.	0.030 max.	0.030 max.	0.030 max.
Phosphorus	0.025 max.	0.045 max.	0.040 max.	0.040 max.
Ultimate tensile strength (MPa)	696 to 951	579	717 to 827	744 to 772
Yield strength (MPa)	430 min	290	393 to 413	365
Elongation (%)	35 min	50	50 to 60	47 to 50
PREN[(A)]	38.6	28.7	39.8	49.1

[(A)] PREN = %Cr + 3.3(%Mo) + 16(%N)

4.7 In the basic form stainless steels have aferritic (α) grain structure, similar to carbon steel, and are magnetic. The addition of nickel in the 300-series stainless steels modifies the crystal grain structure to austenitic. The austenitic grades are mostly non-magnetic in the unworked state due to their nickel content. When 300-series stainless steels are cold-worked, straining of the atomic lattice structure in the areas of cold-working forms the magnetic grain structure called martensite. [14]

4.8 Nickel and Manganese when alloyed to steel act as austenite stabilisers. Austenite is a predominant phase at room temperature because of the addition of sufficiently large amounts of Ni or Mn. In such state, alloy is called austenitic steel. For example, Hadfield steel (13% Mn, 1.2% Cr, and 1% C) and (18% Cr and 8% Ni) austenitic stainless steel. The higher the nickel content the more stable is the austenitic structure and less magnetic is the response from cold-working. Consequently, 316 stainless steel with higher amount of nickel exhibits virtually no magnetism after cold-working in most cases. While 304, with lower nickel content, may become mildly magnetic. [15]

Figure 9 – German Navy's Type 206A submarines with 1.3964.9 nonmagnetic steel hull [2]

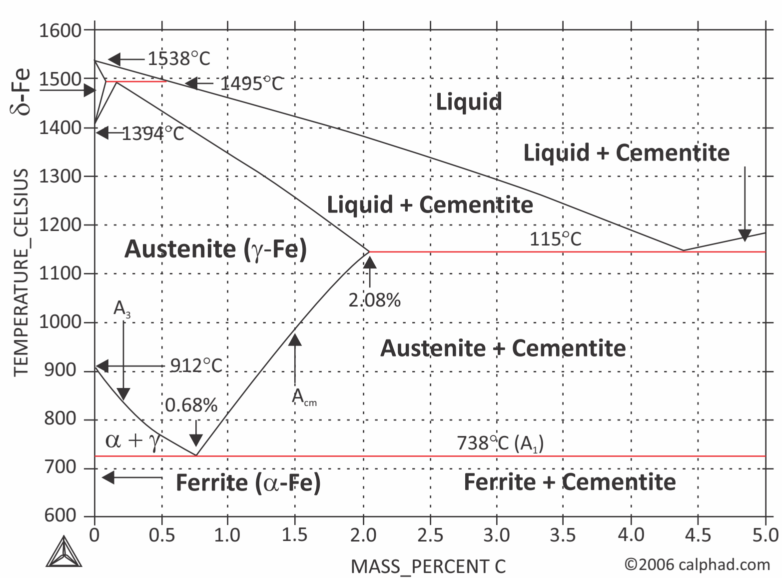

Figure 10 – Iron-Carbon Phase Diagram [15]

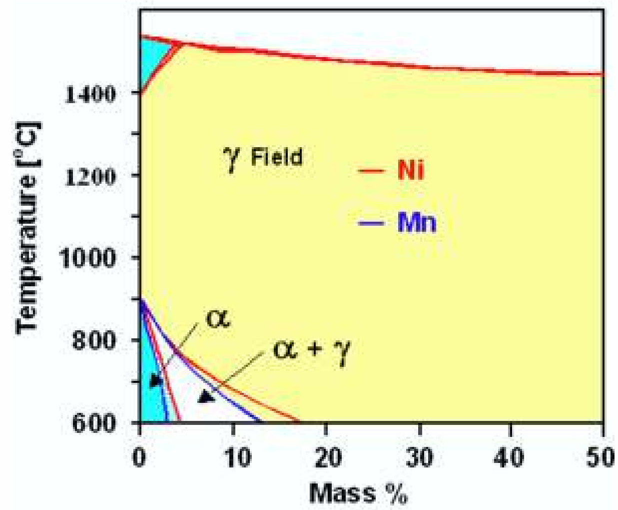

Figure 11 – Stabilisation of Austenitic phase by alloying [15]

4.9 For an austenitic stainless steel to be considered a candidate material for nonmagnetic ship or submarine hull, it must maintain its nonmagnetic behavior even after deformation and welding. Regarding deformation, it should be recognised that during fabrication the metal is bent to the design contours of the ship/ submarine, which may require to be cold worked from 1% to 3%. Also, a combatant vessel may be required to sustain rupture or high plastic whipping loads.

4.10 Accordingly, hull materials should have a deformation-modified martensite start temperature well below the ambient, as the introduction of body-centered cubic (BCC) martensitic phases could change the magnetic permeability of the material. For the German hull steel 1.3964.9, low magnetic permeability in the presence of high levels of deformation has been demonstrated by extensive testing. Comparable testing of 6XN, Nitronic 50, and Type 316 remains to be carried out. Regarding welding, since 6XN is conventionally welded with nonmagnetic nickel-based alloy electrodes such as Alloy 625, Alloy C-276, and Alloy C-22, the welds are expected to be fully nonmagnetic.[2]

4.11 The conventional method of welding austenitic stainless steels such as Type 316 and Nitronic 50 involves producing a final weld microstructure that is a mixture of the nonmagnetic austenite and the magnetic delta ferrite formed at high temperatures. The presence of delta ferrite significantly reduces the susceptibility of the weld to hot cracking/tearing. The optimum delta ferrite content for inhibition of hot cracking is 3% to 8%, and this level of magnetic delta ferrite produces a magnetic permeability that is not acceptable for mine countermeasure vessels. However, it has been possible to identify weld filler compositions that maintain substantial delta ferrite levels just prior to solidification and then convert to the nonmagnetic austenite phase upon final solidification.

4.12 With these fillers, resistance to hot cracking/ tearing is retained, and the final weldment is nonmagnetic. Studies in Australia and Japan have shown that filler composition ranges that exhibit this behavior include the German filler 1.3954.0 (22.0% Cr, 17.5% Ni, 7.5% Mn, 3.5% Mo, 0.7% Si, 0.025% C, 0.2% N, and balance Fe), used for welding the hull steel 1.3964.9. Analysis for crevice and pitting corrosion has also revealed satisfactory results.

4.13 The German Navy uses sacrificial anodes for cathodic protection in areas of the 1.3964.9 stainless steel hulls where additional protection against corrosion is needed. Such methods of protection are a major source of electric currents flowing around the hull. These currents are referred to as "underwater electric potentials" (UEP). At close range the UEP field can activate some types of mines. The UEP field can also generate a related magnetic field which decays more slowly and extends further than the electric field. This magnetic field has a different origin than the magnetic field associated with the ferromagnetic content of hull and machinery materials, and cannot be controlled by conventional degaussing-type treatments. An additional electromagnetic field, called the "extremely low frequency electromagnetic" (ELFE) field is derived from poorly filtered impressed current supply or a modulation of the corrosion protection current flowing through the bearings in the shaft.

4.14 Other electromagnetic fields could arise from the galvanic currents which are generated if the material used for the hull is different than that used for the shafts and propellers. Sedriks [2] has brought out in his work, that no galvanic corrosion occurs when superaustenitic stainless steels such as 6XN are galvanically coupled to titanium alloys or nickel-chromium-molybdenum alloys such as Alloy 625 or Alloy C-276.19 Weld-overlay or spray formed coatings of these materials would be expected to exhibit similar behaviour. Additional investigations are warranted in this area.[16]

4.15 Type 316, which is cheaper than 6XN and Nitronic 50, is a common, commercially available stainless steel that may be useful for fabricating non-wetted internal ship structures such as internal decks and non-watertight bulkheads, which are a significant part of the total structure. For welded construction, Type 316L should be used to eliminate risk of intergranular corrosion, which can occur in the marine atmosphere. Also, possible use of Type 316L for the inner shell of the advanced double hull design cannot be ruled out.[2]

5. Conclusion

5.1 Avoiding detection at sea surfaced or submerged empowers a submarine tremendously and augments the surprise element of warfare. While traditionally steel has been used as the material for hull construction both for ships and submarines, recent developments have focused on use of non conventional material. U3 steel, titanium, GRP are the examples of non conventional ship building material used in the navy. Accordingly submarine construction industry is looking for newer materials for pressure hull design to have better stealth characteristics. While, research is on in the US, German Navy has commissioned Type 206A and 212 non-magnetic hull submarines into the service. Their performance in the service has been reported to be highly satisfactory. This has forced submarine designers to seriously consider the option of innovation in pressure hull design and look for newer material. In the Indian naval context, we are still in budding stages of submarine construction and have our own share of difficulty. However, in order to succeed as a potent blue water navy, we need our defense laboratories to explore newer options of material design and ascertain the suitability of the material in the following regards:-

(a) Magnetic permeability

(b) High strength to density ratio.

(c) High yield strength

(d) Modulus of elasticity

(e) High impact strength/ fracture toughness

(f) Ductility

(g) Good weldability

(h) Corrosion resistance with specific impetus to crevice and pitting corrosion.

(j) Fatigue strength

(k) Fabrication methodology

5.2 The experience of operating U3 steel minesweepers will be very useful in guiding the way ahead for designing a non magnetic material suitable for construction of pressure hull of a submarine. A dived submarine with no or least magnetic signature will surely be a lethal weapon against any enemy.

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article 22

DEFENCE RESEARCH, DEVELOPMENT AND PRODUCTION NEED TO REDESIGN AND REALIGN

(Lt Cdr Vikram Singh)

"According to McKinsey Global Institute (MGI) analysis, as global economic growth slows down in future (as is projected), supply of capital will fall short of demand by 2030. This is especially important for economies with limited Research and Development (R&D) infrastructures as they could become even more restricted in building a foundation for R&D in future than they are now".[1]

Introduction

1. **Defence Products for Indian Armed Forces.** India is located centrally in the Indian Ocean, and shares its border with seven countries. This strategic location exposes India to threats from sea and land. However, the country has following challenges in ensuring defence preparedness:-

   (a) Majorly dependent on imported defence equipment as also a very nascent domestic manufacturing base. Approximately 70 per cent of defence equipment is imported, making India world's largest importer.[2]

   (b) Obsolescence of defence equipment in India has been highlighted by the Service Chiefs at various fora thus raising serious questions about India's war-preparedness.

   (c) India has not kept pace with global standards due to limited success achieved through efforts of DRDO, Defence Public Sector Undertaking (DPSU) and Ordinance Factories to boost indigenous R&D.

   (d) Low investment by Indian private sector in Defence R&D and manufacturing due to challenges faced by them as follows:-

      (i) Shortfall of investment in technology innovation and upgradation.

      (ii) Complex policy environment coupled with bureaucratic delays in procurement.

      (iii) Lack of tax incentives and monetary support for defence manufacturing which suffers from lumpy investments, limited order size and a prolonged gestation period.

      (iv) Lack of supporting infrastructure and robust supply chain including availability of raw materials adhering to military specifications/standards.

2. The concerns of Indian Industry have been well articulated and understood over the past decade or so. The revisions of Defence Procurement Procedures, Increase in FDI limit, revisions in Offsets policies, encouraging participation of major Indian Industrial firms to partake etc. are indicators that the Government is serious in its endeavour to develop the Indian Defence manufacturing industry. The paper discusses the Indian Defence R&D so far, discusses two

Global success models viz US and China with the aim to draw out our plausible recipe for achieving success in Defence manufacturing under the ambit of 'Make in India'.

Defence Research and Development Organisation (DRDO)

3. **DRDO means Defence R&D in India.** Defence manufacturing is an expensive business with minimal incentives for private industry. Defence Research and Development Organisation (DRDO) and Research and Development in Defence Manufacturing have remained synonymous since 1958. The defence industry in India has been largely state controlled. DRDO comprises 46 scientific laboratories and six establishments[3] and maintains a strong partnership with about 40 premier academic institutions, 15 national Science and Technology (S&T) agencies, 50 Public Sector Units [PSU's, including nine Defence PSU's (DPSU's)], 39 Ordnance Factories (OF's) and 1000 plus private sector industries.[4] The investment in R&D by the Indian Defence Industrial Base (DIB), i.e. by the DRDO, DPSU's, OF's, private sector and armed forces, in absolute terms, is relatively insignificant by world standards. The best performing Indian defence industries thus far have been Hindustan Aeronautics Limited (HAL), OF's put together under the Ordnance Factory Board (OFB) and Bharat Electronics Limited (BEL)[5] of which, BEL invests just around 6-8% of its annual turnover in R&D.[6]

4. **DRDO Approach.** On successful development of lab prototype system, trial evaluation and acceptance by the armed forces, technology is transferred to Production Agency (PA) i.e. Indian industrial entities to manufacture the product for meeting requirements of armed forces. While transferring technology to Indian industrial entities, DRDO provides relevant 'know-how's & 'know-whys' to enable industries to add value.[7]

5. **Shortfalls in Defence Products Development**.Despite combined successes in high end technology areas by DRDO-DPSU/OF/Private Industry, R&D ecosystem in India and DRDO in particular has faced criticism for numerous reasons starting from projecting unrealistic cost and time estimates for indigenous projects[8], delays in completion of ongoing projects leading to steep escalation in cost and compelling Forces to import expensive foreign equipment[9], not meeting qualitative requirements as specified by Services, unduly long developmental times, greater focus on technology demonstrator projects to gain publicity, inadequate experience of developing tactical military systems and so on. A detailed study was undertaken by Standing Committee on defence and the report was tabled in the Parliament on December 22, 2014 highlighting areas of concerns as short falls in budget affecting technology development, state of S&T and development of infrastructure and facilities related to projects, no enhancement of scientific manpower in DRDO since 2001 albeit multi-fold increase in number of projects, difficulties in talent retention view increased opportunities/incentives available in other organisations/industries, time and cost overruns in projects, content of research programmes sponsored through universities, budgetary provision and actual allocation of funds to Universities, their system of monitoring etc.[10]

6. **DRDO Rationale for Limited Success.** DRDO has attributed the cost and time overruns issue to a host of factors such as ab-initio development of state of art technologies, inadequate trained/skilled manpower for ab-initio development projects, non-availability of required infrastructure or test facilities, technical / technological complexities of system design leading to major mid-course redesigning, non-availability of critical components / equipment / materials and denial of technologies / sanctions by technologically advanced countries. Certain other cited reasons include enhanced user's requirements, changes in specifications during development, increase in scope of work, extended and long-drawn user trials, failure of some components during testing and trials and in certain cases original PDC not being pragmatic due to under-assessment of developmental effort owing to a lack of experience etc.10.

7. **CAG Observations on DRDO's capabilities.** In 2011, the Comptroller and Auditor General (CAG) put a serious question mark on DRDO's capabilities. To cite the CAG observations "the organisation, which has a history of its projects suffering endemic time and cost overruns, needs to sanction projects and decide on a probable date of completion on the basis of a conservative assessment of technology available and a realistic costing system..."[11]. The CAG also observed that nearly 60 percent of DRDO produced products were rejected by the armed forces, while crucial projects were delayed for decades. A few notable delays of DRDO projects are:-

(a) Arjun Main Battle Tank

(b) Light Combat Aircraft (LCA) Tejas

(c) Nag anti-tank missile

(d) Trishul anti-aircraft missile

(e) Kaveri engine for the LCA

(f) Nishant UAV

Global R&D Investments at a Glance

8. **Investments in R&D.** The global R&D investments made by nations are closely linked to their economies or Gross Domestic Product (GDP) and are expressed in Gross Expenditure on R&D (GERD). In 2014, global R&D funding had brought out United States (US) with a GDP of 16,616 billion US $ as the world's largest R&D spender recording a GERD of USD 465 billion (Table I)[12]. This R&D investment was 2.8% of US GDP and accounts for 31.1% of global R&D spending of USD 1618 billion. The world's top 10 R&D investors are tabulated below. US, China and Japan invest beyond USD 100 billion, Germany, South Korea and France between USD 50 to 100 billion and UK, India, Russia and Brazil between USD 30 to 50 billion. Further, India's expenditure on R&D as a percentage of GDP is a meagre **0.9% which is the least out of the top 10 spenders** while, the Asian economies of China and South Korea spend more than 2%.

Table I, Gross Expenditure on R&D

Sr	Country	GDP PPP bn US $	R&D as % GDP	GERD PPP bn US $	% Global R&D Spending
(a)	US	16,616	2.8	465	31.1
(b)	China	14,559	2.0	284	17.5
(c)	Japan	4,856	3.4	165	10.2
(d)	Germany	3,312	2.9	92	5.7
(e)	S Korea	1,748	3.6	63	3.9
(f)	France	2,319	2.3	52	3.2
(g)	UK	2,454	1.8	44	2.7
(h)	India	5,194	0.9	44	2.7
(i)	Russia	2,671	1.5	40	2.5
(j)	Brazil	2,515	1.3	33	2.0
Global Spending		**88,733**	**1.8**	**1,618**	**100.0**

Source*: Adapted by the author from Battelle, R&D Magazine, IMF Fact Book, December 2013*

9. Collaborations with technology firms and research organisations in US and Europe are increasing as Asian economies are seeking to leverage global scientific knowledge and capabilities. Major infrastructure investments continue to be made, often with goal of creating an innovation ecosystem, with mechanisms for technology commercialisation and industry engagement, leading to amplified economic returns from research investment[13]. Developing countries like Brazil, China and India, which are striving for R&D based growth, need to build their talent and capabilities, identify technology markets and have the will to invest. India being the world's fourth-fastest growing economy, has developed substantial academic infrastructure, a large population dividend and enhanced its global connectivity[14]. ***Yet, the social and political compulsions have kept the investment away from R&D.***

10. **Global Lessons**.The models adopted for R&D by the top two spenders in R&D have been discussed in the succeeding paragraphs with a view to derive the best practices for the Indian context.

Research and Development in US

11. The United States have consistently committed 2.5-3.0% of their GDP towards R&D with participation of both public and private research. In the U.S., the government seeds innovation with investment in basic research and provides tax and policy incentives. However, technologies to invest in for immediate future are determined by the markets. The

sources for R&D in order of investment and performance in the US are:-

(a) Industry

(b) Academia

(c) Federal government

(d) Non-profit organisations[15].

12. The US Department of Defence's (DOD's) Research Development Test and Evaluation (RDT&E) programme supports development of future military hardware and knowledge and technological base which helps build defence products. RDT&E programme budget of approx USD 66-73 billion (doubled since 1990) constitutes 53% of federal government's R&D budget[16]. Over 80% of RDT&E budget goes to develop or demonstrate specific military systems and components called Weapon Development Activities (WDA's)[17]. Balance 20% is for primary R&D in sciences and technologies which are identified as vital for developing improved military capabilities and operations. DOD's Defence Technical Information Center (DTIC) serves the DOD community as the largest central resource for DOD and government funded scientific, technical, engineering, and business related information. With a broad footprint, DTIC allows the DOD to reduce duplication and build on previous research, development, and operational experience. DOD's basic research programme (almost 60%) is for universities while 25% is for DOD's own R&D facilities.

13. Federally Funded R&D Centres (FFRDC's) funded by the US government to address research and development, engineering, and analytic needs that cannot be met as effectively by existing government or other contractor resources. FFRDC's, of which some are operated by industrial firms, research institutes (non-profit) or universities are governed by a sponsoring agreement with operational restrictions and must follow as befitting their special relationship with the government, including operating in public interest with objectivity and independence, being free from real or perceived organisational and personal conflicts of interests, and having full disclosure of its affairs to its primary sponsor. FFRDC's are intentionally located outside the government to provide a long-term strategic relationship and management flexibility to attract and retain high-quality scientists and engineers.

14. US R&D mechanisms evolved between 1970 to 1990 and DOD's introduced the Dual-Use Applications Programme (DUAP) meant to stimulate the Services into pursuing dual use programmes. DARPA was given the lead in initiating these kinds of programs.

15. **DARPA Success.** DARPA is a non-hierarchical organisation with primary role to oversee creative research in short programmes typically for four to six years. It does not have any of its own R&D labs. It identifies talent and ideas from the industry, academia, government laboratories and individuals and awards R&D contracts. DARPA has six technology programme offices with about 140 programme managers and a small support staff: a workforce of around 250 personnel. DARPA's overall objectives are to "demonstrate breakthrough capabilities for national security" and "catalyse a differentiated and highly capable U.S. technology base. For this, DARPA solicits and reviews proposals with the military

services and awards grants for basic and applied research with the most innovative potential. DARPA serves as a catalyst for developing disruptive capabilities, with support from the upper echelon of defence acquisition community. DARPA has been successful in several radical innovations including in the areas of stealth, internet, Global Positioning System (GPS) and Unmanned Aerial Vehicles (UAV).

Research and Development in China

16. China by increasing its R&D investments between 12% to 20% annually from 1990's reached USD 284 billion investment in 2014. China through sustained R&D intensity would surpass the US by about 2022[18]. To become an innovation-based economy by 2020, China has accelerated its research conversion into development demonstrated by investment in both civil and military hardware. Also, China's significant advanced R&D is pursued in collaboration with the U.S and European research organisations respectively.

17. **Military R&D.** China's allocation on military RDT&E is estimated to be more than 6% of its total defence budget[19]. Also, the RDT&E policy directive mandates state-run defence enterprises to spend at least 3% of annual revenues on R&D by 2020. Further, several agencies and government departments invest in R&D as Civil Military Integration (CMI) policy encourages dual sector integration. In addition, there are inflows from China's promotion of foreign investments in non-defence R&D sectors. Since late 1990s, Chinese defence R&D apparatus has undergone a revamp and grown to conduct high quality work. The key goals of the reforms include enhancing basic research capabilities, diversifying the managements funding from state to corporate sector, bringing defence R&D system closer to national innovation system, and maintaining close linkages with universities and civilian research institutes[20]. Much of China's defence technological development over last two decades is attributed to import and absorption of technologies and knowledge from abroad, especially from Russia. China regularly produces near-replicas of foreign weapons systems based on Russian, Ukrainian, French, Israeli or U.S. designs but aspires to be more indigenously innovative. Efforts have been made to corporatize R&D institutes by allowing major defence conglomerates to take them over. In the Chinese defence innovation system, imitation (where there is no research constituent), is primary focus of actions, besides effort to promote innovation, leadership and management are both top-down in nature. The Chinese Government and military organisations that manage defence science, technology, and industry are as follows:-

    (a) State Administration for Science, Technology and Industry for National Defence (SASTIND)

    (b) General Armament Department (GAD) of the PLA

    (c) Ministry of Industry and Information Technology (MIIT) with Civil-Military Integration Promotion Department (CMIPD)[21].

18. SASTIND and CMIPD are both key regulatory agencies in the new State Council. SASTIND issues defence industry regulations and inspects their implementation, directly allocates research funds through programmes such as the Defence basic research programme, and determines, with GAD, which enterprise may and may not engage in weapons and equipment research and production. CMIPD is to develop an integrated system of standards for both military and civilian products. New GAD and SASTIND regulations for licensing weapons and equipment producers have opened up defence contracts to civilian enterprises, enabling private companies to provide R&D services directly to the military. Notwithstanding, China's DIB is now increasingly becoming decentralised, with enhanced scope for local State-Owned Enterprises (SOEs) and privately owned enterprises to contribute to R&D and production. However, the responsibilities for R&D, testing, procurement, production and maintenance are with different units thereby leading to major gaps in information sharing.

Indian Context

19. Indian dependence on foreign manufactures for defence equipment has been an area of concern since the 1990s. Notwithstanding, limited success has been achieved in the past and it is likely that our commitment to invest in R&D remains under 1% of the GDP. The first step is to understand the environment in which our Military R&D has progressed. A like to like comparison with DARPA (though both organisations are different in their role) has been drawn up to derive a new Object Oriented Approach w.r.t the Indian context.

20. **DRDO Vs DARPA.** DRDO is the premier research organisation for India and DARPA the lead organisation for innovation in the US. While DARPA and DRDO were established around the same time (in 1958), DARPA has moved far ahead and established global benchmarks in defence R&D while DRDO is burdened with increased bureaucracy, endemic cost and time overruns, high expenditure on defence R&D, low risk taking appetite and virtually no accountability to the Services. A comparative between the organisations is as follows:-[22]

(a) DRDO annual budget is approx Rs 10,000 Crs (USD 1.8 billion) and DARPA has a budget of USD 2.8 billion.

(b) DRDO comprises of approx 7,000 scientists and 25,000 technical staff /support personnel and DARPA has approx 240 personnel (includes 140 technical staff).

(c) DRDO has dedicated state-of-the-art laboratory infrastructure comprising 52 Labs and DARPA operates from academia, corporate and government laboratories (operated by industrial firms).

(d) DARPA has field stations (DARPA Forward Cells in Combat Commands) in Afghanistan and Iraq, where they field emerging technologies and get direct feedback from forward troops and Combat Commands on the military application of these. The approach instills user confidence in equipment delivered by DARPA apart from being involved in future technologies. DRDO is yet to provide cutting edge technologies for field applications.

(e) DARPA participates actively in the conduct of field trials.

(f) DARPA projects typically last three to five years while some DRDO projects are spanning over two to three decades and finally lead to foreclosure.

21. **Creation of DARPA like Organisation for India.** The Kelkar Committee had proposed measures for greater self-reliance in defence production, benefits in terms of R&D, technology spinoffs, higher industrial growth and exports, increase the competition and provide more employment opportunities as well as cost savings. The impact analysis of recommendations of the Kelkar Committee conducted by a parliamentary committee concluded that implementation of measures outlined would result in a high degree of indigenous production and defence preparedness. The initial approach involved constitution of a multidisciplinary Task Force which was to prepare the proposal and indicate fund requirement, modalities of functioning, etc. The Task Force was to evolve a model for consideration of the government. However, this was not progressed and an approach paper on the proposed Agency for Defence Science & Technology Advancement and Research (ADSTAR), modelled on the lines of DARPA, was proposed.

22. The Rama Rao Committee had recommended replacement of present grants-in-aid programme of DRDO. The committee recommended forming a Board of Research in Advanced Defence Science (BRADS) on the lines of Defence Advanced Research Projects Agency (DARPA). It was recommended that BRADS should endeavour to access and utilise outstanding human resources available in non-defence laboratories and universities. BRADS should also encourage SMEs to undertake radically innovative research through the Small Business Innovation Research (SBIR) programme.

23. **Lessons from Chinese Approach.** The Chinese being a communist country have State controlled Defence R&D and have so far focused on low end technologies and reverse engineering / imitation. However, being a democratic country India has been marginally successful through the State Model approach and therefore, the Chinese investment in R&D should be the only take away for self reliance in Defence. From the Indian perspective, the Collaborations with US and Europe defence manufacturing firms may be better executed through Indian Private Firms wherein bottom lines would govern imbibing technology for future. Also, several agencies and departments in China invest in R&D as the CMI policy encourages dual sector integration and in areas of industry connect. On the other hand India, in the last few decades albeit it's lowest R&D to GDP ratios, has invested 55% of the GERD in strategic sectors of defence (DRDO), atomic energy (DAE), and space (ISRO)[23] and therefore has had a weak connect with the industry.

Conclusion

24. DRDO to follow the DARPA model has been discussed at the highest fora and finds favour with the Apex bodies within the country. Whilst the recommendations of various committee's aims to establish a DARPA equivalent for India, merely re-structuring of DRDO/CSIR/ISRO will

defeat its intended purpose. Therefore, we need to form a separate organisation which should be tasked to perform the DARPA function (identical to the US model) and transfer the DRDO labs to Indian Industries in a phased manner. India needs to provide the DARPA environment (unlike the existing DRDO safe and bureaucratic model) and provide enormous freedom to the New Indian DARPA to award R&D contracts to any agency without having to go through protracted bureaucratic approval processes. It must also be known that 85-90% of DARPA's projects fail to meet their full objectives[24] and is well understood and accepted by US government. India needs to be ready through its policies for this very high percentage of failure.

25. DRDO has in the past has acted independently and on most occasions missed the requirements of Users/ Production Agencies (Pas). The state controlled PAs viz DPSU's and OF's have proved inefficient and unproductive in the past and have still been shielded and sheltered. Present day Indian private industry is more enthusiastic about entering the defence sector than ever and are Collaborating both with Foreign OEMs as well as Indian Academia through IITs, IISc, NIITs etc. The armed forces have at the moment limited confidence in DRDO's capabilities. Thus, the has time come when India, like US and China, also needs to initiate serious and meaningful reforms in its research and development, design and engineering and manufacturing and production segments of the defence sector. Merely forming synergistic committees and retaining archaic review mechanisms would defeat the long term objectives of 'Self Reliance'. Defence Business has proved a lucrative business for the developed countries and therefore the same should hold for the Indian context as well.

Recommendations

26. The Services provide the Long Term Integrated Perspective Plan (LTIPP) to the DRDO, which outlines the broad requirements of the Services. DRDO prepares a document on Long Term Technology Perspective Plan (LTTPP) derived from the LTIPP, which highlights the expected new technology developments in various areas. However, in these the milestones and budgets allocated for developing all the identified technologies by the Services and the DRDO and contribution of Indian industry are not mapped as done in the US system. Therefore, R&D ownership from the private sector has not been forthcoming. Further, the environment to ensure seamless technological information between the military R&D stakeholders i.e. developers, policy-makers and users (armed forces) can only be achieved if no turfs are drawn and all are equal partners in the national technology development process. The recommendations that emerge for ensuring a self-reliant defence industry are as follows:-

(a) India needs to increase its investment towards R&D from the present 0.9% of GDP to atleast 2.5% of GDP and sustain the commitment for 10-15 years.

(b) Indian Industry needs to be the major contributor for R&D and this can only be ensured through hand-holding by Government. Like the US, Indian Industry must contribute 70-

75% of the R&D and Government should reduce its stake to 15% or so and the rest could be from Academia.

(c) Economies of Scale can be ensured through investing in technologies with Dual application (Civil and Military) and should have a Global market. Whilst ISRO and DAE have contributed to space and atomic energy, their niche nature and requirement to closely guard their technologies defeats industries opportunity for economic growth and therefore India must spend at least 60-70% of its R&D investments in areas with industry connect.

(d) Roadmap for Basic Research, Advanced Research and Applied Research should be comprehensively drawn up to derive industrial applicability of this research work for civil-military applications. For this, national goals in certain fields needs to be identified and the requisite funds allocated to support the various types of research with priority to applied research. The applied research needs to be steered by Indian industry partners (50-60%) and the balance may be undertaken by DRDO (with increased participation from the Indian Private Firms). The existing role of DRDO partnering with DPSUs/OF's therefore needs a revisit.

(e) Developmental Plans should be drawn up with four – six year horizons with 'performance based budgeting'. The project reports must bring out anticipated areas where challenges are likely as well as their mitigation strategy. The Projects with DRDO must be audited by and independent body for their progress and performance. Also, this body should be rated for its precision in assessment. The higher rated organisations (could be private) would graduate to evaluation of higher value projects (in a phased manner).

(f) Creation of a central repository of technological requirements, projects, research and personnel database etc. must be available for utilisation by the conceived Indian DARPA.

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Author's Biodata

Commander Achal Malhotra is a graduate from the National Defense Academy and was commissioned into Engineering Branch on 01 Jul 1997. The officer completed his B Tech (Mechanical) from Naval College of Engineering (80th Basic Engineering Course) in Dec 99 and is an active submariner since Dec 03. In 2007, the officer completed his ME (Marine) with distinction from Defense Institute of Advanced Technology, Pune where he was awarded Lord Rayleigh award for standing first in 'Vibration Studies' as also Gold Medal for standing first in order of merit. Further, in Oct 13, the officer was awarded Chief of Naval Staff Gold Medal in the Technical Management Course at Naval War College, Goa.

Cdr UP Singh, was commissioned into the Engineering Branch of the Indian Navy in the year 2003. The officer completed his BE (Mech) in 2003 from Naval College of Engineering, INS Shivaji, Lonavla and MTech in Nuclear Science from Homi Babha National Institute in 2011. His appointments include tenures as Senior Engineer Officer onboard INS Sindhuraj & INS Sindhuvijay and Engineer Officer onboard INS Sindhuratna. The ashore appointments held by the officer was Deputy Project Director and Senior Instructor Diesel & Gas Turbine Wing at INS Shivaji, Lonavla. The officer is presently posted at Directorate of Submarine Acquisition at IHQ MoD (N).

article 23

'PROJECT MANAGEMENT' AN ESSENTIAL TOOL FOR SUBMARINE CONSTRUCTION PROJECTS

(Captain Gaurav Doogar)

"How does a project get to be a year late? One day at a time".
- Frederick Brooks

Background

1. The developments in India's immediate neighbourhood over the past decade have led India to take a close look at her security policies. The recent advances have increased the widely-sensed need for the rapid modernisation of the Indian Armed Forces.

2. However, many defence analyst have raised a question on preparedness of Indian armed forces. According to published literature, India's land forces lack sophisticated weapons and armoury, the Navy's submarine fleet has dwindled down to 40 percent of the minimum requirements, and the fighter squadrons are at the level of 60 percent of the mandatory need, which indeed is a cause of concern.

3. In order to bridge this gap and overcome the deficiencies in the defence capabilities, the Government of India has taken key initiative through 'Make in India' programme, to boost economic growth, induct state-of-art technology and give impetus to up-gradation of defence capabilities. This initiative by the GoI also gives a great responsibility and onus on the Armed forces and its personnel to participate in the Nation building process with full commitment, professionalism and competence and make the programme a thriving success.

4. This paper is an attempt to highlight the use of 'Project Management' as a management tool to fast-track the shipbuilding and submarine construction process, by avoiding delays and cost overruns, which can be achieved through various techniques and methodologies employed by project management.

Need for Robust Submarine Construction Programme

5. The Indian Navy's area of operation includes the Arabian Sea, the Indian Ocean, and the Bay of Bengal. These waters include numerous sea lines of communication (SLOC) chokepoints, such as the Strait of Hormuz, Bab El Mandeb, and the Malacca Straits. Almost 97% of India's foreign trade by volume and 60% of the world's sea-borne trade and energy resources are transported through these strategic bottlenecks. This share of critical global trade is likely to be amplified by the growing energy demands and industrial exports of East and Southeast Asia.

6. There has been a gradual reduction in both the number and operational status of the present submarine fleet. The **Figure 1**, shows the existing gap between the desired and present gap between the vintage of submarine with the Indian Navy.

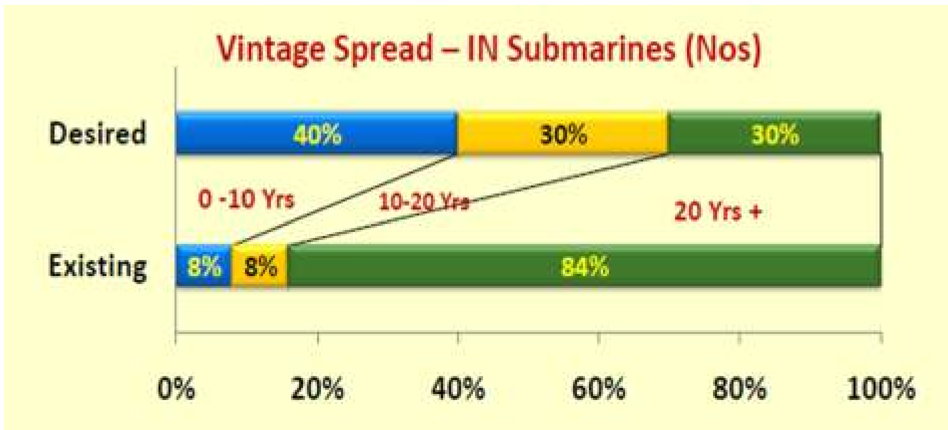

Figure 1

7. Thus, there is a strong felt need to focus and strengthen the modernizing programme of the Indian Navy's submarine fleet, with specific emphasis and attention on its nuclear and diesel submarine construction programmes, to build a strong deterrent attack force.

Project Management in Submarine Construction

8. Unlike any other form of surface ships, submarines must be able to operate quietly, swiftly, independently and for extended periods on-as well as deep under-the surface of the world's oceans. As warships, they also carry a remarkable array of weapons-offensive and defensive, as well as nuclear and conventional-which must be ready at all times. As a result, they are among the most complex inventions ever developed by mankind.

9. To survive safely and effectively in an alien environment, these machines must be rigorously built and maintained, and their operators must be carefully screened and trained for any scenario from normal daily operations to nuclear holocaust. The need for stealth, range and flexibility, while controlling the size and cost of the submarine has resulted in stringent design and construction requirements, which become more complex, when dealing with nuclear submarines. Few of the design and constructions complexities are as follows:-

   (a) Limited space and maintenance envelop

   (b) Peculiarity in onboard equipment due to depth requirements

   (c) High pressure and shock resistant material

   (d) Water Tight / Gas Tight integrity

   (e) Restricted shipping / unshipping routes

   (f) Stealth requirements

(g) Lethal weapon system

(h) Quality of workmanship such as Welding operations

10. It is essential that today the defence PSU and private shipyards, engaged in indigenous submarine design and construction are optimally equipped with latest design software, management tools, heavy engineering equipment, professional workforce and cutting edge technology, to ensure that these stealthy platforms are delivered in right time, quality and cost. It has become quintessential that the complete process of design, construction, monitoring and control are undertaken in a methodical manner using systematic tools and software. Though, the shipyards, both public and private, have adopted to this new requirement quite aggressively, it is opined that the Indian Navy is yet to adopt any robust management tool for managing, monitoring and controlling the new construction projects. One such tool, which is slowly growing importance, especially in Indian and Defence Industry is use of Project Management (PM).

11. Project Management is a set of principles, methods and techniques for effective planning of objective-oriented work, thereby, establishing a sound basis for effective scheduling, controlling and re-planning in the management of programs and projects. In other words, it provides an organization with powerful tools that improve the organization's ability to plan, organize, implement and control its activities and the ways it uses its workforce and resources. **Figure 2** shows how PM ensures optimal utilization of resources to produce desired goals, within allocated budget and planned timelines, and to desired level of performance.

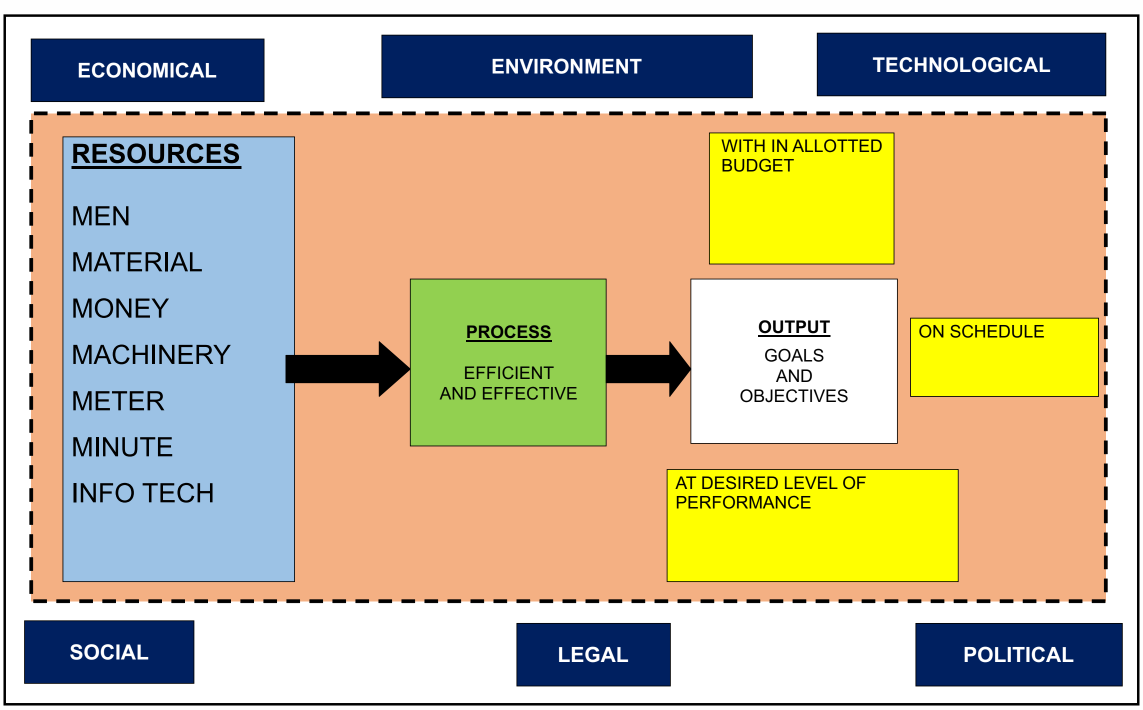

Figure 2

12. The project management technique has found use in widespread fields / sectors, such as following:-

    (a) Construction (buildings, bridges, motorways, etc)

    (b) Manufacturing Industry

    (c) Defence

    (d) Maritime, shipyards

    (e) Software development

    (f) Maintenance of large industrial plants

    (g) Critical Surgery operations

    (h) Films production

    (j) Elections Project

13. It is pertinent to mention that we often feel that Project Management is responsibility of the Contracted agency, such as supplier, vendor, shipyard, etc and not contracting agency or the Customer. However, PM is equally relevant for both and often becomes a leveraging tool for the Contracting agency to adapt to the various internal procedures of the shipyards, and to form close links with the nominated representatives and other stakeholders , for ensuring that the key issues of cost, time, quality, and above all, customer satisfaction, can be realized.

14. It is, therefore, right time, if not late, that the Indian Navy too realizes the potential of PM and implements the technique as an inherent management tool in all its internal process and work systems. It is required that officers and men who tenant important and crucial appointments in Design and Production Directorates are professionally trained to be certified PM professionals, so that they can perform their duties seamlessly.

Salient Aspects of Project Management (PM)

15. In the succeeding paragraphs, few salient characteristic and versatility of PM technique have been illustrated with focus on how it can used in any submarine construction project for better planning, monitoring, control and quality assurance.

16. **Project Planning and Organisation.** Project planning plays a vital role in successful implementation of a project. It includes stating the project objectives, defining tasks necessary to reach the objectives, making cost estimates, and preparing schedules & budgets. It also involves assigning overall segments of the plan to individuals, with a minimum of overlap problems.

17. **Planning Process**. The first step in project planning process is to prepare a list of overall project objectives or deliverables. Deliverables are the clearly defined results or outputs produced as an outcome of the project. A project objective has three dimensions; it must address the

following: -

(a) **What** is to be achieved (Specifications / QRs / Build Specs)?

(b) By **when** is it to be achieved (Time)?

(c) At **what** cost (Resources / Allocated Budget)?

18. In the Indian Navy, the Design and Production Directorates are responsible for managing the new construction projects. It is important that the personnel appointed in these organisations are aware of the above dimensions and their inter-relatedness. PM techniques, when applied to any complex submarine construction project, makes an individual or a project manager better aware of these conflicting goals of technical performance (Qrs), cost standards and time target and aids in better and quicker decision making.

19. **The Traditional Triple Constraints.**

(a) As brought out above, the most essential part of any project is maintaining the right balance between the triple constraints, namely scope, time, and cost. These are also referred to as the **Project Management Triangle** (Refer to **Figure 3**), where each side represents a constraint. One side of the triangle cannot be changed without impacting the others. A further refinement of the constraints separates product 'quality' or 'performance' from scope, and turns quality into a fourth constraint.

Figure 3

(b) As a customer, the Indian Navy, should realize that any change in scope will have an adverse effect on the cost and time of the project. It is, therefore, imperative that once the design and build specifications have been frozen, there should be no change in the scope or design specifications. Also, it is important that these specification should be frozen during the planning stage itself, much in advance to commencement of construction. The later the change in the construction stage, more are the time and cost penalties, as can be seen in the figure below (Refer to Figure 4):-

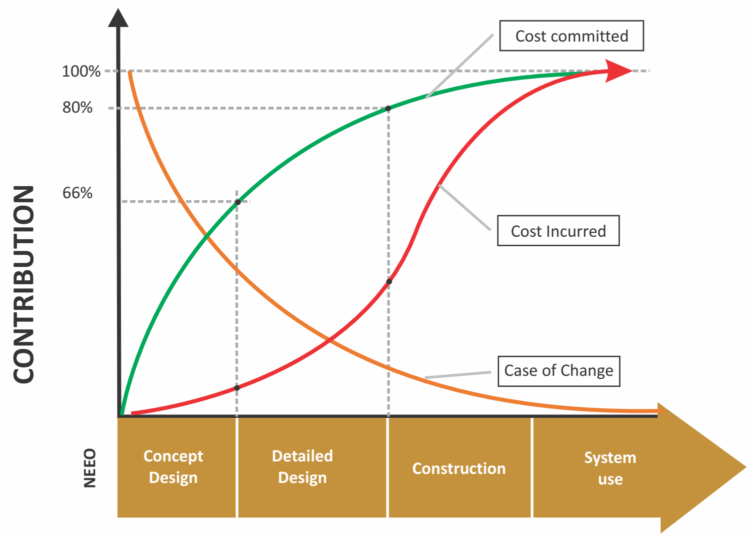

Figure 4

20. **Development of a Project Plan.** Once clear objectives have been set, the development of a project plan follows from answering a logical sequence of questions. A project manager / project monitoring team should be well aware of these tools to successfully monitor and control the construction project. These are outlined below: -

(a) **What is to be Accomplished?** Given the objectives, determine what tasks have to be done to achieve the objectives. This is done by what is often known as a **Work Breakdown Structure (WBS).** The WBS represents a systematic and logical breakdown of the project into its component parts. For example, construction of submarine can be broadly divided into three major sections i.e Hull, Engineering and Electrical / Weapons. These can be further divided into smaller sub-parts or activities, till there are in terms of manageable units of work for which responsibility for accurately defining, budgeting, scheduling and controlling can be assigned. For example, engineering construction can be further divided into Main Propulsion, Auxiliaries and Ship Systems and so on. **Figure 5** below shows WBS for installation of Main Engine on the submarine.

WBS (MAIN ENGINES)

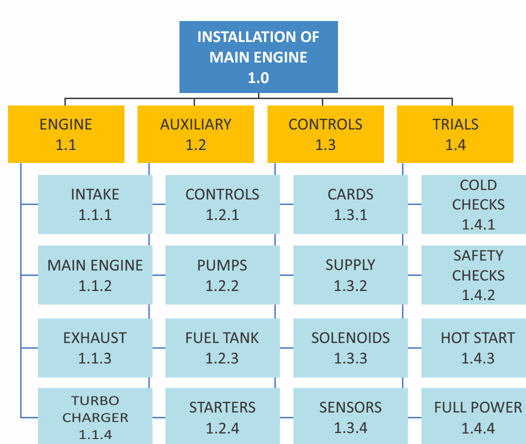

Figure 5

(a) Who is Responsible for What? Decide who is to be responsible for carrying out each task, determine the project team, and define a **Task Responsibility Matrix** (TRM). Work as defined by the WBS is assigned to responsible organisational units, contractors and individuals. The responsibility matrix lists down the tasks in project breakdown structure on one side and the appointments responsible for execution / supervision on the other. TRM is very relevant for Design / Production Directorates, as it useful for monitoring and assessing how well the responsibilities are being carried out amongst various stake holders. It also helps avoid 'passing the buck', between the stake holders, a common cause of delays and cost overruns in Government organisations. A typical method was for assigning responsibilities is shown in **Figure 6** below:-

Action By / Decisions By	DESIGN DIRECTORATE	PROFESSIONAL DIRECTORATES	DQA / CQAE	SHIP YARD	CLASS AUTHORITY	OEM	TRADER	IN TRIAL TEAM
DESIGN	R	-	-		C	-	-	-
SELECTION OF EQUIPMENT	C	R	I	A	C	A	-	-
CONSTRUCTION	I	-	-	R/A	C	-		-
MONITORING AND QA	R	I	R		R	-	-	-
TRIALS	I	R	R		R		I	R

Figure 6 R- RESPONSIBLE, A-APPROVE, I- INFORM C-CONSULT

(c) **What Resources are Required?** Identify what resources will be used for each task, answering questions such as: How many man-days or man-weeks are involved? What will they cost? What purchases and materials will be needed? At the end of which a **Project Cost Estimate** (PCE) is produced. Therefore, a PCE serves as a standard for comparison, a baseline from which to measure the difference between the actual and planned uses of resources. Hence, it is a very important tool was exercising strict control over the progress of the project and can be used by the Design Directorates / **Project Monitoring Group** (PMG) to ensure optimum utilization of resources.

(d) What must be Done When? Develop a Project Schedule (PS), putting the tasks into a logical sequence, and taking note of the time required for each task. A schedule is a project plan against calendar time. It is generally prepared by integrating the WCP, TRM with the project schedule shown by a bar / Gantt chart.

(e) How will Resources be Allocated? The cost estimate and project schedule synchronised together develop a Time-Phased Budget (TPB), which will allow the project to be monitored closely, at each cardinal milestone of the construction phase.

21. **Detailed Project Report (DPR).**

(a) A detailed project report is prepared by the Professional entity in consultation with the Shipyard, which is essentially a project plan in an executable format. It is an elaborate and systematic adoption of the feasibility report, which was prepared with the purpose of taking a decision regarding the go-ahead of the project. The DPR is essentially a tool for implementation answers basic questions such as when, why, what and who, as shown in **Figure 7**.

Figure 7

(b) The preparation of the DPR involves in-depth planning and detailed examination of all aspects of the project. The DPR consist of following major heads, viz. Project Summary, Technical plan, Reliability and Assurance provisions, Management plan, Risk Analysis and Contingency plan, Procurement and Logistics plan, Schedules, Financial plan, Environment, Safety and Health Protection plan, etc, typical to any construction project.

(c) A thorough knowledge of the DPR is, therefore, imperative for the PMG / Customer organisation, to understand the various activities involved at various stages of the construction phase, and can thus be used to identify check points or milestones, to measure the progress of the project, both in terms of money and time.

22. **Project Scheduling using Networks.**

(a) Shipbuilding involves multiple activities that are inter-related, inter-dependent and time-critical. Apart from conventional methods, like bar charts or Gantt charts (Refer to **Figure 8**), more scientific tools and techniques are required to be employed so that complexities of such operations are better comprehended and more easily visualised. Networks are powerful tools which could be effectively used for planning and controlling various new construction projects. Their employment can assist in better management and control of each complex activity, so that the delays and cost overruns can be avoided.

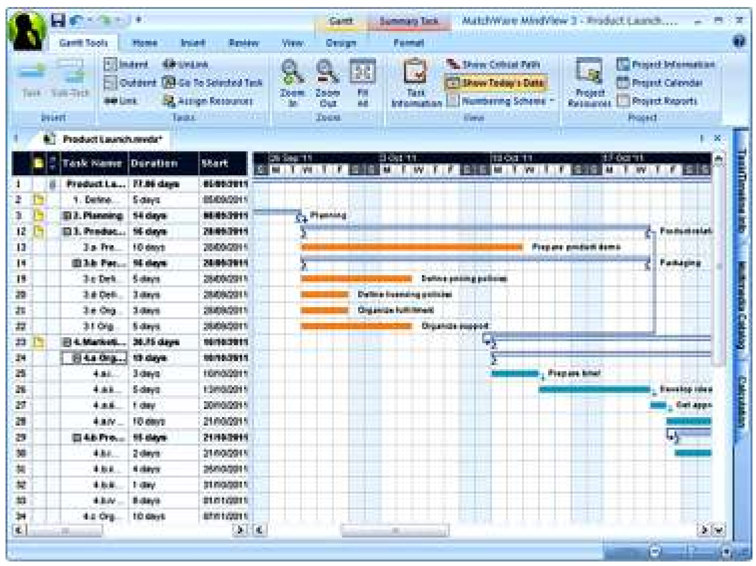

Figure 8

(b) The two most widely used Network techniques are PERT and CPM. PERT stands for 'Programme Evaluation & Review Technique' is a Probabilistic model and CPM is the abbreviation for 'Critical Path Method' is a Deterministic model. The techniques of PERT and CPM can be used by PMG / Design Directorates in monitoring that various activities are completed on schedule. The Network techniques minimize production delays, interruptions and conflicts. These techniques are very helpful in coordinating various jobs of the total project and thereby expedite and achieve completion of project on time.

(c) The additional advantages of this technique are that it permits the customer / PMG to foresee the effects of resource constraints (and if necessary, make contingency plans) and during execution enables the project manager to monitor deviations between predictions & actual results and institute corrective measures.

23. **Earned Value Management System (EVMS).**

(a) Economic viability of the project is assessed and reassessed at intervals throughout its development, both before and after the project has been approved. A low assessment, therefore, could bring a lot of trouble to those involved in the project. But a high estimate is also undesirable since it leads to a waste due to non-allocation of funds for alternate uses.

(b) Management must compare the time, cost and performance schedule of the programme to the budgeted time, cost and performance, not independently but in an integrated manner. Being within one's budget at the proper time serves no useful purpose if performance is only 75 percent. All three resource parameters - time, cost and schedule must be analysed as a group (or else we might "win the battle but loose the war") to verify that the correct standards were selected and that they are properly used.

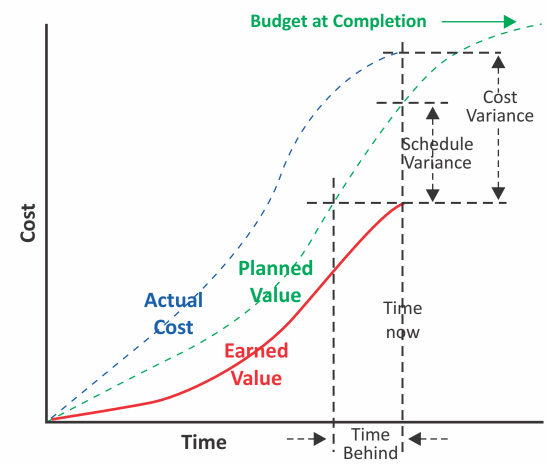

Figure 9

(c) EVMS is thus a very effective tool of PM for monitoring of projects as it gives true picture on the progress of the project in terms of Cost and Schedule Variances (Refer to **Figure 9**) and aids in taking corrective action at correct point of time.

24. **Project Monitoring & Control.**

(a) Monitoring involves watching the progress against time, resources and performance schedules during the execution of the project and identifying lagging areas requiring timely attention and action. The essence of good monitoring system is the speed of communication of dependable information on key result areas, the competence of the monitoring agency (Shipyard or Indian Navy) to interpret the signal and the ability to lead to intervention in a constructive manner.

(b) Monitoring and Control go hand in hand. While monitoring helps in identification of deviations from the plan, the control involves corrective action and ensures that deviations are overcome and performance is brought back to the planned course. Some of the common causes for deviations in any ship / submarine construction project are as follows: -

(i) Excessive optimism on the part of project planners, resulting in unrealistic estimates with regard to time, funds, manpower, work performance and other resources required to do an activity.

(ii) Change in the scope and design of the project, post commencement of the project.

(iii) Inefficient administrative procedures like delays in according sanctions, deployment of staff, procurement of materials etc.

(iv) Delays in selection and supply of equipment.

(v) Lack of coordination between the Contracting and Contracted agencies.

(c) For monitoring to be effective, the monitoring system has to be integrated in project organisation at the planning stage. Project monitoring, an integral part of project management provides benefits at minimal cost. It is estimated that on an average, the cost of monitoring varies between 0.05 percent and 0.5 percent for very large projects and relatively small projects respectively. It is essential that monitoring is treated as a staff function and control as a line responsibility. Monitoring should be organised at various levels of the organisation and should be integrated with the organisational hierarchy and functional responsibilities. The progress of the project can be monitored through a number of reports, such as Project Status Report, Project Schedule Chart and Project Financial Status Report.

25. **Project Risk Management**. Project risk management seeks to manage and control the risk of project success to an acceptable level. Project risk deals with the risk to project success in terms of scope, cost, and schedule, including customer satisfaction. Other processes deal with other risks, such as health, safety risk and environmental risk. Project risk management seeks to control risks beyond the scope of the project plan and beyond the circle of control of the project manager.

(a) **Risk Management.** As we have highlighted earlier that submarine construction projects are one of the most complex projects to handle. The development of a realistic project schedule and detailed plan, is made on large number of assumptions, both by the shipyard, as well as the Contracting agency. Unfortunately, even the best prepared plans, the project schedule could go wrong from time to time. However, efforts can be made to identify these problems at the earliest and take necessary actions to avoid them. There is always the possibility of unforeseen risks leading to unexpected issues. These could be addressed with prompt reaction from the project manager. It is therefore necessary to identify the signals or triggers that suggest a risk that is likely to happen and keep the project team alert to the possibility of any risk becoming a reality.

(b) **Risk Management Process.** Project Risk Management Process starts with identifying the risks projects may encounter. Risk assessment may be quantitative or qualitative. Quantitative risk assessment tools include failure modes and effects analysis (FMEA), Monte Carlo analysis, project simulation, PERT, probabilistic safety assessments (PSA), and management oversight or risk tree (MORT). The risk can be quantified in terms of Risk Priority Number (RPN) based on the probability of risk, severity of risk and detection capability.

(c) **Risk Contingency Plan.** After the risk have been quantified based on their RPN ratings, the next important task by the project manager is to seek necessary risk mitigation or risk avoidance strategy, in form of a contingency plan (Refer to Figure 10). Risk mitigation strategy is not an easy task in any complex construction project, since the problem area at times is beyond the control of all stake holders. Thus, it is very essential that all stakeholders work in synergy to identify these problem areas well in advance and resolve them amicably, without affecting the project time lines and cost.

Identified Risk	Probability of Risk	Serverity of Risk	Detection Capability	RPN	Risk Mitigation
Accident	5	5	8	200	Safety Precautions
Materials Failure	4	8	5	160	Stringent Quality Checks
Weather	3	3	4	36	Forecast
Labour Strike	4	8	4	128	Outsourcing
Delay in Supply of Equipment	5	6	5	150	Multiple Vendors

Figure 10

26. Project Management Software.

(a) There are large number of PM software available in the market. These software are very powerful and can aid in preparation of WBS, Gantt charts, Network diagrams, EVMS calculations, project status reports, base line charts, etc. Thus, we can see that with even shallow knowledge of PM techniques, we can still use these software to provide large amount of information of the project, which can help in identifying the bottlenecks and take necessary corrective actions.

(b) Most of these software can be purchased online. The Design / Production Directorates can greatly benefit from these software, as they can parallelly monitor all construction activities along with the shipyard with help of these software and keep a close control on each activity. A few examples of PM software are MS project, Atlassian JIRA, Podio, Smartsheet, Basecamp, Teamwork PM, etc.

Training on Project Management at College of Defence Management (CDM)

27. Project management is being taught at various public / private institutions, primarily under two certifications viz. International Project Management Association (IPMA) and Project Management Professional (PMP).

28. The College of Defence Management (CDM) at Secunderabad is a premier Tri-services Defence Institute imparting management training to senior officers of Armed forces, selected civilian officers from Ministry of Defence and officers of friendly foreign countries. The college is affiliated to Osmania University. CDM is institutional member of various professional associations including All India Management Association (AIMA) and International Project Management Associates (IPMA).

29. With its Motto of "Victory through Excellence", the college endeavors to ensure the academic curriculum has high professional relevance. The college is the only Defence Services institute, where in Project Management is being covered as a separate full-fledged subject, in training curriculum of various courses such as Higher Defence Management Course (HDMC) and Management Development Programme (MDP) with training throughput of more than 200 officers / civilians. CDM has the unique honour of being an authorized testing center for Level 'D' Certification and has empowered 284 armed forces officers to be certified on Project management skills.

30. CDM imparts training in the concept and practical utility of project management practices including software skills to participants. The participants are also encouraged to carry out research and case studies in the subject of Project Management. While focusing on PM aspects, the College endeavours to emphasize on its interdisciplinary nature and utility over a wide arena including operations, logistics administration, knowledge management and human resource enrichment. As a part of consultancy, the intellectual outputs generated have been disseminated to the defence services environment. These have been creatively implemented at various levels to enhance organisational effectiveness.

31. The College has a competent faculty which consist of a healthy mix of academic prudence and field experience. The college encourages its faculty to participate in external courses, seminars, workshops and paper presentations held at other professional institutes. This year, the college undertook IPMA Level 'C' Certification examination for the first time. A total of ten officers from the faculty underwent rigorous training followed by a comprehensive evaluation consisting of written examination, group discussions, case studies and interview, to qualify successfully for IPMA Level 'C' certificate. The college is also fortunate to have two of its Ex-Commandants being Level 'A' certified PM professionals.

Conclusion

32. The military budget over the years have been kept at a near steady growth rate of just below 2% of GDP catering for the basic needs. Though the nation may understand the need of armed forces to modernize, the competing priorities of social and other infrastructural needs combined with political and regional compulsions may hinder the free flow of finances. This demands that the future planned infrastructure creation, induction of new equipment, force accretion and modernization plans are undertaken with utmost planning and optimal resource

management. This fine balancing act of achieving the strategic goal by harnessing the effective power of combination of technology, human resource, financial and other resources is accredited to Project Management.

33. We have seen in the above-mentioned paragraphs that how powerful and versatile are the techniques and tools of project management in monitoring and control of any huge complex project, such as ship construction. The fallacy that project management is a tool to be adopted and implemented by only shipyards / contracted agency, should be completed removed from our thought process. In fact, it has become increasing important to adopt to such scientific management tools, to be able to understand the nuances of the ever changing technology / processes and overcome the challenges in effective and efficient manner.

34. It is, therefore imperative that Indian Navy looks at adopting project management as essentials skill and management tool for all young / mid-level officers, who are entrusted with responsibilities of handling projects, operations, refits, logistics, procurements and ship construction. The Indian Navy should utilize the expertise and training facilities at College of Defence Management to train maximum officers on PM through HDMC and MDP courses. In the long run, the subject should become part the various ab-initio / professional course conducted by the Navy, so that all officers / sailors are given formal training on PM, to ensure that Indian Navy can operate as an advanced, deterrent and a professionally competent 'Blue Water' force.

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Author's Biodata

Captain Gaurav Doogar, was commissioned in Indian Navy in Nov 94. He did his B. Tech in Mechanical Engineering from INS Shivaji, Lonavla and M.Tech in Industrial Engineering Management from IIT, Kharagpur. The officer has also undergone 64th DSSC and HDMC-11. The officer's afloat appointments include Asst. Engineer Officer on Rajput and Mysore (Commissioning Crew), Senior Engineer on Delhi and Engineer Officer on board Mumbai. The Officer's Staff appointments include Senior Instructor at EPCT School, Shivaji, Manager Systems (MSYS) at ND(Mbi), Joint Director at IHQ MoD (N) / DME and Additional Command Refit Officer at HQWNC, Mumbai. The officer has distinction of being awarded 'CNS Silver Medal' during B.Tech, MESC Trophy at Shivaji, MPCTC Trophy at DIAT, Pune and 'Institute Silver Medal' at IIT, Kharagpur. The officer has contributed several papers for journals and seminars on varied topics. The officer is presently serving as 'Directing Staff' at College of Defence Management, Secunderabad. The officer is a certified Project Manager with IPMA Level 'C' certification.

article

24

UNDERWATER OPTICAL WIRELESS COMMUNICATION AN ALTERNATIVE TO CONVENTIONAL ACOUSTIC TECHNIQUES FOR UNDERWATER APPLICATIONS

(Lt Cdr Ankit Atree)

Abstract- *With the rise of asymmetric threats in the military scenario, a potent underwater arm is a must have for all world navies. Towards this, keeping abreast with the threat scenario on land is critical for submarines. Relaying of information in the fastest possible time can help in better planning and quicker response. This requires transfer of high bandwidth data (plots, images, videos) in a reliable fashion with minimum latency. The present day technology of underwater acoustic communication is a legacy system and cannot provide the high data rates required. Underwater Optical Wireless Communication is being seen as the best alternative to meet this challenge. The paper discusses an underwater optical wireless link in detail covering aspects pertaining to the transmitter, receiver, channel properties and suggests methods to overcome the challenges discussed. From the analysis it is concluded that high data rate underwater optical wireless networks are a feasible solution for the emerging needs in the underwater domain.*

1. Introduction

Conventionally, underwater communication has been undertaken using acoustic techniques. The propagation of sound in water is fairly well studied and systems using sound as a source have been in existence for a long time. Whilst sound is able to travel for long distances in water, the propagation is highly dependent on temperature, pressure and salinity. As a result, the presence of thermo clines (temperature gradients) and haloclines (salinity gradients) in the ocean cause sound waves to refract when encountering these boundaries. This can drastically change the direction in which the sound is moving. The performance of acoustic communication models vary considerably with time of the day and depth of operation thus making it unreliable when the need is real time communication. Being legacy systems, the data rates of acoustic modems are restricted to a few thousand kilobits per second due to severe frequency based attenuation and surface induced pulse spread[1]. In addition, since the speed of propagation of sound in water is only 1500 m/sec, acoustic communication systems fall short when the requirement is high latency and synchronisation. As a result, acoustic communication systems are unable to satisfy the needs of emerging underwater applications. An alternative means of underwater communication is based on optics, wherein considerably high data rates are possible. Since the speed of light in water is only marginally lesser the that in free space, an optical communication can deliver the high latency and synchronisation where acoustic systems fell short. However, the underwater channel poses a challenging environment for propagation of an optical signal. Effects like scattering and absorption cause the optical beam to widen in the spatial, angular, temporal and polarisation domains. Inspite of the threat posed, it is possible for an optical beam to travel long distances in water as is shown below.

2. Figure 1 shown the absorption spectrum of electromagnetic radiation in water[2]. The absorption coefficient is plotted as a function of wavelength. In the visible domain (350-750nm), the absorption coefficient drops to as low as 10-4/cm. This indicates that an underwater optical link designed to function within the blue/ green region is capable of working over a large range. The succeeding paragraphs bring out an analysis of the various facets involved in setting up such a link.

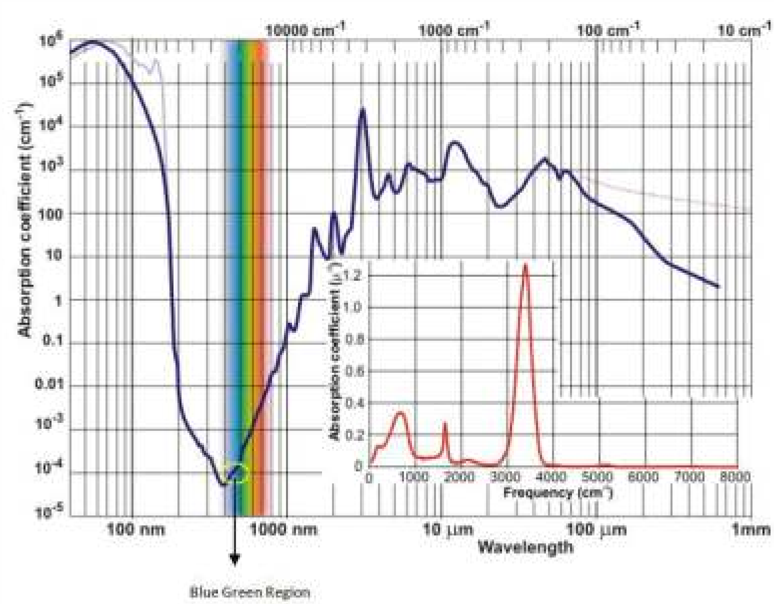


Figure 1 – Absorption Spectrum of Electromagnetic Radiation in Water

An Underwater Wireless Optical Communication Link.

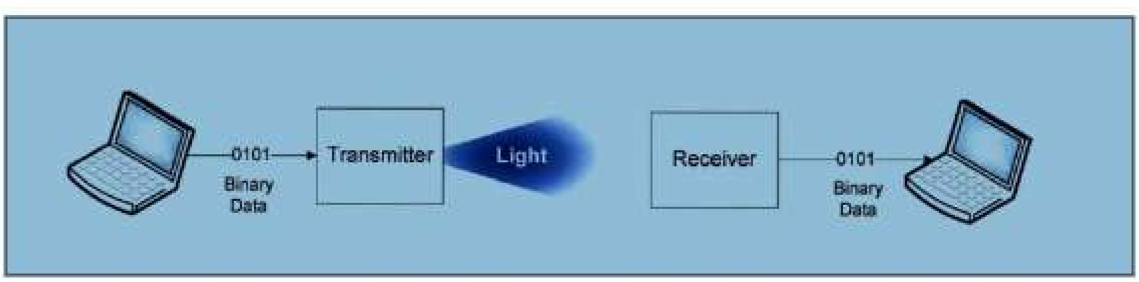


Figure 2 – An Underwater Optical Communication Link

3. An underwater communication link is made up of certain key components as indicated in Figure 2. An optical transmitter is fed binary data through a source and this binary data is converted into light and transmitted over the channel. The channel (ocean water) changes the characteristics of the light being transmitted and post traversing through the channel, the optical beam reaches the receiver, which senses the incoming light and converts this optical signal back into binary data which is then processed. There are many different ways in which light can carry data but the simplest method is on-off keying, wherein the presence of data or a

1-bit is represented by switching one of the optical source and a 0-bit is represented by switching off of the optical source. The speed (bandwidth) and reliability of the link depends upon how fast the transmitter can undertake the switching and how quickly and reliably the receiver can sense the state of the light. The paper discusses each aspect of the underwater communication link sequentially.

4. **Optical Transmitter.** An optical transmitter converts electric data signals into optical signals and projects this optical signal into the transmission channel. It consists of a photon source which undertakes the electro-optical conversion as well as associated circuitry required to drive the optical source to a desired power level. Optical instruments like lenses or reflectors required to condition the output beam may also be required.

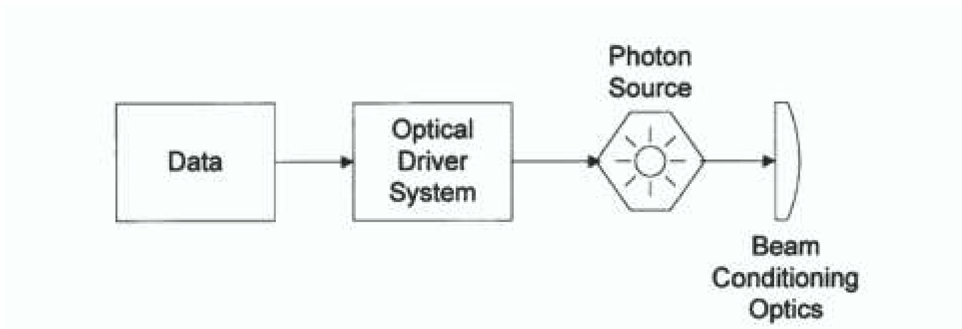


Figure 3 – Optical Transmitter

5. Choosing the correct photon source is critical to the link design. Whilst any optical source can be used, the high switching speed and power level constraints which the link requires place restrictions on the possible sources. The most commonly available sources which adhere to these restrictions are Light Emitting Diodes (LEDs) and Laser Diodes.

   (a) LEDs are p-n junction diodes which emit light when the junction is forward biased. The wavelength of light transmitted depends upon the band gap energy of the semiconductor used to make the diode. By using specific semiconductors, it is possible to keep the output spectrum as narrow as 50nm. The power of the light transmitted depends upon the amount of drive current that is connected across the junction. The switching speed of LEDs depends on the recombination time between electrons and holes and may vary from 1nsec to 1msec. This essentially means that LEDs can be used for achieving modulation speeds upto a few Mhz. LEDs are advantageous as they are known to be stable and reliable light sources with long life and are cheap and easily available. They are also immune to changes in temperature and pressure.

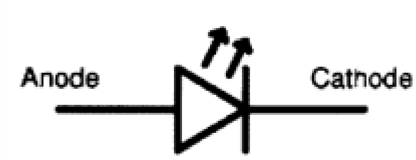


Figure 4 - LED Schematic

(b) Laser Diodes work on a principle similar to LEDs as they too are made on p-n junctions. However, they are modified to allow the spontaneously emitted photons to cause other electron hole pairs to recombine. This results in the emitted photons having the same energy, frequency and phase as the original photon which initiated the process. This is called as stimulated emission and leads to the emitted light being coherent and therefore confined in a much narrower spectrum (as narrow as 1nm). This is one of the biggest advantages of using Laser Diodes. They also have much faster recombination times andcan switch at speeds as high as a few GHz. The problem with Laser Diodes is that they are highly sensitive to changes in temperature and pressure and such changes can cause the frequency of transmission to shift. Therefore, a thermal, optical and electrical feedback is required to prevent the laser diode from failing. This adds complexity and cost to the system and also reduces the life and reliability of Laser Diodes. A tabulated comparison of LEDs and Laser diodes is brought out in Table 1.

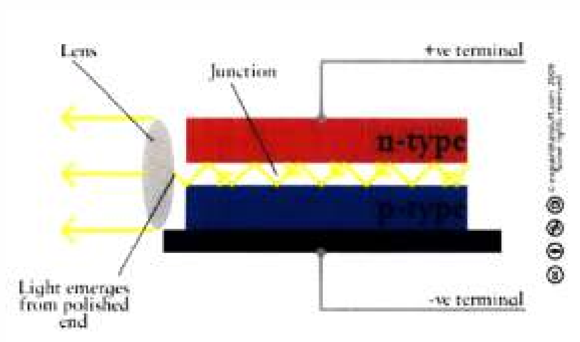


Figure 5 – Laser Diode Diagram

Table 1 – Comparison between LEDs and Laser Diodes

Characteristic	LED	Laser Diode
Optical Spectral Width	25-100 nm	.01 to 5 nm
Modulation Bandwidth	<200 MHz	> 1 GHz
Minimum Output Beam Divergence	Wide (about 0.5°)	Narrow (about 0.01°)
Temperature Dependency	Little	Very temperature dependant
Special Circuitry Required	None	Threshold and temperature compensation circuitry
Cost	Low, off-the-shelf components available	High, need specialized optics and electronics
Lifetime	Long, with little degradation of power levels	Medium, power levels degrade over time
Reliability	High, 10^8 hours	Moderate, 10^5 hours
Coherence	Incoherent	Coherent
Eye Safety	Eye safe	Must take precautions

6. **Optical Receiver.** The optical receiver system detects the incoming optical signal and converts it into an electrical signal. It consists of a photon detector which performs the optical to electrical conversion. Additionally, associated electronics which convert the electrical signals into TTL voltage levels are also a part of the receiver. A variety of devices can be used as the photon detector. A few of these are discussed in the succeeding paragraphs:-

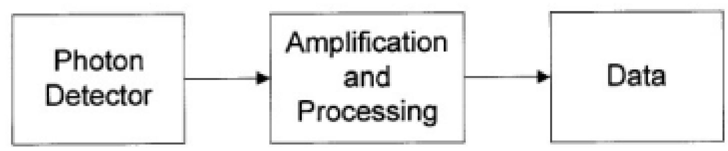


Figure 6 – Optical Receiver System

(a) **Photoresistors.** Photoresistors or Light Dependant Resistors work on the principle of varying conductivity with incident light. They have very high resistance in the dark and the resistance reduces as light is incident on them. Though they have very good light sensitivity, they respond very slowly. It typically takes over a millisecond for a photoresistor to fully respond to the presence of light. Additionally, it can take a couple of seconds for the photoresistor to return to its dark resistance after the light signal has ended. This is unacceptably slow for switching speeds of over 1 Mhz.

(b) **Photothyristors.** Photothyristors function quite similar to diodes. Like diodes, thyristors conduct current when their anode has a higher voltage than their cathode. But unlike diodes, thyristors have a third lead (the gate) that controls when the thyristor starts conducting current. The gate must have a positive voltage and sufficient current before the thyristor will turn on. After the thyristor is activated, the gate does not affect the thyristor anymore. This means that once a photothyristor has been optically triggered, turning off the light will not turn off the thyristor. Only turning off power to the circuit or making the cathode have a higher voltage compared to the anode will do that. For this reason, photothyristors are not ideal for high speed communication purposes.

(c) **Phototransistors.** Phototransistors (FETs) are like regular transistors, only their base is exposed to light. When the photons hit the base, either a current or a voltage is produced which starts to turn "on" the transistor. This means that when the phototransistor is in the dark, very little current flows through the transistor, but in the presence of light, the current or voltage signal produced by the light is amplified by the transistor's current gain as the transistor turns on and allows current to flow from the collector to the emitter. This internal gain (from one hundred to several thousand) makes phototransistors incredibly sensitive to any light signal. Unfortunately, they are only moderately fast (a few KHz) even though they are relatively robust with regards to noise.

(d) **Photomultipliers.** Photomultiplier tubes (PMTs) are a type of vacuum tube that is very light sensitive. Incident light produces electrons, which are accelerated and multiplied by dynode plates. The current can be multiplied over a million times after going through multiple dynode stages. Photomultiplier tubes are great for detecting low light level signals, as they are able to detect even single photons. Because of their high sensitivity, they are easily affected by ambient light. In order to produce such high gains, photomultipliers are large and need high voltage levels (thousands of volts). They are fragile, easily affected by magnetic fields, and expensive.

(e) **Photodiodes.** Similar to other photon detectors, photodiodes convert light energy into electrical current. When incident light hits the photodiode, it turns the photodiode into a current source that pumps current from the cathode to the anode. When a photon passes through the diode it can excite an electron, creating an electron-hole pair. If this happens close enough to the depletion region, the inherent electric field will push holes towards the anode (p side) and electrons towards the cathode (n side). This separation of charges leads to a voltage potential across the p-n junction. This potential produces a photocurrent, as electrons flow from the electron-abundant cathode towards the hole-abundant anode. Since each photon can only excite one electron at most, photodiodes do not have any internal gain, but they are incredibly linear. Additionally, since photons can go through a diode without exciting any electrons, photodiodes do not have the sensitivity (quantum efficiency) of photomultiplier tubes that can detect single photons. Photodiodes can have rise times as short as 10 picoseconds and are relatively robust to noise.

(f) **Avalanche Photodiode.** Avalanche photodiodes are similar to conventional photodiodes, except that they can generate multiple electron-hole pairs as a result of absorbing a single photon. This multiplication effect is due to a strong electric field across the photodiode which gives photon-generated electrons enough energy to create secondary electron-hole pairs, which in turn can create more electron-hole pairs in avalanche multiplication. The internal gain, which can be on the order of 102 to 104, gives the avalanche photodiodes much more sensitivity, but also introduces more noise into the signal, especially in the presence of ambient light. Avalanche photodiodes are non-linear, since their multiplication is non-linearly dependant on supply voltage and temperature. Because of their sensitivity to these factors, special circuitry is needed adding complexity and cost while reducing reliability. They also require large supply voltages, ranging from 30-300 volts.

Table 2 – Comparison of Various Optical Receivers

	Photoresistors	Phototransistors	*p-n* Photodiodes	Avalanche Photodiodes	Photomultipliers
Speed	Slow *<1 Hz*	Moderate *<250KHz*	Fast *Tens of MHz to tens of GHz*	Fast *Hundreds of MHz to tens of GHz*	Fastest *>1 GHz*
Size	Small	Small	Small	Small	Large
Gain	Little	100-1500	Unity	100-10,000	>1 million
Linearity	Over small regions	Good	Excellent	Not Linear	Good
Ambient Noise Performance	Very good	Excellent	Very Good	Fair	Poor

7. **The Underwater Channel.** Prior trying to design an Underwater Optical Communication Link, it is important to study the Optical Properties of the medium. Sea water contains particles with size ranging from water molecules of size 0.1 nm to small organic particles of size 1 nm, phytoplankton's size ranging from 1?m to 100's of ?m. Each of these particles contributes in some way to its optical properties.

(a) Losses Encountered by an Optical Beam in Water. The losses encountered by an optical beam while propagating in water can be broadly classified into Attenuation and Turbulence. Attenuation can be further classified into Absorption and Scattering, while Turbulence can be further classified into Beam Wander and Scintillations.

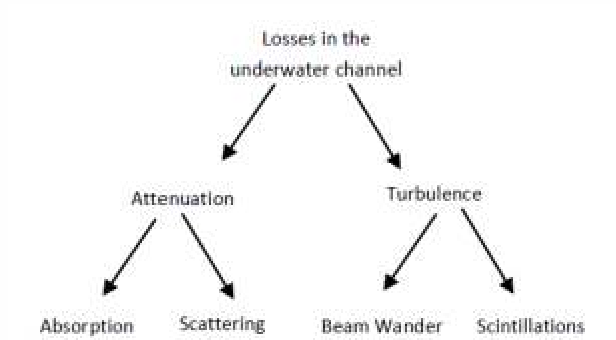


Figure 7 – Losses Encountered by an Optical Beam in Water

(i) **Absorption.** Absorption refers to the loss of energy that is suffered by an optical beam when it interacts with the water molecules and other particulate matter present in water. As mentioned earlier, water consists of a large number of particulate matter and each particulate matter has its own absorption spectrum. One of the most commonly found dissolved constituent of sea water is chlorophyll. The absorption spectrum of pure seawater and absorption by a few types of chlorophyll generally found in sea water is shown in the Figure 8[3]. Further, at different parts of the ocean, due to varying composition of these particulate matters, the absorption is likely to be different. It can be seen from the figure that while pure seawater absorbs blue/ green light minimally as compared to other wavelengths, the absorption of light by particulate matter varies for different kinds of particles. This gives an indication of how complex the underwater absorption scenario is.

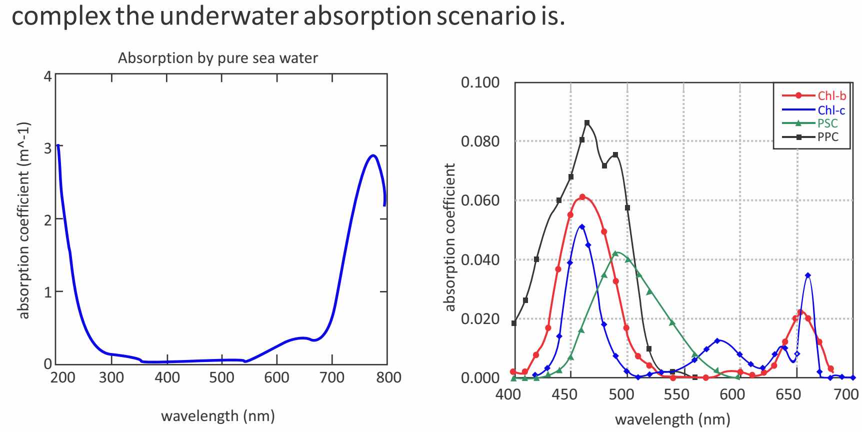


Figure 8 – Absorption Spectrum of Pure Seawater and Different Types of Chlorophyll Found in Seawater

(ii) **Scattering.** Scattering of light is basically the deviation of photons from their straight trajectory caused due to non uniformities in the medium. Scattering is not principally a loss of energy, as no part of the energy is actually lost, however itresults in the energy spreading out over a larger distance. For wavelengths in the visible region, photons would experience Rayleigh scattering from particles of size much smaller than the wavelength of light while Mie scattering would occur for particles of size equal to or larger than the wavelength[4]. The difference between the two lies in the fact that while Rayleigh scattering scatters uniformly in all directions, Mie Scattering is predominantly forward directional.

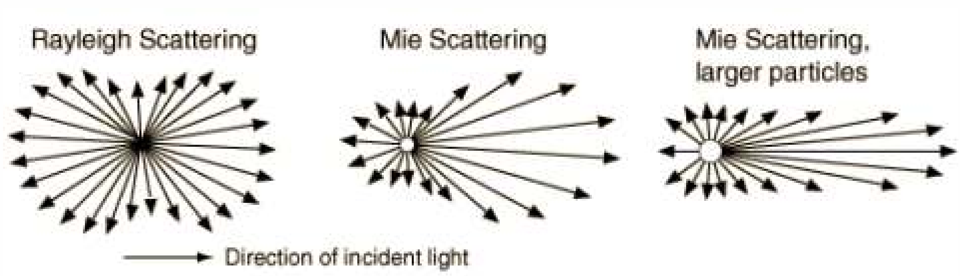


Figure 9 – Rayleigh Scattering and Mie Scattering

(b) **Turbulence.** Turbulent ocean flow causes variations in temperature, pressure and salinity. These parameters in turn result in localised variations in refractive index of the medium. These localised variations in refractive index cause the entire water medium to act as if consisting of a large number of lenses of varying sizes[5]. These lenses of varying sizes can be thought of as eddies which cause the incident beam to be refracted. Eddies of size smaller than the incident beam will cause localised irradiance fluctuations in the beam. This happens because a part of the total beam gets refracted and upon emerging out of the eddy, interferes with the original beam. This interference may be constructive or destructive depending upon the phase difference between the two beams. This in turn leads to areas of high and low irradiance within the laser beam called as Scintillations. Figure 10 shows the image of a laser beam which has traversed 60 m from the source. The localised irradiance fluctuations can be clearly seen in the picture. The problem of scintillations can be overcome by ensuring that the aperture of the receiver is large enough to capture the entire beam.

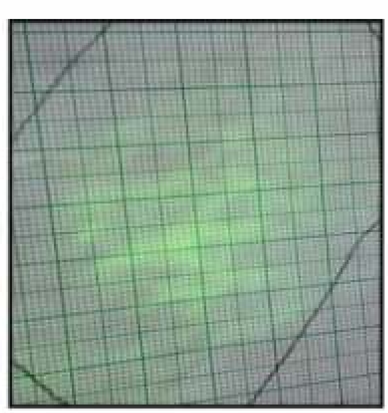
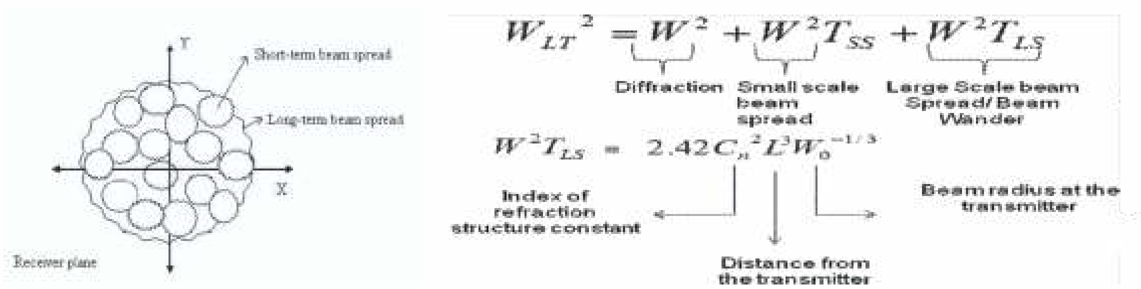


Figure 10 – Scintillations Observed on a Laser Beam which has Travelled 60 m from the source

(c) **Beam Wander.** Eddies of size larger than the optical beam would cause the entire beam to be deflected. This would manifest itself in the form of a wandering of the entire beam also known as Beam Wander. An illustration of Beam Wander is given in Fig 6. Beam Wander would result in alignment issues at the receiver and would require precise pointing and tracking systems to overcome.



$W_{LT}^2 \longrightarrow$ Long term beam spread

Figure 11 - An Illustration of Beam Wander[6]

(d) **Additional Sources of interference** In addition to the losses discussed above, there are a multitude of other sources of interference which the optical link might encounter. These include:-

(i) **Solar Interference** This interference would particularly exist in the top layers of the water channel, e.g. euphotic zone of the ocean. This would manifest itself in the form of background noise at the receiver. Appropriate filters for the transmitted wavelength would reduce the effects of background radiation considerably.

(ii) **Multi-Path Interference** Multi-path interference is caused when scattered photons are re-scattered back towards the receiver, thereby creating dispersion and spreading in the received signal. This phenomenon, which is routinely experienced in RF communication, is a relatively explored area of research in the field of free space optical communication, however the effects of such interference on an underwater optical link are unknown.

(iii) **Physical Obstructions** Physical obstructions such as fish or other marine animals will cause momentary loss of signal at the receiver. Appropriate error- checking and redundancy measures must be taken to assure that lost data is retransmitted.

(iv) **Turbulence at the Air Water interface** An optical beam reflecting/ refracting from the water surface would further experience heavy turbulence at the surface which would require precise beam tracking systems along with suitable optical arrangements to be able to capture the beam. In a scenario where the beam is required to interact with the Air Water interface, the turbulence faced would far exceed the turbulence due to beam wander or scintillations.

8. **Mitigating Channel Effects.** Having understood the basic optical properties of the underwater channel, suitable methods to mitigate the effects of the channel need to be investigated. Since systems using optical signals for communication/ detection in free space are already in use, certain concepts can directly be borrowed from the free space scenario. A large number of research models are available for optical beams travelling in a medium. Whilst writing this paper concepts researched by Kolmogorov[7],[8] have been utilised. As per Kolmogorov, when an optical beam interacts with a medium, the energy is transferred from larger turbulent eddies (pockets of varying refractive index) to smaller ones till such time as the energy is completely dissipated due to viscosity of the medium.

(a) **Scintillations and Beam Wander.** As already mentioned, scintillation refers to localised irradiance fluctuations within a beam, whereas beam wander refers to movement of the entire beam. In order to depict scintillation and beam wander in a real time scenario, an underwater link using a laser source (532nm (Green), 5mW power output) and a receiver using a silicon phototransistor (L14G2) was set up in a 30 m glass tank. The link setup is shown in Figure 12. The laser was externally modulated using a driver circuit and the receiver was connected with an Op Amp (OPA 656) in transimpedance configuration. The data was captured on an oscilloscope and transferred to a laptop for post processing in Matlab. The laser beam travelled a distance of 20 meters in water and was made to interact with the air-water interface as well in order to study the effect of turbulence at the interface. The tank had a wavemaker which could be utilised for inducing turbulence in the tank. The captured beam after travelling through the turbulent media is depicted in Figure 13. From the figure, it can be concluded that the long term turbulence (which causes the beam to go outside the aperture of the receiver) is due to beam wander, whilst the short term turbulence (due to localised irradiance fluctuations) is due to scintillations. In order to reduce the effects of optical turbulence, the following methods can be utilised:-

(i) Increasing the size of the receiver aperture offers an effective and simple way to reduce scintillations. This method is called as "Aperture Averaging" and is fairly well studied and applied for free space optics and thus a similar method could also be utilised for mitigating scintillation effects for underwater optics. The aim is to keep the receiver aperture larger than the laser beam diameter.

(ii) A light diffuser can be used as a beam expander to counter beam wander. A light diffuser would spread out the incident light equally in all directions thus allowing for detection of at least a part of the incident beam even if it wanders over a larger area.

(iii) Multiple transmitters and receivers can be used to capture a larger part of the beam (MIMO).

(iv) A combination of all the above techniques can be used to counter turbulence.

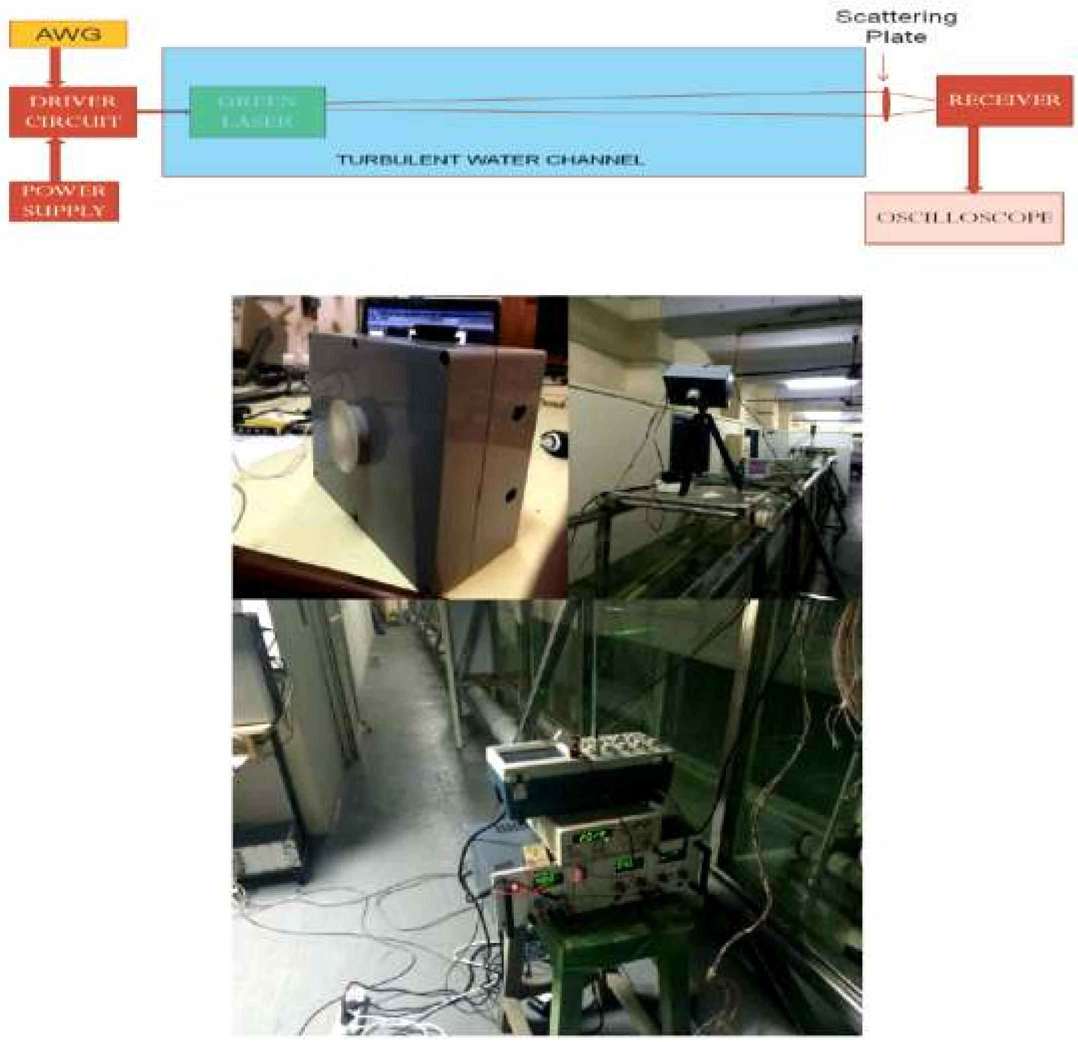


Figure 12 – Link Setup

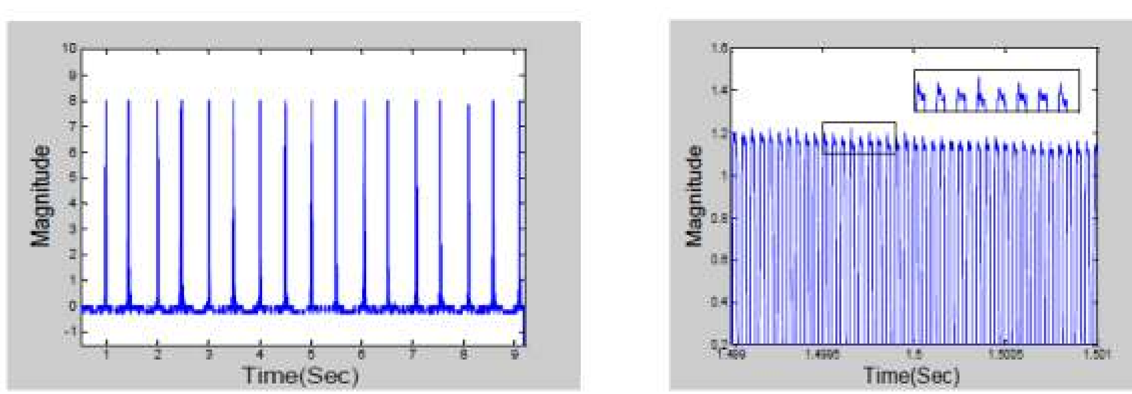


Figure 13 – Laser Beam Captured after Travelling 20mtr in a Water Tank

Light Diffuser.

11. A light diffuser would act as a beam expander thereby mitigating the effects of beam wander to a certain extent. A scattering plate (Figure 14) was used a light diffuser in the experiments conducted. Scattering of light upon falling on the scattering plate can clearly be seen in the picture. The receiver can lie anywhere behind the scattering plate and would still be able to capture the incoming light. The downside would be the reduced intensity of the light.

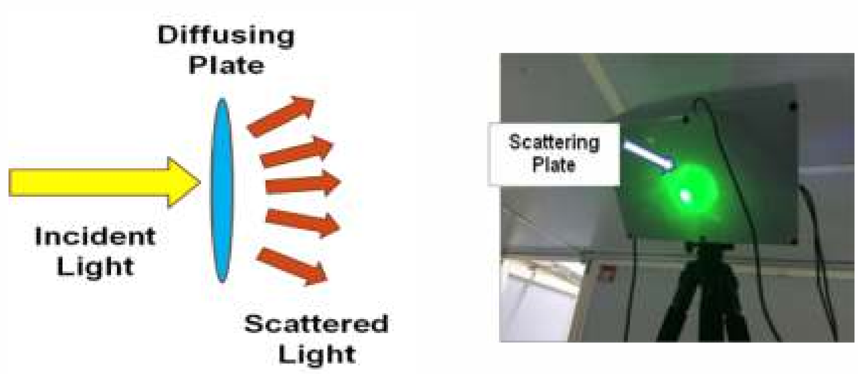


Figure 14 – A Scattering Plate

Fresnel Lens.

13. One possible method of undertaking Aperture Averaging is by using a Fresnel lens. A Fresnel lens is basically a plate with concentric rings with varying thickness and is particularly useful for applications requiring large apertures and small focal lengths, as they can be made much thinner as compared to comparable conventional lenses. A Fresnel lens acts like a focusing lens converging all light falling upon it to its focal point. A setup using a Fresnel Lens is shown in Figure 15.

Figure 15 – Fresnel Lens Setup

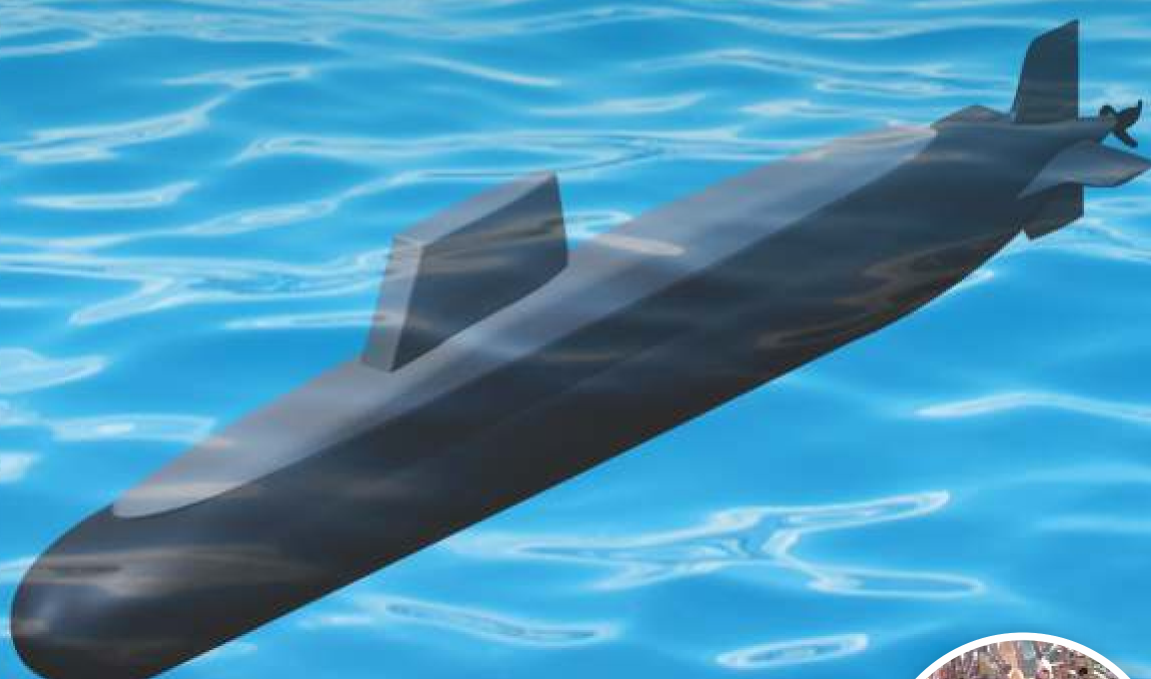
Conclusion

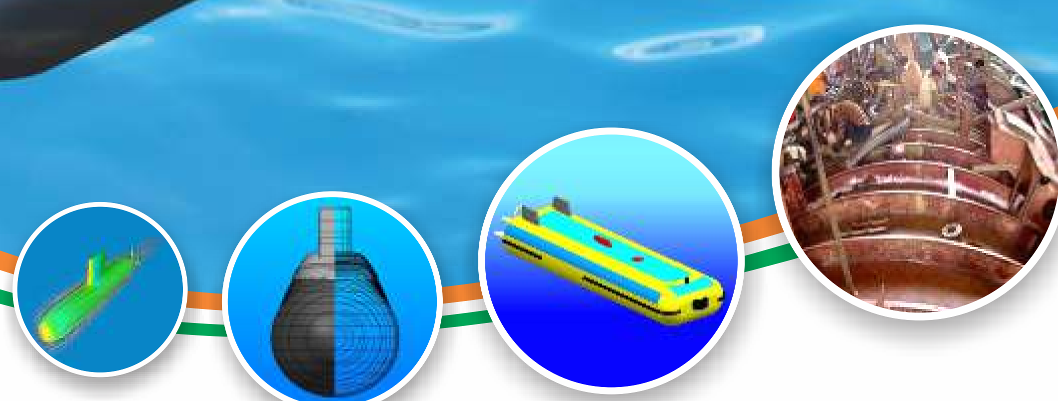
14. This paper discusses an alternate to the conventional acoustic communication systems used by Submarines whilst deployed underwater. The current demand is of systems with high data rate and minimum latency. Underwater Optical Communication is superior to its acoustic counterpart in this regard. Various facets of an underwater optical communication link have been discussed. The underwater channel poses certain challenges for the propagation of an optical beam. Methods to overcome these challenges have also been investigated. While underwater acoustic communications might still be the preferred method of communicating underwater, ongoing research in the field of underwater optical communication make it a worthy challenger in the coming future. Methodical research in this field would definitely see more systems utilising this technique.

Author's Biodata

Lt Cdr Ankit Atree belongs to the 19th Naval Engineering Course and the O-150 batch at INS Valsura. The Officer has done his PG from IIT Madras in the field of Communication Systems. His previous tenures include ALO(ASW) onboard INS Mumbai and Staff Officer at INS Valsura. He is currently posted as an Instructor at the Indian Naval Academy, Ezhimala. His areas of interest are Fibre Optics, Free Space Optics and Signal Processing.

INDUSTRY CONTRIBUTION





SYSNOPSIS

'Platform design implications of emerging technologies in Batteries/Energy Accumulators'

Currently Indian Navy employs two types of submarines. The first type being the conventional diesel generator propelled submarine and the other being with latest technology of Nuclear powered submarine. The conventional diesel submarines are propelled by Flooded Lead Acid Batteries when under water. The batteries get charged during the night with the help of Diesel Generators when the submarines surface above the water.

Whereas the nuclear submarines have the capability to stay submerged for a very long time typically from one month to six months owing the reliable nuclear power generators on board the submarine which are employed for AIP (Air Independent Propulsion). Currently the world over latest technology batteries are employed for P & PS (Propulsion and Power Supply). The competing technologies for this usage is VRLA batteries (AGM Version as adopted by US Navy and Tubular Gel Version as adopted by German Navy). Both these VRLA versions are Valve Regulated Lead Acid Batteries with immobilized sulphuric acid electrolyte with self resealing valve which is normally closed but opens and vents out excess gas (Hydrogen) in high internal pressure conditions. VRLA batteries when employed for submarine P & PS, do not normally vent out Hydrogen as in the case of Flooded Lead Acid Batteries currently employed. Hence the hydrogen burners as employed currently for Flooded Lead Acid Batteries is not required. As these VRLA batteries are sealed, there is no need to pour distilled water in to the cell to maintain specific gravity, hence the issue of corrosion of floor damage is virtually avoided.

A further milestone in submarine design is about to enter the market in the form of Lithium based High Energy Batteries. In combination with High Energy Batteries based on Lithium Polymer technology the future submarine will have increased capabilities not only in long term slow speed endurance but also in flank speed and transit. Modern construction methods, materials and maturing of TRL (Technology Readiness Level)and MRL(Manufacturing Readiness Level) the safety and hazardous issues are almost solved with perfection of Lithium Battery and Battery Management systems.

With these new battery modules it is possible to increase the battery capacity by factory of 2 for long time discharge for same volume and factor of 4 for maximum speed discharge compared to traditional lead acid technology. Furthermore the Lithium batteries are lighter owing to higher energy density of 200 to 250 Wh / Kg compared to 35 to 40 Wh / Kg of Lead Acid batteries. Lithium cells can take very high charging currents which can enable lower indiscretion rates. They can be discharged upto 80 % DOD regularly and upto 100 % occasionally which gives an even larger capacity advantage compared to lead acid batteries. These batteries are completely maintenance free, they can be stored any loading condition, they don't consume distilled water, they don't release gases, no water cooling is required, the battery efficiency is very high due to low internal resistance. The last advantage of low internal resistance is at the same time the only disadvantage to the designer. The very low internal resistance causes very high short circuit currents which have to be handled by appropriate measures in the design of the ship's network.

At present TKMS and GAIA have tested the first 500 Ah Cells in Germany. Concurrently Isreal Navy, Japanese Navy, American, Australian and Chinese Navies are conducting trials with these batteries.

It is suggested to immediately try the VRLA technology as transit step to ultimately try the Lithium based technology in line with the technology advancement happening around the world.

Author's Biodata

1962 born **Mr. A. Srinivas Nagaraj**, Vice President NED Energy Limited is an Electrical & Electronics Engineer graduated from JNTU College of Engineering, Hyderabad in 1984. He has rich experience as professional engineer for over 25 years working in various reputed companies. He has completed his schooling from prestigious Hyderabad Public School, Ramanthapur in Hyderabad.

He has worked with various reputed companies in the capacity of Electrical Engineer before working with NED Energy Limited, Hyderabad which has been started as a startup company in 2000 with technology tie up with Indian Institute of Science, Bangalore with funding from TDB (Technology Development Board) and IREDA (Indian Renewable Development Agency)

He is part of the core group of battery professionals in NED Energy Limited which started as Start Up Company way back in 2000 and reached self sustain business objectives of Rs over 200 Crores.

He has been working with NED for over 15 years in the capacity of Vice President responsible for R & D Technology and Lean Operations Management including design, quality control, production and overall profitability of the company apart from marketing of lead acid batteries.

He takes keen interest in avid reading and upgrading his skill set by continual learning. He also works as chief learning and Chief Information Officer in NED Energy Limited.

NED has technical collaboration with Indian Institute of Sciences, Bangalore for Design, Development and Production of various types of lead acid batteries serving the telecom,solar,ups sectors.

He is also involved with Indian Institute of Sciences Bangalore in R & D activities of new material, new processes and new lead acid batteries and has published over 14 international papers in International journals and participated in European Lead Acid Battery.

He regularly involves and participates various solar related activities for energy storage with MNRE and other solar companies. His interest in solar energy storage devices spans lead acid batteries of various types including conventional AGM batteries, Advanced VRLA Lead Acid Batteries, Tubular Gel VRLA batteries including Flooded conventional Lead Acid Batteries.

He is part of the team from NED Energy Limited coauthored with IISc Bangalore which published 17 international papers in International Jouranals and hold 8 Indian and American Patents as co-applicants

Professor Vladimir N. Tryaskin (Saint-Petersburg State Marine Technical University, Russia)

Saint Petersburg State Marine Technical University – the Russia's leading higher educational establishment, conducting training of specialists for design, construction and operation of underwater technical means

ABSTRACT

The presentation begins with a short history of the establishment and evolution of Saint-Petersburg State Marine Technical University (formerly known as the Leningrad Shipbuilding Institute) with emphasis on some academic and research activities related to training of engineers in the field of design, construction and technology of production of underwater vehicles. The presentation includes reference to famous professors, which laid the foundation for special courses, and outstanding graduates who largely contributed to the development of underwater vehicles for both the Russian Federation and foreign countries. The presentation touches upon the structure of the educational programs and disciplines related to the matter under discussion as well as some manuals and monographs used for training of the future engineers specializing in conception and implementation of advanced underwater technique. Some examples are provided of underwater vehicles designed by the SMTU graduates. Peculiarities are noted of the methodology of training and special features of the SMTU academic process related to establishment of industrial affiliations of the academic departments of the University. Examples of research and development of underwater vehicles, conducted at the SMTU, are presented with the goal to illustrate cross-fertilizing effects of cooperation of the university, industrial enterprises (design bureaus and shipyards) and innovation technology companies. Synergetic role is discussed of internal and international conferences organized by the university in widening the knowledge and contact base in the areas related to underwater vehicles.

Author's Biodata

Vladimir N. Tryaskin graduated with honors from Leningrad Shipbuilding Institute (now Saint-Petersburg State Marine Technical University-SMTU) in 1972. He got his PhD and Doctor of Technical Sciences degree correspondingly in 1979 and 2007 from the same Institution. Professor and Chairman of the Department of Ship Construction from 2000 until present time. Dean of the Faculty of Shipbuilding and Ocean Engineering of SMTU from 2008 through 2013. From 2013 until present time- Vice-Rector for Academic Affairs and the First Vice-Rector of the University. Professor V.N. Tryaskin is a famous scientist and engineer in the field of shipbuilding, the author and co-author of many publications and patents. His research achievements include development of methodology of parametric design of ship hull structures, creation of methodologies of estimation of admissible conditions for operation of ice-going ships and simulation of action of ice loads upon ship hull. He laid the foundation of approaches to the development of algorithms and software for determination of technical state of the ship hull in compliance with regulatory provisions of classification societies. He has significantly contributed to the preparation of normative documents of the Russian Maritime Register of Shipping and the development of software in provision of Common Structural Rules of the International Association of Classification Societies. He actively supervises Master and PhD theses of Russian and foreign postgraduate students. Professor Vladimir N. Tryaskin is a member of numerous scientific councils and dissertation committees and, starting from 2015, – a member of the Presidium of the Higher Attestation Commission of the Ministry of Education and Science of the Russian Federation.

Full-scale test facility for testing submarine fire protection systems: parameters and capabilities

Since India, as it has already been repeatedly emphasized at this seminar, is striving for self-reliance in submarine design, your naval architects might probably already be facing numerous challenging technical tasks, and submarine safety is one of them.

The emergencies that happen from time to time at the submarines of various navies are a lamentable proof of the fact that safety is not to be underrated. Thus, in 1989 Soviet nuclear submarine Komsomolets was lost in the aftermath of the fire, and the reason for this disaster was a sealing failure in her high-pressure air system.

KSRC has many years of experience in analytical assessments of survivability and fire & explosion safety of various platforms, as well as in assessing technical safety of nuclear power plants aboard submarines. Fire effect parameters are calculated as per the in-house procedure by means of the software package based on it.

Indeed, we have advanced significantly in our studies, yet a number of mathematical models describing the progress of emergencies, as well as the effects of these emergencies upon hull structures and equipment, still require validation in full-scale experiments.

We would like to inform you about our new development likely to be quite helpful in coping with many of these challenges.

In 2017 KSRC will commission an extension module to its existing test facility for simulation of fires aboard ships, and this will be a full-scale testing module for experimental studies of fires in watertight spaces, as well as for development of fire protection tools for submarines.

The module consists of the body; the hardware that ensures the functioning of the module itself and the equipment being tested there; and the instrumentation system.

As of now, our module, including its internal equipment, is 100% ready. Hydraulic tests are scheduled for spring 2017.

This test facility is meant to provide the most realistic simulation of structures aboard a real submarine.

The body of the testing module has the total volume of 700 m3and consists of two adjacent cylindrical watertight compartments simulating those of a submarine. The body is the main element of the testing module and intended to perform the entire scope of experiments according to the module's purpose. Maximum design overpressure of the module is 5 kg/cm2 (0.5 MPa).

The first compartment of the module has the volume of 260 m3 is divided by two welded decks running one above another.

The second deck of the 1st compartment has a strength enclosure simulating the cabin post (volume 18 m3). Maximum design overpressure of this enclosure is 2 kg/cm2 (0.2 MPa).

The hold of the 1st compartment accommodates another strength enclosure (volume 50 m3) that will serve to experimentally study the equipment resistance not only to fire but to steaming, too. Maximum design overpressure of this enclosure is 3 kg/cm2 (0.3 MPa).

The 2nd compartment accommodates a zonal module consisting of three decks connected by pillars.

Outside the 2nd compartment, there is a tank that can be filled with water to simulate diving.

The module is intended to support the following tasks:

- Experimental studies of real fire escalation dynamics inside submarine compartments, considering the changes in pressure and oxygen content;
- Determination of thermal effects upon the submarine's hull and equipment;
- Testing fire-fighting tools and fire alarm systems of a submarine, as well as her structural fire protection means, including the passages through bulkheads and decks, fire-resistant doors and hatches;
- Experimental determination of submarine equipment resistance to fire and pressure.

Temperature studies regarding fires inside submarines compartments, as well as the tests of fire-fighting, fire alarm and TV monitoring systems, can be performed in the entire volume of Compartments 1 and 2, used either severally or together (bulkhead hatches open).

Besides, to perform the experiments as per the scope of the tasks intended for this facility, there is a number of dedicated testing sites inside the compartments of the testing module, and namely:

- Site for functional testing of filters for air cleaning systems (Deck 1 of Compartment 1);
- Site for fire resistance testing of fire protection means applied on strength bulkheads, cabling and piping routes (Deck 2 of Compartment 2);
- Site for fire resistance testing of structural fire protection means applied on light gas-proof bulkheads and decks, cabling and piping routes, doors and hatches (Cabin / Post);
- Site for fire resistance testing of high-pressure air system equipment (Deck 1 of Compartment 1);
- Site for fire resistance testing of hydraulic and lube oil systems equipment (Deck 3 of Compartment 2);
- Sites for fire and pressure resistance testing of radioelectronic equipment cabinets, control panels, electric and mechanic equipment (Compartments 1 and 2);
- Site for fire resistance tests of cabling routes (Deck 2 of Compartment 2);
- Site for fire resistance tests of chemical air regeneration and cleaning devices (Deck 1 of Compartment 1);
- Site for steaming resistance tests of submarine equipment (strength enclosure in the hold of Compartment 1).

Instrumentation system of the module allows monitoring of the following parameters:

- Gas-air mix temperature: up to 1000°C;
- Overpressure: up to 5 kg/cm^2;
- Optical density of smoke: 0-42 dB;
- Heat flux power: up to 50 kW/m^2;
- Air-gas flow speed: up to 30 m/s;
- Chemical composition of gas-air mixture (O2, CO, CO2, CH, freons, etc.).

As of today, the module to be commissioned has nothing similar anywhere in the world. This facility will be a real breakthrough in studying the dynamics of fire escalation inside submarine compartments and will provide a better understanding of how the fire breaks out, how it propagates throughout compartments, how to detect and extinguish it and how to combat its outcomes.

Currently, fire-fighting and fire alarm systems of submarines are tested at non-watertight test rigs as per the procedures developed for surface ships, whereas our module will allow testing in the conditions as close to real ones as possible, thus making these tests more reliable and efficient.

The tests on the elements of strength bulkheads and decks, as well as efficiency testing of structural fire protection means will be possible to perform under simultaneous effect of temperature and pressure, which will also contribute to working out more reliable and efficient solutions to be adopted in submarine design.

We are ready to examine your proposals regarding the tests at this facility in support of Indian submarine development.

Author's Biodata

Aleksandr A. Ismagilov, Captain 1st Rank (Reserve)

Chief Expert of Underwater Platforms Design Department, Krylov State Research centre.

Born in 1960 in the town of Gorlovka, USSR. Graduate of Leninsky Komsomol Higher Naval School for Underwater Navigation (Class '82), qualification "Engineer". Joined KSRC in 2015 after retirement from the Russian Navy. An expert in design of underwater platforms.

Sergei V. Shedko

Head of Department of Ship Damage Control, Safety and Ergonomics, Krylov State Research Centre. Awarded with the Scholarship of the President of the Russian Federation for military industry employees.

Born in 1969 in the city of Leningrad (now St. Petersburg). Joined KSRC in 1992, after graduation from Leningrad Shipbuilding Institute (now St. Petersburg State Maritime University). Having started his work as an engineer, Mr. Shedko was going steadily up the career ladder, and 2016 saw his promotion to the position of Head of Department.

The main focus of his activities is to develop design support methods and tools to ensure survivability and safety of surface ships, submarines and support vessels by means of emergency simulations. Having pursued these efforts over his 25-year long career, Mr. Shedko is now the co-author of 13 technologies (in 7 of these, he was the principal developer) and 11 patented software products.

Author of numerous scientific papers, including the 50 ones available from publicly-accessible sources.

SUBMARINE CONSTRUCTION IN INDIA: THE MDL EXPERIENCE

By Capt Rajiv Lath IN (Retd)
Director (Submarines & Heavy Engineering), MDL

Introduction

Mazagon Dock Shipbuilders Ltd (MDL) is the only shipyard in the country to have built conventional submarines. MDL has built two SSK class submarines, undertaken the Medium Refit of all four SSK submarines of the Indian Navy, and is presently engaged in the series production of six Scorpene class submarines. It is also poised to undertake the Medium Refit and Life Certification of two SSK submarines and future Submarine projects for Indian Navy.

Objective & Scope

This paper highlights the unique experience of MDL in the field of submarine construction, especially w.r.t. the ongoing Scorpene project P75. The sea trials of the first submarine are well underway, the second is about to be launched, the boot-together of the third will be completed this month, and the balance three boats are in various stages of structural/ engineering outfitting.

The initial trials and tribulations, the overcoming of teething challenges with sheer perseverance and determination, the innovations, lessons learnt and applied, the build-up of infrastructure, achievements et al, are all dealt with in the paper.

Conclusion

The paper will conclude by highlighting the experience gained in building conventional submarines and how MDL overcame the challenges faced during construction process & is now ready to take on new projects.

Keywords: Submarine construction, Refits, Scorpene, MDL

Author's Biodata

Captain Rajiv Lath took over as Director (Submarines and Heavy Engineering) of Mazagon Dock Shipbuilders Limited in Sep 13. A Project Management expert, he has been associated with the prestigious Scorpene project at MDL for more than 10 years, heading various groups viz. Design, Planning, Production, & Project Management.

An alumnus of the National Defence Academy, Defence Services Staff College and Naval College of Warfare, Captain Lath is an experienced engineer, who has completed more than 20 years in the Submarine Branch of the Indian Navy. He has served in the Naval Dockyards with distinction, for more than 10 years, in multifarious roles of Planning, Production, HR and Resource Planning. He is a qualified Six Sigma Green Belt & Black Belt and Lead Auditor for ISO 9000/2000, ISO 14001 (EMS) and OHSAS 18001.

An experienced Submariner, he has been the squadron Engineer & also the chief Engineer of Submarine Squadrons. Commended twice by the Chief of Naval Staff for his outstanding contributions, Captain Lath was selected for the 'Outstanding Engineer Award' by the Institution of Engineers (India) in Nov 2015, at the 29th National Convention of Marine Engineers.

Future Solutions for the lifecycle management of submarines

By Stéphane Neuvéglise
Senior Business & Industry Consultant – Marine, AVEVA

Abstract

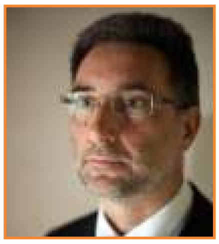
The spiralling costs of new warships, and the time taken to bring them into front-line service, frequently make headlines in national newspapers, add to this a world-wide shortage of experienced naval designers and technical specialists.

Besides this, Submarines are the most unforgiving of vessels and, from their introduction, methods have been sought to rescue their crews in the event of an unrecoverable submergence.

Such a complex and pioneering vessel represents a huge design challenge. Every new vessel begins as a concept in response to an operational requirement, and its early design must bring together many different disciplines in an iterative process of outline design, analysis and review.

In this presentation we will go through Future Marine solutions&lifecycle management of submarines. And how integrated computing technology can deliver better warships, more quickly, at less cost.

Author's Biodata



Stéphane Neuvéglise is a senior business & industry consultant within AVEVA focussing on our marine solutions. He has a deep knowledge of the shipbuilding industry and a clear understanding of market trends, which he initially acquired in previous roles as Senior Consultant in charge of Product Strategy and Product Marketing for Marine, Marine Business Developer for AVEVA Southern Europe. Stéphane joined AVEVA in 2005, following a successful career in shipbuilding. He first worked for 14 years for a major cruise-ship builder, where he held various positions, focusing on FEM calculation and CAD/CAM, becoming HVAC Contract Manager and finally Head of the Coordination Design Office. In this way, he acquired an in-depth understanding of shipyard processes in the design, workshops, production and commissioning of large passenger ships. He then spent a couple of years as the head of a ship design agent, providing design services for navy shipyards, before joining AVEVA.

Current Trends in SSK Design

Main challenges faced by the evolution of non-nuclear submarines nowadays are determined. The presentation addresses current trends in the making (design, construction) and operation of future underwater platforms. Offered are the major directions of further development for non-nuclear submarines. Primarily they include universality of platforms, increased stealth and submerged endurance, submarine cost optimization. Examples and proposals for creation of advanced non-nuclear submarine are given based on the Amur 1650 submarine.

Author's Biodata

Andrei Baranov is the Deputy to Director General of the Rubin Design Bureau (incorporated into the United Shipbuilding Corporation). He is responsible for foreign-economic affairs and military-technical cooperation with foreign countries and has been working in the Design Bureau since 1986. Andrei Baranov has a diploma in microelectronics and master's degree in submarine design.

INDIGENOUS CAPABILITIES IN STRUCTURAL DESIGN OF MARINE VESSELS

Synopsis

Design of naval vessels/special ships has been done through first principles since ages that depended a lot on technical knowhow, skills and past experience. The process being spiral in nature took long time to develop but with the advent of modern computers algorithms the long process of calculations has not only shortened, from months and years to days and weeks but has also given designers the ability to carry out structural experiments and develop innovative designs in the safe environments of efficient computer algorithms that generate quick results and help designers decide on the acceptable designs. Finite Element structural design packages are such commercially available tools. Developments of Naval ship rules by certain classification societies also highlight the importance of FEM analysis to prove the deviations/ innovations/ compliances in designs.

Maestro is unique Finite Element software developed by none other than Dr Owen F Hughes, author of ship structural design bible that not only provides FEM analysis but also provides evaluation of structural designs based on in-built empirical relations derived from numerous research papers and theories on design of plated structures/beams/frames/girders etc. The software is being used by 13 navies and numerous design agencies and shipyards in 23 countries and provides an unhindered capability in design of floating/non-floating structures with desired reliability and unmatched efficiency. The software has strong applications in structural designs of ships/submarines/off-shore structures/aircraft structures and general purpose (floating/non-floating structures). Even though the software is under Export restrictions of US government but is commercially available on case to case basis. The software is now brought to India with local expertise to develop indigenous platforms with much potency.

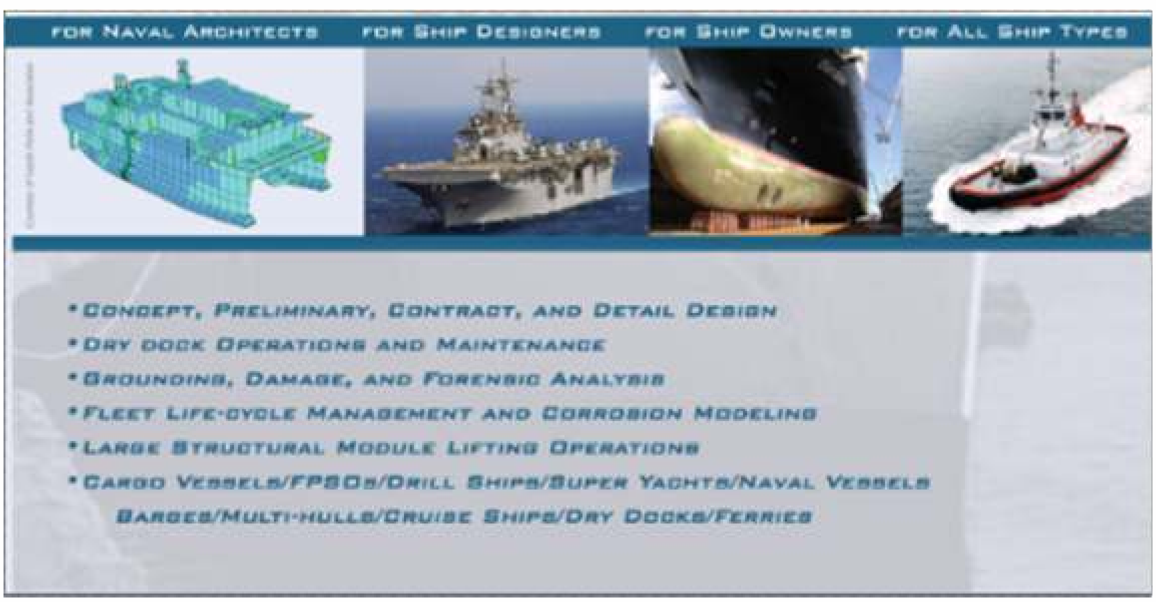
About Maestro

MAESTRO is a design, analysis, and evaluation tool specifically tailored for floating structures, and has been fielded as a commercial product for over 30 years with a world-wide user base. MAESTRO's history is rooted in rationally-based structural design, which is defined as a design, directly and entirely based on structural theory and computer-based methods of structural analysis (e.g., finite element analysis and structural limit state evaluation). It's a unique one of its kind software that also reports structural adequacy parameters (33) in addition to FEM results. At MAESTRO's core is a structural design tool developed to suit the needs of ship designers and naval architects. Further, the MAESTRO development staff and support team are themselves naval architects who understand the ship design and analysis process. The MAESTRO technology is organized within an open software architecture, with a set of core components and integration with supporting software modules and interfaces.

At Maestro's core is the philosophy of a rationally based computer aided optimization approach by Dr Owen F Hughes, its creator and developer. Dr Hughes was a BS and MS in Naval Architecture from MIT, Boston and PhD in Naval Architecture from New South Wales, Australia. He was professor of ship structures at Department of Aerospace and Ocean Engineering, Virgina Tech, Blacksburg, VA. Dr Hughes was NavSea Research professor at the US Naval Academy, chairman of the SNAME panel on design procedures and chairman of ISSC committee on Computer-Aided Design.

Importance of Maestro

MAESTRO is an important tool because it is the only software which is made exclusively for floating structures, keeping in mind the needs of structural designers, manufacturers and shipyards. This software is much more than just designing. It is a tool to predict the motions and wave loads of floating structures; a tool to calculate hull girder load response RAOs; a tool to predict extreme values of the maximum loads for a given vessel; a tool to perform global fatigue screening of the vessel and much more. It is truly unique software in that allows you to optimize your structural designs in an efficient and cost effective manner.

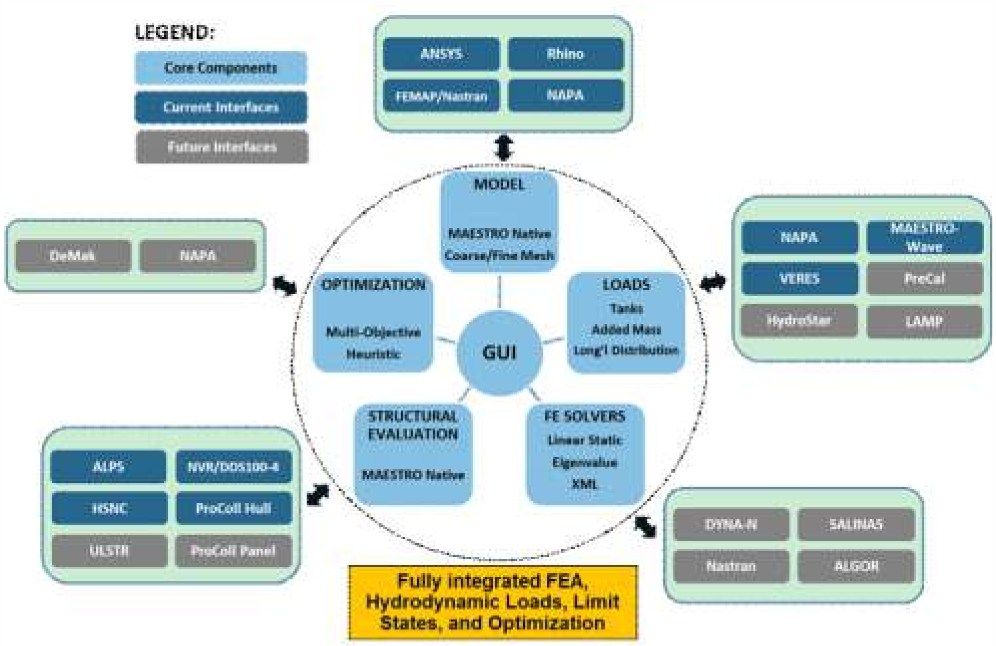


Organisations using Maestro

The computer program MAESTRO is used by 13 navies around the world including the US, Canada, Brazil, and Australia, various structural safety authorities, and by structural designers and shipyards in Europe, North America, Asia and Australia. It is also used by most major shipyards and many design firms around the US and the world. MAESTRO is in use in 23 countries by over 90 organizations. Maestro is used by largest shipyards in US, namely Ingalls Shipbuilding, Bath Iron Works, and NASSCO. In Europe, examples of two large shipyards that use MAESTRO are Navantia in Spain, and Fincantieri in Italy (their subsidiary Cetena).

Maestro Environment

The MAESTRO Technology is organized within an open software architecture, with a set of core components, and integration with supporting software modules and interfaces. The MAESTRO Technology depiction below highlights the key functional and integrated features of this advanced system developed specifically for the structural design, analysis and optimization of ship structures.

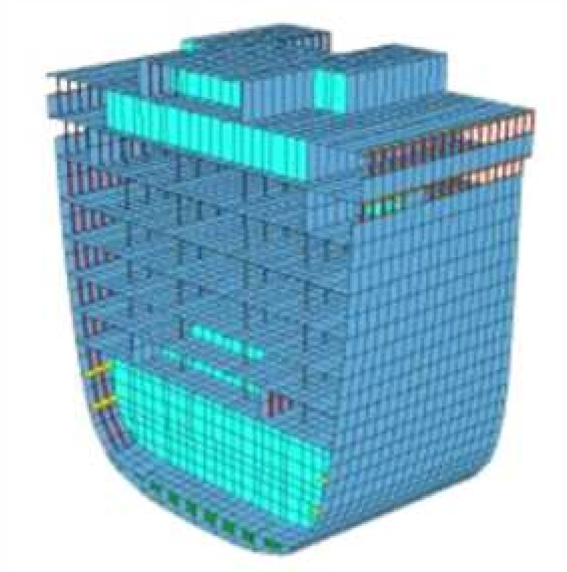


Capabilities of Maestro Modules

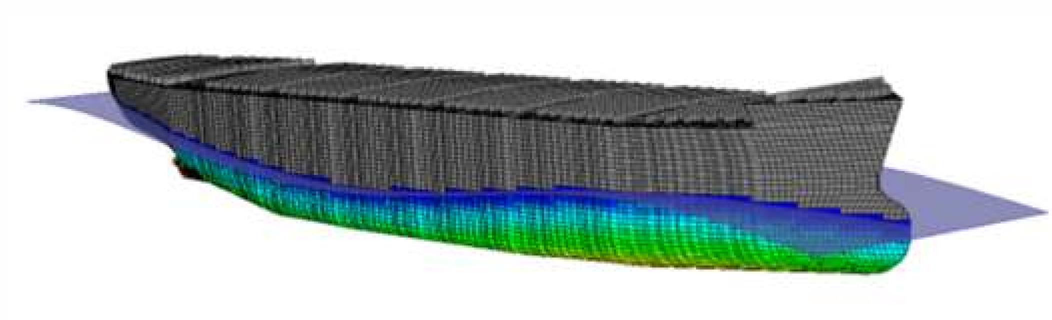
MAESTRO offers a number of features in different modules that play a critical role in making of an optimized design. The capabilities of Maestro are briefly described below.

Modeling – MAESTRO's modeling paradigm is organized to rapidly generate a finite element model of an entire ship. Hull girder properties such as inertias, cross-sectional area, neutral axis, and section modulus can be plotted and queried for any section cut within the model. In addition to its built-in modeling capabilities, MAESTRO can read geometry from FEMAP, Nastran, NAPA Steel, DXF, and polygon mesh (.ply) files. Once a model is loaded into MAESTRO from another source, all of the hull girder properties, ship-based loading, post-processing, and advanced capabilities are available to the user just as if the model had been created in MAESTRO.

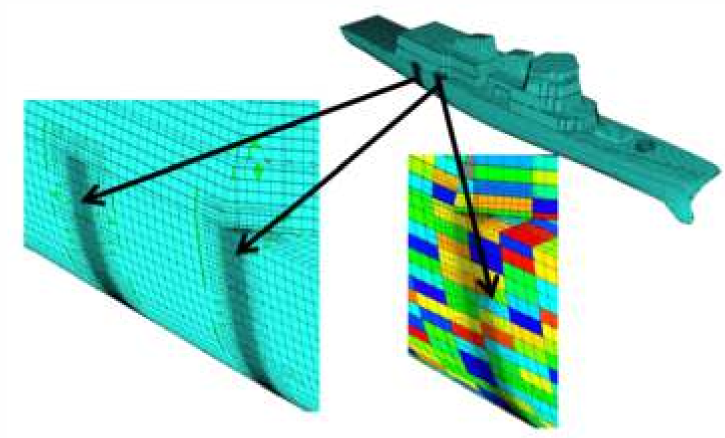
MAESTRO also provides fine meshing capabilities which allow the global model to be automatically refined while maintaining the original scantling properties and loads. The fine mesh model(s) can be analyzed as a separate model or integrated into the global model. Either option automatically applies the appropriate boundary conditions to impose the global loads onto the fine mesh model(s).



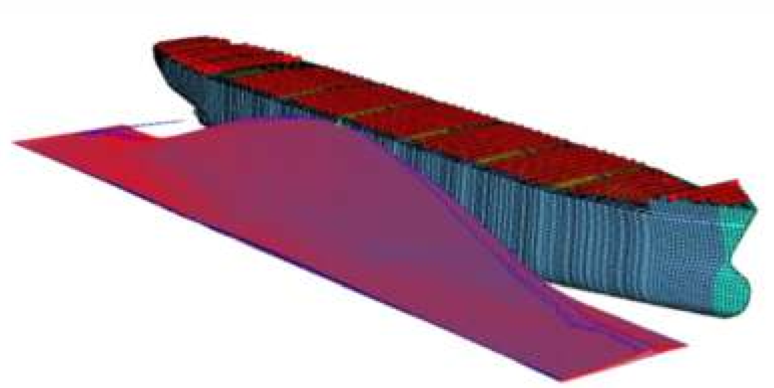
Loading – MAESTRO offers numerous ship-based loading patterns (e.g., Basic Loads: Cargo Loads, Liquid Tank Loads; Sea Environment: Hull Girder Loads/Sea Loads/Ship Motion Loads; and Operational Loads: Slamming/Flooding/Docking) to accurately and efficiently produce the necessary load cases. MAESTRO also includes a load balance capability which automatically balances the model in a stillwater or wave condition for each load case. Once a model is loaded and balanced, multiple longitudinal and transverse distributions (e.g., weight, buoyancy, shear force, bending moment, etc.) are available to quickly QA the model before solving.



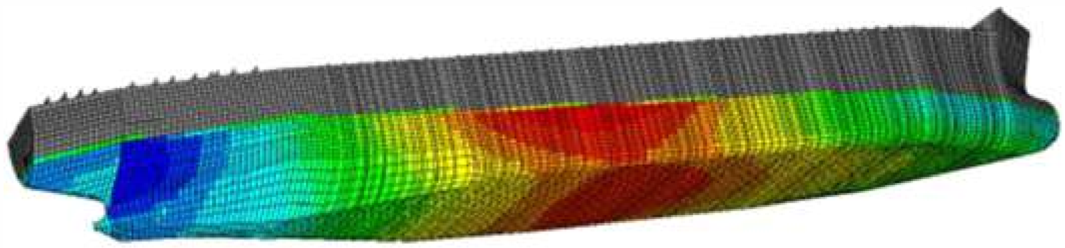
Structural Evaluation – In addition to calculating displacements and stresses using the finite element analysis method, MAESTRO also performs an automatic failure evaluation of the principal structural members. These failure evaluation modes address yielding, buckling, and other major failure modes typically found in design criteria. This is one of the most powerful failure evaluation capabilities available to the ship structural engineer, and results in a comprehensive level of information that identifies structural problems associated with events such as buckling. The available structural evaluation methodologies include MAESTRO Evaluation, ALPS/ULSAP, ALPS/HULL (hull girder ultimate strength), ABS High Speed Naval Craft (HSNC) and Offshore Buckling Guide, and US Navy NVR criteria. A structural evaluation framework in MAESTRO exists so that additional design criteria and class rule checks can be easily implemented as needed.



MAESTRO-Wave (Integrated Hydrodynamic Loads Prediction) – The MAESTRO-Wave module provides the ship designer with an integrated frequency-domain/timedomain computational tool to predict the motions and wave loads of floating structures. Because this tool is integrated into the MAESTRO interface, the learning curve is greatly reduced and the need to transfer data between programs is eliminated. MAESTRO-Wave takes advantage of the existing structural mesh and defined loads to formulate the equations of motion. This approach results in a perfect equilibrium for the structural model so no inertia relief or artificial loads are required to balance the model. Bending moments, shear forces and torsional moments are all automatically in closure. MAESTRO-Wave can also account for tank sloshing loads and provides several roll damping options. The MAESTRO-Wave output provides a unit wave database and panel pressure loads for all of the speeds, headings, and wave frequencies run. A variety of visualizations and output data are available to aid the user with post-processing.



Extreme Load Analysis (ELA) – The ELA module allows the user to calculate hull girder load response RAOs, and provides the necessary short-term and long-term statistical computations to predict extreme values of the maximum loads for a given vessel. This includes the ability to define or import wave scatter diagrams, operational profiles, and wave spectra, as well as to compute hull girder RAOs for the most common dominant load parameters (e.g., vertical bending moment). Finally, extreme equivalent regular waves (equivalent design waves) are internally computed and selected for assessment of extreme global loads. The user has a variety of options to add still water loads to the wave-induced loads and to re-balance these components.



Spectral Fatigue Analysis (SFA) – The SFA module provides the ability to perform global fatigue screening of the vessel and introduces additional functionality to the ELA module to compute Stress and Displacement RAOs, define and associate structural groups to SN curves and Stress Concentration Factors (SCFs), and compute fatigue damage based on the Miner cumulative damage principle.

NAPA/MAESTRO Interface – MAESTRO can interface directly with NAPA in order to leverage existing geometry and loading information. This interface enables shorter design cycle times by using a single 3D structural design model (from NAPA) that can be re-used as the design matures and is ready for MAESTRO analysis in a matter of minutes.

Natural Frequency Analysis – MAESTRO allows the user to perform a natural frequency analysis and visually identify the dominant global modes. The analysis can be performed in a dry or wet mode, in which the added mass of the seawater is automatically applied to the "wettable" elements based on the immersion condition.

Corrosion Modeling – MAESTRO provides the capability to model corrosion as an additive property associated with a particular load case. The new plate and beam thickness are automatically used in the finite element analysis and strength assessment. This enables the user to use a single finite element model throughout the lifecycle of the vessel, easily analyzing "as-is" corrosion information or "what-if" scenarios.

ULS-Based Optimization - The MAESTRO Optimization module allows a user to optimize a given structure ranging from a single stiffened panel to a hull girder cross section to a full-ship model using a multi-objective, heuristic-based optimization approach. During the optimization setup, users are able to define design clusters which ensure scantling properties are consistent throughout the group to support realistic and producible designs. For each scantling optimization iteration, a new finite element analysis is run with the updated properties and adequacy parameters are evaluated and used to optimize the structure for the next run. The optimization module allows the user to select from a variety of optimization methods including Simulated Annealing, Genetic Algorithms, Monte Carlo, and an exhaustive search.

Applications of Maestro

The software has strong applications in structural designs of ships/submarines/off-shore structures/aircraft structures and general purpose (floating/non-floating structures).

Export Restrictions on Software

The SOFTWARE is subject to the United States Export Regulations, as administered by the Department of Commerce, Bureau of Industry Security. The SOFTWARE may not be used in or exported/re-exported to any country to which the United States embargoes goods. The same restriction applies to persons, no matter where they are located, that appear on the Table of Denial Orders, the Entity List, or the List of Specially Designated Nationals.

Make in India/IDDM/Role of MSME

We intend to share our expertise in structural design and analysis using the MAESTRO software with both government and private institutions. We will work with our clients throughout the design process covering hull form design, ship structures, resistance and powering analysis, stability calculations, hydrodynamic predictions, as well as seakeeping and maneuvering analysis. Our structural design and analysis services include creating conceptual designs, functional level drawings and detailed production level drawings in accordance with industry and government regulatory standards. We also offer structural optimization services to those customers looking for an optimized structural design that minimizes structural weight, minimizes cost, assures structural safety and manages the structural vertical center of gravity. These optimization services can be applied to an existing customer's finite element model, or model can be built by Inoviea. Besides, we also offer license for the MAESTRO software, provide training, provide second opinion on already designed structures and conduct forensic analysis of damaged ship/floating structures. In India, Inoviea is the only company in India that has expertise of using the software for structural design and analysis of floating vessels with demonstrable experience.

We at Inoviea are very excited to make our contribution towards the Make in India initiative and since defence manufacturing is one of the 25 sectors indentified for this initiative. We feel that we can make some significant contributions towards this sector in the areas of manufacturing, designing, training, consultancy and making possible the IDDM (Indigenously Designed Developed and Manufactured). Involving and enhancing the role of MSMEs holds great potential in keeping the costs of platforms competitive. We strongly believe in India's ability to design and manufacture aircraft carriers, destroyers and submarines in India and are here to provide full technical support to the government and private institutions in this niche domain.

Author's Biodata

Cdr Suchin Jain (Retd) A naval architect from CUSAT, Kochi, Post Graduate from IIT Delhi & Certificate Business Management from IIM Ahmedabad. An Ex-Indian Navy Commander has 26 years of rich professional experience. Undertook extensive FEM analysis of India's first indigenous aircraft carrier. Associated with design and construction of ASW corvette, destroyers, Follow-on stealth frigate and nuke sub. Finished over 100 refits on more than 40 ships and subs. Handled over 600 contracts in various stages &was part of IN projects worth over 14 billion USD. A member of CII North Regional Committee on Aerospace and Defence, Member & Technical Secretary Institution of Naval Architects (Delhi Chapter) and Fellow Institutions of Engineers (India). Hefounded Inoviea, a consulting and Services Company (www.inoviea.com) offering holistic solutions in design, technical, management and marketing domains.

About FICCI

Established in 1927, FICCI is the largest and oldest apex business organisation in India. Its history is closely interwoven with India's struggle for independence, its industrialization, and its emergence as one of the most rapidly growing global economies.

A non-government, not-for-profit organisation, 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. It serves its members from the Indian private and public corporate sectors and multinational companies, drawing its strength from diverse regional chambers of commerce and industry across states, reaching out to over 2,50,000 companies.

FICCI 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.

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