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TECHNOLOGICAL ADVANCEMENT AND FUTURE OF WARSHIPBUILDING

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ABSTRACT

The history of ship design has been influenced by factors such as sea, wind and weather conditions, global conflicts, war strategy, andtechnological advancements. Ship design involves specialists with diverse requirements, and the use of software has made the process more efficient, effective, and safe. The Digital Revolution has significantly improved the efficiency, effectiveness, and safety of ships. Designing a ship involves a combination of theoretical analysis and empirical data gathered from past successful designs. It is an iterative process that must meet various techno-economic requirements. Currently, China, Japan, and Korea are the primary constructors of merchant ships.However, classification societies are crucial in ensuring a ship's structural strength and safety. The most important stage in ship design is the concept design phase, where calculations are used to translate the mission or ship owner's requirements into naval architectural and engineering characteristics. Despite the progress made, ship design remains a challenging task, and naval architects and marine engineers must continue to refine and improve their methods to meet the industry's constantly evolving requirements. Research and development along with navy requirement, are play important role in warship designing and construction.It’s an analytical paper which discusses the amazing technological development and wonderful constructional skill in war shipbuilding along with future technology which will influence entire shipbuilding.

Key Words:
Diesel-electric, nuclear powered, drone carrier, 3D printer, IoT

INTRODUCTION

1. Wind and weather conditions have been considered important factors in ship design throughout history. The ancient Egyptians used reed-built vessels with sails and masts for fishing and transportation on the Nile in 4000 B.C. In the 16th century, the Spanish and Portuguese created larger ships with built-in canons and the ability to travel longer distances, such as the Nao, Galleon, and Carrack. By the 18th century, ships were built with up to fifty canons and resembled the typical pirate ship. During the Industrial Revolution, marine engineers made significant changes to improve the power of steam engines, which had a major impact on ship design. This led to ships becoming the fastest and most powerful vessels in the early 20th century. Ship design was heavily influenced by global conflicts such as the World Wars. Today, ships are capable of carrying thousands of passengers, large amounts of cargo, and numerous weapons while remaining at sea for extended periods. To reduce manufacturing costs in the long term, ships are now being designed with reusable and recyclable components. The ship design process is complex and involves specialists with diverse requirements. In the past, ship frames were built using reusable templates created on drawing boards, but now entire ships are

designed using thesoftware. The foundations of modern ship design were established by Pierre Bouguer(1698-1758) and William Froude (1810-1879), whoare considered the fathers of naval architecture.[1]

2. The Digital Revolution has significantly enhanced the efficiency, effectiveness, and safety of ships, providing naval architects and marine engineers with peace of mind. Water transportation has been utilized for centuries for both passenger and cargo traffic due to its cost-effectiveness, particularly for transporting bulky items over long distances. One significant advantage of water transportation is the interconnectedness of the world's oceans, allowing ships of various sizes to traverse them. Ship design is a blend of theoretical analysis and empirical data gathered from past successful designs.[2] It is not an exact science but rather a process of trial and error. The construction of warships involves balancing perfection with intended purpose and cost, with compromises often necessary to achieve the desired result. To meet the necessary requirements, parameters such as 'must', 'required,' and 'nice to have' must be meticulously sorted out and methodically fitted into the design platform, which is a time-consuming, demanding, and challenging task.[3] Thanks to the Digital Revolution, the design process has become more efficient, effective, and safe, with software and technology providing new solutions to old problems. However, the fundamental challenges of ship design remain the same, and it is up to the naval architects and marine engineers to continue refining and improving their methods to Maintain a stride that aligns with the continuously evolving requirements of the industry.

3. The process of ship design is an iterative process that must satisfy a range of techno-economic requirements, some of which may be contradictory. The design process typically consists of four stages: concept design, preliminary design, contract design, and detail design, with the first two stages also referred to as basic design.[4] The concept design stage is a critical phase in ship design where a set of calculations is used to create documentation and models that describe the necessary requirements for the construction of the ship. This stage ensures that the ship meets the demands of the client for merchant ships and accomplishes the task or mission for naval ships. It is the most crucial stage of the design process as it translates the mission or ship owner's requirements into naval architectural and engineering characteristics. The Naval Shipbuilding and its conceptual solutions[5] preparation usually contain a few broad processes:

a. Ships function and mission.

b. Principle dimensions associated with purpose, mission, roles and local restriction.

c. Ships basic features and concept design.

d. Primary calculations to ensure compliance of Class Rules, applicable of conventions and international regulations.

e. Construction of ship in accordance with suitable and sustainable technical procedures with safety standards, regulations, and methods.

f. Selection of propulsion and machinery package according to desire speed, purpose and mission.

g. Selection of material, equipment, systems and other essentials to solve the assigned task and ensure habitability of the naval platform.

h. Selection of armament, gun, missile, torpedo, sensor, combat system, command & control system, etc as to accomplish the assigned mission and task of the naval platform.

4. The majority of the world's merchant ships are presently constructed by China, Japan, and Korea, which jointly accounted for approximately 90% of the gross tonnage delivered in the year 2023. Although classification is not mandatory for all vessels, it is widely practiced in the industry as it is an excellent endorsement for the ship and its owners. If a ship is not classified, the ship owners must satisfy the relevant government regulatory bodies to guarantee that the vessel has the required structural strength to obtain a load line and a safety construction certificate. Nevertheless, classification societies publish regulations and guidelines concerning the adequacy of equipment, the dependability of onboard machinery, the ship's strength, and other pertinent factors.[6] Any ship may be constructed in any country and is not confined to classification solely by the society of that particular country. They may comply with the rules and regulations of any

classification society as per their preference.Research and development along with navy requirement, are play important role in warship designing and construction. It's an analytical paper to discuss the amazing technological development and wonderful constructional skill in war shipbuilding on the basic of primary and secondary information along with future technology which will influence entire shipbuilding.

AMAZINGTECHNOLOGY OF SUBMARINE

5. The modern nuclear power submarine has a crew of fewer than 200 individuals; comparable to an infantry company, yet these skilled submariners wield an immense amount of power and can command the seas or even destroy an entire civilization. This concentration of power is made possible by a variety of innovative technologies, including rocketry, acoustics, hydrodynamics, nuclear power, advanced chemistry, and unique materials. The submarine, unlike other military innovations of the 20th century such as tanks, aircraft, and nuclear explosives, is still considered a truly secretive and silent service.[7] While the US Navy is currently constructing only one type of submarine, the general-purpose Virginia Class, they will soon be joined by the Columbia Class ballistic missile submarine. In contrast, Russia is building six distinct classes of submarines, with many already operational and others in various stages of construction at Russian shipyards. By 2040, Russia is expected to have an exceptionally formidable submarine force.[8] Meanwhile, China continues to develop its navy and military power with new innovations and surprises on a daily basis. Historyand operation of submarine has been shown in this video.[9]

6. Conventional submarines face a significant challenge due to the restricted energy capacity of electric batteries, allowing them to stay submerged for just a few days at low speeds or a few hours at high speeds. Nevertheless, air-independent propulsion submarines[10] have made advancements in tackling this limitation. A nuclear submarine, powered by a nuclear reactor, may not necessarily be equipped with nuclear weapons but offers significant advantages and operational capabilities over conventional diesel-electric submarines. Nuclear propulsion is completely independent of air, enabling the submarine to remain submerged for extended periods without surfacing, unlike conventional submarines which need to surface frequently. However, due to the high cost of nuclear technology, only a few of the world's military powers possess nuclear submarines. Radiation incidents and accidents have occurred on Soviet Navy submarines, while the US Navy has operated its nuclear submarines without any incidents or accidents since 1954 when USS Nautilus was commissioned.[11]

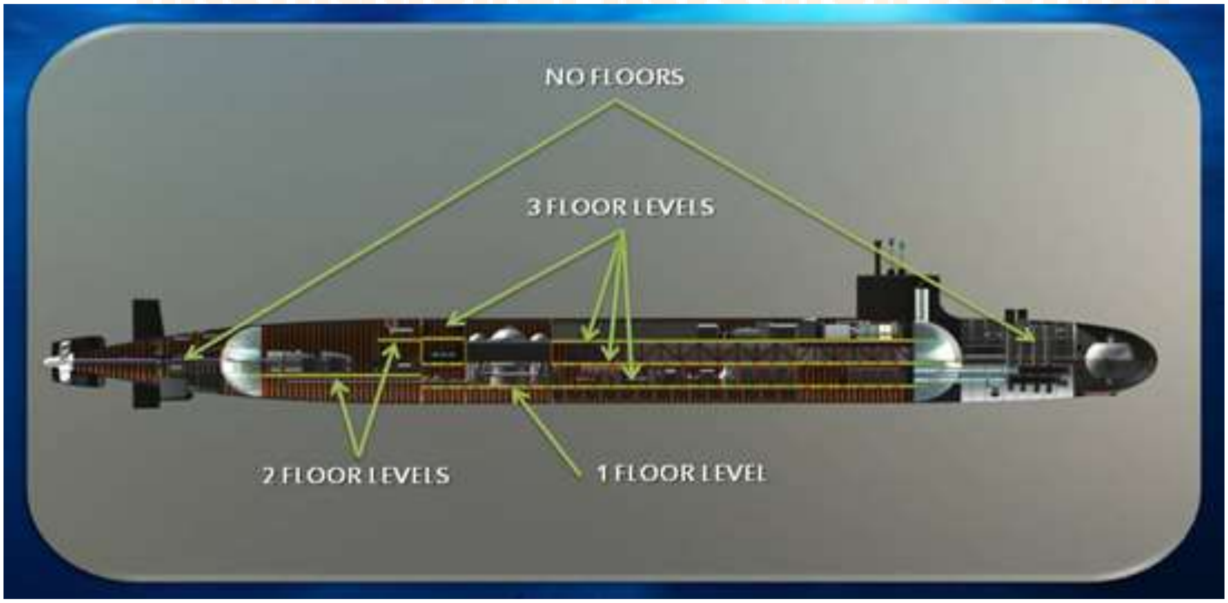

Fig 1: US Navy Virginia class nuclear submarine modular hull construction[12]

7. Nuclear ballistic-missile submarines are regarded as potent strategic weapons due to their ability to remain submerged for extended periods and stay hidden under arctic ice for months. They operate quietly and are difficult for the enemy to detect. The world's first nuclear-powered submarine was constructed thanks to a successful nuclear propulsion plant development by a group of scientists and engineers at the Naval Reactors Branch of the Bureau of Ships and the Atomic Energy Commission. The primary difference between nuclear and conventional submarines is the power generation system, as nuclear submarines use nuclear reactors to generate electricity for powering electric motors connected to the propeller shaft or to produce steam that drives steam turbines.[13] However, nuclear propulsion must maintain its stealth property even when the submarine is not moving, which requires cooling the reactor to dissipate approximately 70% of its output heat into seawater. This creates a thermal wake or plume of warm water that rises to the surface and can be observed by thermal imaging systems, while the reactor's continuous operation generates steam noise that can be detected by passive sonar. The large size and capacity of the reactor pump also create noise when circulating reactor coolant, unlike a conventional submarine that operates almost silently using its electric motors.[14]

8. The US Navy currently has 18 Ohio-class nuclear submarines, including 14 At present, the US Navy possesses 18 nuclear submarines of the Ohio class, which consist of 14 ballistic missile submarines (SSBNs) and 4 cruise missile submarines (SSGNs).ballistic missile submarines (SSBNs) and 4 cruise missile submarines (SSGNs). These submarines are the largest ever built for the US Navy, weighing in at 18,750 tons when submerged. While they are the world's third-largest submarines, they are only surpassed in size by the Russian Navy's 48,000-ton Typhoon class and 24,000-ton Borei class submarines. The Ohio-class submarines are capable of carrying 14 Trident missiles, each loaded with three thermonuclear warheads, which means that a single submarine can effectively destroy anything short of a major nuclear power.[15] Additionally, Ohio-class submarines can carry more missiles than either the Borei or Typhoon classes.[16] The SSBN submarines are part of the US nuclear triad, and each is equipped with up to 24 Trident II submarine-launched ballistic missiles (SLBM). Each An SSGN has the capacity to carry a maximum of 154 Tomahawk cruise missiles.AndUp to 154 Tomahawk cruise missiles and a set of Harpoon missiles fired through their torpedo tubes can be carried by each SSGN. Complement of Harpoon missiles fired through their torpedo tubes. The first of the existing Ohio-class SSBNs is set to be decommissioned by 2029. The Columbia-class was officially designated on December 14, 2016, and it is expected to be commissioned in 2031.[17]

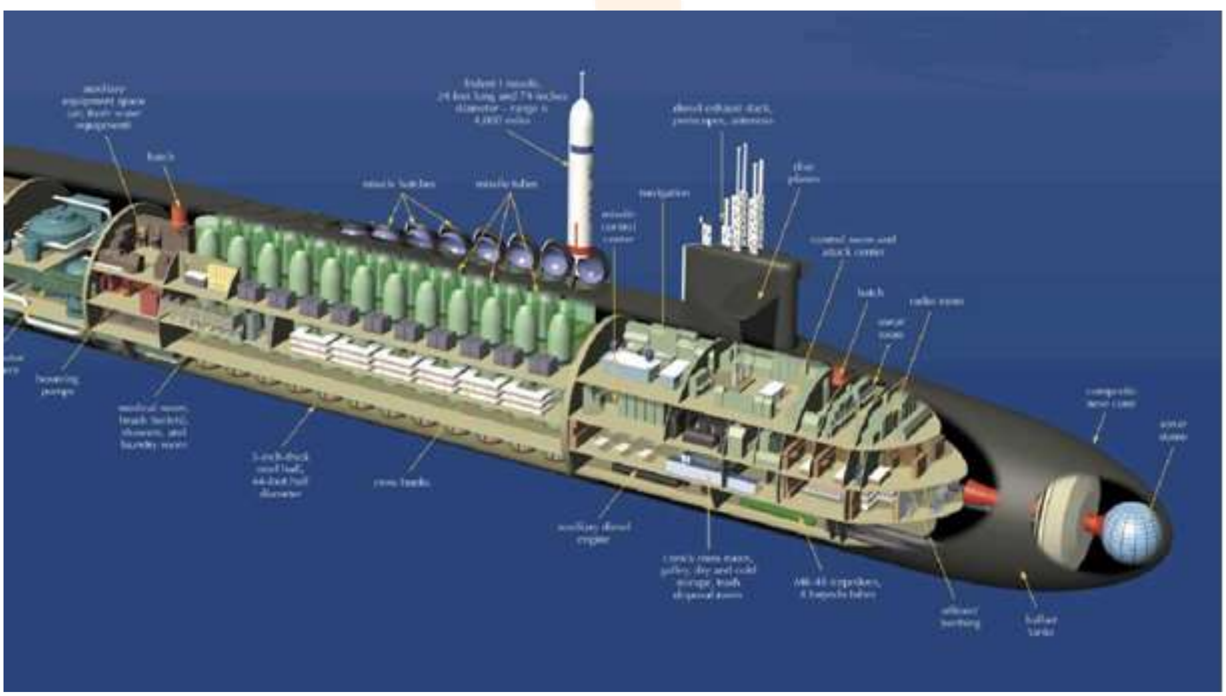

Fig 2: US Navy Ohio class nuclear-powered submarine with single hull design[18]

9. The US Navy has developed and operates the Virginia Class, which is a highly advanced nuclear-powered fast attack submarine (SSN). Its primary objective is to replace the aging fleet of Los Angeles Class attack submarines and provide an affordable and flexible multi-mission stealth platform for theater commanders. The Virginia Class has been specifically designed to excel in a wide range of war-fighting missions, with a focus on littoral operations, and its several innovative features significantly enhance its war-fighting capabilities. One of the most notable features of the Virginia Class SSNs is the fly-by-wire ship control system, which improves the handling of the submarine in shallow waters. Additionally, it has special features that support special operation forces, such as the ability to reconfigure the torpedo room to house a large number of personnel and equipment for extended missions and future off-board payloads. The class also boasts a large lock-in/lock-out chamber for divers.By replacing traditional periscopes with two Photonics Masts that feature color, high-resolution black and white, and infrared digital cameras atop telescoping arms, the Virginia Class SSNs have enabled the ship's control room to be relocated one deck lower and away from the hull's curvature, resulting in more space and a better layout that enhances the commanding officer's situational awareness. Moreover, the Virginia Class is designed to remain state-of-the-art throughout its operational life by using modular construction, open architecture, and commercial off-the-shelf components. This approach facilitates the rapid introduction of new systems and payloads, ensuring that the submarine remains highly capable and relevant for its entire operational life.Ultimately, the Virginia Class is a highly advanced and versatile platform that enhances US national security by providing theater commanders with a robust and effective means of performing a wide range of war-fighting missions. Operation of US Virginia class submarine has been shown in those two video.[19,20]

10. Since its commissioning in 2004 with USS Virginia (SSN 774), the Virginia Class submarine design has undergone a continuous evolution. With each successive Virginia Class SSN Block, the submarine design incorporates additional capabilities and advanced technology while reducing costs. The first two blocks of Virginia Class have a vertical launch system (VLS) in the bow for 12 Tomahawk missiles, similar to the preceding Los Angeles-class attack submarines. However, the Virginia Payload Module (VPM) marks the most significant design change to the Virginia Class starting with Block V. An 84-foot section known as the VPM is incorporated into the submarine's existing design, and it includes four large-diameter payload tubes that can each carry seven Tomahawk missiles. Future VPM-equipped submarines are the most cost-effective solution to restore the US Navy's undersea strike capacity, which is set to decrease by 60% as the Ohio Class SSGN force will be retired by 2028. In 2019, the first VPM-equipped submarine was constructed. The open architecture design of VPM enables the submarine to deliver a broad range of capabilities, including weapons, unmanned systems such as Large Displacement Unmanned Undersea Vehicles, seabed sensors, and other undersea capabilities. As the threats to national security around the world continue to evolve, the submarine industrial base will continue to deliver a submarine that allows the US Navy to meet these challenges.[21] It's worth noting that the Virginia class isn't the Navy's newest submarine design. Still, continuous upgrades and the integration of new technologies into the Virginia-class design ensure that each of the submarine blocks is progressively more capable than its predecessors.

Fig 3: US Navy Virginia Class nuclear submarine with single hull design[22]

11. The US Navy's ballistic missile submarines are capable of carrying a large number of intercontinental missiles, some of which can contain multiple warheads. These missiles are quite large, and a single submarine can carry over 100 nuclear warheads. These submarines are primarily designed for quiet and concealed operation and are not typically used to engage surface ships or other submarines. However, they may carry smaller missiles and torpedoes for self-defense. The Soviet Navy developed a double hull design that allowed for a wider body and more missile capacity. This design includes two side-by-side cylindrical inner hulls, connected to make the submarine structure stronger. The Soviet/Russian submarines have crew compartments made of titanium and interconnected spheres and can dive to depths most military submarines cannot reach. In contrast, the US prefers smaller ballistic missile submarines, known as Boomers, with smaller missiles and a smaller hull. Ballistic missile submarines play an important strategic role, while hunter/killer or attack submarines are used more tactically, such as for protecting carrier fleets or hunting enemy submarines and surface ships. These submarines are smaller, faster, and equipped with powerful sensors. They do not require a large missile capacity but may carry smaller nuclear missiles or torpedoes. During WWII, Japan developed a side-by-side hull design to carry and launch bombers, which allowed for a large and stable design. The submarines never saw significant action, but were intended for bombing the Panama Canal.[23] Russia's nuclear weapons are considered its ultimate insurance policy against NATO intervention in Ukraine. At the Army 2022 defense expo, the latest design for a ballistic missile submarine has been unveiled by Rubin, the Russian submarine design bureau. The submarine, named 'Arcturus,' features an angled outer hull with sloping sides and blended lines, resembling a modern low-observable aircraft. The design is intended to increase the submarine's stealth capabilities and ability to deflect incoming active sonar, similar to other designs like the German-designed Type-212CD[24] and British Dreadnought Class ballistic missile submarine.[25] Russian nuclear power submarine operation has been shown in this video.[26]

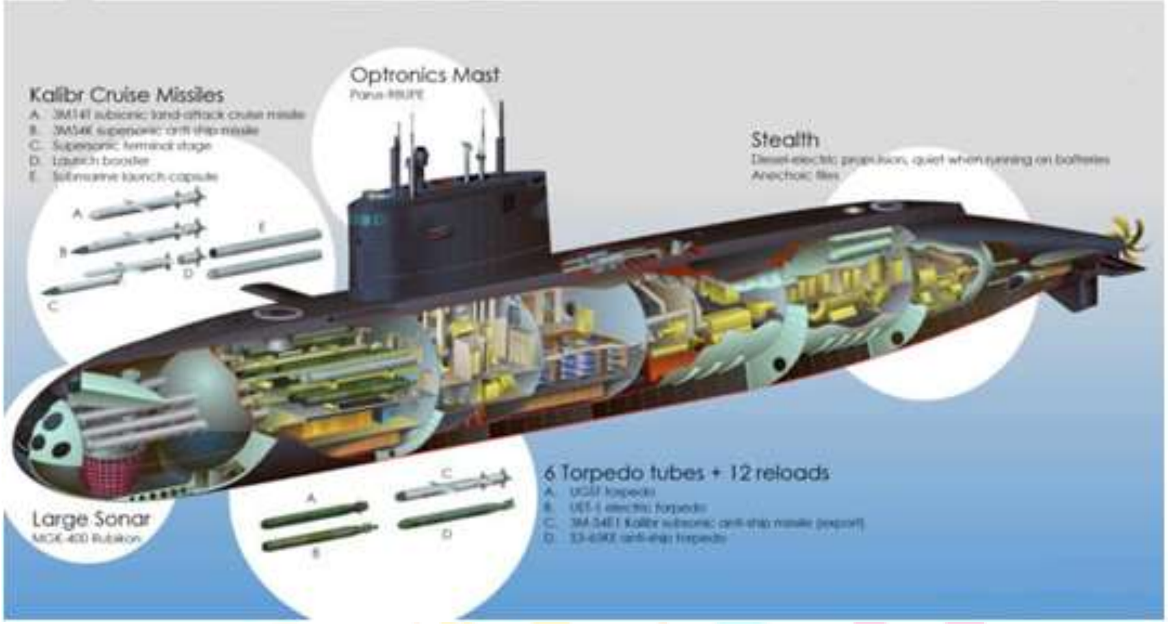

Figure 4: Russian Navy Kilo class submarine 3D view[27]

AMAZING AIRCRAFT CARRIER TECHNOLOGY

12. The term "aircraft carrier" refers to a battleship that doubles as an ocean-going airfield and is furnished with a full-length flight deck and equipment for storing, loading, deploying, and retrieving aircraft.[28] From a tactical or strategic standpoint, it took the battleship's position as the fleet's flagship for a strong Navy. Sailing in foreign seas is one of its many benefits. In reality, the carrier is a multifaceted, unique characteristic airport on the water. A former US Secretary, Henry Kissinger stated that one aircraft carrier is equivalent to 100,000 tons of diplomacy.[29] Eugene Ely, a civilian pilot from the United States, took off from a specially constructed platform on the deck of the US cruiser Birmingham in Virginia on 30, November 1910. On January 18, 1911, Ely employed wires attached to sandbags on a platform built on the quarterdeck of the battleship Pennsylvania as arresting equipment in San Francisco Bay. The British Navy also experimented with the carrier; during the fast World War, the HMS Argus was built on a modified merchant ship hull and was the first real carrier with an unobstructed flight deck. Before the Argus could be deployed, the war ended, but the US and Japanese warships swiftly adopted the British model. The USS Langley, a converted collier, became the fleet's first American carrier in March 1922. The Hosyo, a Japanese carrier, was the first aircraft carrier to be planned and constructed from the keel up and entered service in December 1922.[30]

13. Aircraft carriers can be categorized according to the kind of aircraft they carry and their operational responsibilities. As it enables a naval force to project air power globally without relying on local bases for staging aircraft operations, it is the flagship of a fleet. The United States launched the first nuclear-powered carrier, the Enterprise on September 24, 1960.[31] On the other hand, light carriers with substantial electronic equipment for submarine detection and helicopter carriers designed for amphibious assault. Another adjustment was the widespread replacement of the outdated anti-aircraft armament with missile armament. Multipurpose carriers are defined as those having several capacities.[32] Based on the methods used by current Navies for aircraft takeoff and landing, there are four basic classifications of the carrier. Number of aircraft carrier are in operation under different navy has been shown in this video.[33]

a. **Catapult-assisted takeoff barrier-arrested recovery (CATOBAR)**. All current CATOBAR carriers are nuclear-powered, typically transporting the biggest, heaviest, and most heavily armed aircraft.[34] There are twelve of these carriers in operation: 11 fleet carriers are owned by the US, consisting of 10 Nimitz class, 1 Gerald R. Ford class, and 1 Charles de Gaulle class.

b. **Short takeoff barrier-arrested recovery (STOBAR)**. These carriers can often only transport smaller, lighter fixed-wing aircraft with constrained payloads.[35] Admiral Kuznetsov is a good example of a STOBAR carrier, frequently designed more for air superiority and fleet defense missions than strike/power projection tasks.[36] Five of these carriers are in operation: two each in China, India, and Russia.

c. **Short take-off vertical-landing (STOVL)**. Aircraft are often the only ones that this type of carrier can carry. The typical characteristics of STOVL aircraft are a small payload, poor performance, and significant fuel consumption. Modern STOVL aircraft perform significantly better, like the Lockheed Martin F-35B Lightning II.[37] There are fourteen these types of carriers are in service. Currently nine STOVL amphibious assault ships US, two each in UK and Italy,one each in the Spain.

d. **Helicopter carrier**. Helicopter carriers resemble other aircraft carriers in appearance but exclusively transport helicopters.[38] Some helicopter carriers fall under the category of amphibious assault ships,[39] and their job is to land on hostile territory and help ground forces there. A combatant nation's capacity to reach the enemy at sea is unique and expanded thanks to helicopter carriers. These battleships are more affordable to buy and smaller in terms of dimensions. Supply, Search and Rescue (SAR), MEDEVAC, submarine hunting, combat surveillance, personnel insertion/extraction, and general reconnaissance are a few of these ship types.[40] Seventeen carriers of this kind are now in operation: four in Japan,[41] three in France, two in Australia, China, Egypt, and South Korea, as well as one in each Brazil and Thailand.

14. Present day active aircraft carrier and their principal information have been shown in this video clip.[42] Ten modern aircraft carriers coming in near future has been shown in this video.[43] The Gerald R. Ford (CVN 78)[44] is the newest and most technologically sophisticated nuclear-powered aircraft carrier ever built for the US Navy. It will ultimately replace Enterprise (CVN-65) and the current Nimitz class carriers. The new ships' hulls are comparable to those of the Nimitz class but feature many more cutting-edge innovations.[45] The crew size reduction brought about by automation will contribute to the lower whole-life cost of the Gerald R. Ford-class ships. These ships are built to support 160 sorties daily for at least 30 days and have a surge capability of 270 sorties daily.With state-of-the-art technology, the new Gerald R. Ford class carriers will launch 25% more sorties, generate three times as much power with improved efficiency, and boost crew quality of life. This aircraft carrier has advanced nuclear reactor architecture for higher power generation and the capacity to transport up to 90 aircraft. Such aircraft carrier construction and maintenance is few billion dollar affair.It is interesting to know that, today modern helicopter carriers provide a fighting nation a unique, extended capability at sea with very less expense.[46] However, in CVN 78 traditional steam catapults will be replaced with Advanced Arresting Gear and Electromagnetic Aircraft Launch System (EMALS) for launching and stopping aircraft.[47]

15. The Gerald R. Ford class of aircraft carriers were designed and planned for construction by Newport News Shipbuilding utilizing a full-scale 3D dimensional product model made in the CATIA simulator by Dassault Systems.[48] Better weapons mobility pathways were included in the CVN 78 class's design, substantially avoiding horizontal ship motions that use more human resources. The carrier was put together at Newport News Shipbuilding in Newport News, Virginia, a branch of Huntington Ingalls Industries (formerly Northrop Grumman Shipbuilding). This one is the only shipyard in the US capable of producing nuclear-powered aircraft carriers. The Gerald R. Ford building cost US$14 billion to design and construct, of which US$5 billion went toward research and development and US$9 billion for construction.[49] Various stages of construction and final product of Gerald R. Ford aircraft carrier (CVN 78) has been shown in figure 6 below. Construction video of US CVN Gerald R. Ford has been shown in those two video.[50,51]

16. The world's first drone carrier and largest home-built battleship were both unveiled in Turkey on April 10, 2023. TCG Anadolu, which was constructed at the shipyard Sedef in Istanbul, is 231 meters (758 feet) long and 32 meters (105 feet) broad. It can transport up to 94 vehicles, including 13 tanks, as well as combat helicopters and military drones.[52] The clip suggests that the layout of Turkey's potential Anadolu Landing Helicopter Dock (LHD) has been changed to accommodate more crewless aerial aircraft (UAV) deployment.[53] According to satellite and open source images provided last week by USNI News contributor H I Sutton, Iran's sectarian naval force is transforming a dry dock located at the entrance to the Persian Gulf which was used to convert a previous merchant container ship into a drone aircraft carrier. The former container ship ShahidMahdavi of the Iranian Revolutionary Guard Corps Navy is currently undergoing warship conversion at

the Iran Shipbuilding and Offshore Industries Complex Co (ISOICO) in Bandar Abbas, close to the Strait of Hormuz, to carry both helicopter and fixed-wing crewless aerial vehicles.[54] Based on the hull of a sizable cargo ship, the Iranian drone carrier is 240 meters long. The ShahidMahdavi and ShahidBagheri are two of the vessels that are anticipated to be built.[55] The development of cutting-edge drones and drone carriers for powerful navies like the US, China, UK, France, and India is already underway.[56] Future fleet carriers will, once again, be equipped with more drones than human aircraft. A fascinating video clip has been displayedin the link, which will show the ten most potent and technically advanced navies in the world at present.[57]

Figure 5:Turkeyunveils its first drone Carrier[58] Iran is building drone aircraft carrier[59]

Figure 6: Construction stages and images of the latest nuclear powered aircraft carrier Gerald R. Ford(CVN 78) for US Navy[60]

Figure 7: Model of future drone carrier (may substitute of aircraft carrier) for powerful navy[61]

MISSION-FOCUSED DESIGN CONCEPT

17. Designing armed forces platforms, especially naval ships, is a precise and complicated process. The future design of armed forces platforms and naval ships will have a significant impact on the shipbuilding industry. It is important that future armed forces platforms are designed with a mission-focused approach, where concepts, activities, technologies, requirements, programs, and budget plans are synchronized, managed, and coordinated to guide key decision-making on the end-to-end mission. The current methodology differs from the recent platform-centric design idea that didn't incorporate departments into more extensive warfare concepts.[62] The effectiveness of future Navy systems will not be measured by the individual attributes of a single hull type but by the combination of the hull's combat capabilities, capacity, and ability to interact with off-hull systems. To embrace this paradigm shift, the modern Navy must possess the essential resources and personnel, and Navy acquisition leaders must take affirmative steps to attain this goal. In order to attain this objective, the contemporary Navy needs to enhance its creation of digital prototypes and simulations for proposed systems and confirm the practicality of deployment concepts using live, virtual, and constructive (LVC) testing scenarios. Decision-makers and planners must be able to integrate digital models and simulations to optimize concepts of operation and integrate mission-focused design.[63] This will help ensure that future naval ship designs are efficient, effective, and properly equipped to fulfill their mission requirements.

LESSONSLEARNED FROM WORLD MOST ADVANCED NAVY

18. During the late 1980s, the Seawolf-class submarine brought about a major shift in US submarine design, much like the shift currently occurring with SSN(X). The Seawolf (SSN-21) was larger, faster, and capable of diving deeper than previous submarine classes, and boasted twice the torpedo capacity. However, the significant new design and engineering required also led to complexity and problems that ultimately caused the cancelation of the program after only three submarines. Supporting weapon system programs were also canceled. The littoral combat ship (LCS) was another attempt at a paradigm shift in surface ship design and construction, in the early 2000s. It aimed to create a system of systems based on interchangeable mission modules, allowing for rapid changes in missions. However, technical and financial challenges resulted in delays and some mission modules being canceled. As a result, the LCS program delivered hulls that were largely incapable of fulfilling their intended purposes. The Navy sought not only new platforms but also new technology to operate on those platforms in both the Sea wolf and LCS programs.

19. The US Navy faces the challenge of integrating advanced unmanned systems into the SSN(X) submarine while also introducing a new operational concept for the boats. The acquisition of unmanned systems, though relatively low in cost, poses more numerous challenges than major defense acquisition programs such as the Sea Wolf and LCS. Instead of persisting with unachievable designs, the Navy terminated these programs early. To avoid such mistakes with SSN(X), digital engineering should be leveraged from the early concept development stage through the entire life cycle. It is easier and less expensive to adjust a system's operational concepts during the requirements and design process rather than later after the system or platform is in production. The Navy is in the initial phases of designing and acquiring several weapon systems, including the SSN(X), Next Generation Destroyer (DDG[X]), and Next Generation Air Dominance (NGAD) fighter aircraft programs. Well-defined concepts of operations will be necessary before the Navy purchases systems expected to be in service for the rest of the century.

20. The US Navy has gained valuable insight from the Seawolf program, which has helped them with the successful Virginia program. Nevertheless, there are still valuable lessons to be gleaned, as recent mistakes show. The use of digital engineering methods can help prevent errors by allowing for the prototyping and assessment of new platform designs, as well as their integration with current and future systems. When operational and technical requirements are not clearly defined prior to detailed design, it can lead to acquisition programs that struggle to achieve their intended objectives. Even though the US Navy tests prototypes with fleet units such as the unmanned task force (CTF-59) and development squadrons, these evaluations are conducted too far into the development cycle to have a significant impact on system requirements. Therefore, the Navy must use digital engineering methods to prototype and examine new designs and make necessary adjustments early in the development process to ensure that the programissuccessfulandmeetsitsobjectives.

DIGITAL ENGINEERING VS DIGITAL MODELS

21. The Navy's traditional approach to platform design relies heavily on physical prototypes for testing operational concepts of operations. However, this method places greater emphasis on platform integration rather than integration with other systems. While physical prototyping is essential for effective material design, it fails to provide critical information necessary for fulfilling complex concepts such as distributed maritime operations. The process of systems engineering that relies heavily on documentation, known as legacy systems engineering, produces fixed design elements such as diagrams, documents outlining specifications, and plans for testing. In a typical Defense Acquisition System, it takes around 100 separate design documents to meet regulatory, statutory, or component requirements. The accumulation of these document libraries creates challenges for integrated product teams when a decision is made.

22. Digital engineering provides a model and reliable data to synchronize and combine all work disciplines and stages throughout the entire lifecycle of the platform or system, unlike the alternative. With a central digital model, any design team accessing the model always has access to the "single source of truth," which is key for integrating and coordinating the design process. Functional models can be developed to investigate potential system configurations or digital models can replicate real-world conditions and physics. This model-based approach allows engineers and acquisition professionals to evaluate designs in the digital space with a high degree of fidelity before building costly physical prototypes. The full implementation of digital computer-aided design (CAD) software made a significant contribution to the success of the US Navy's Virginia-class submarine program.[64] The CAD software utilized in Virginia was particularly proficient in generating geometric models that proved valuable in various aspects of design, including piping arrangement, maintenance task analysis, and physical object arrangement. CAD is only one of the tools used in the digital transformation toolkit. Usually, it is used after codifying the system requirements and when the rough shape of the system is established. Although a CAD model can be beneficial, it does not provide designers with the same ability to evaluate trade-offs as an integrated digital model.

23. An important advantage of exploring multiple resource configurations using an integrated digital design approach is the ability to accurately determine performance capacities. The reliability, availability, and maintainability (RAM) of Navy resources are regularly evaluated by the Congressional Research Service and the Government Accountability Office. Digital models also provide the ability to make changes across a system in a seamless manner. Traditional program management practices require the government to develop detailed technical requirements after assessing potential concepts of operations. This information is then handed over to industry for the detailed design process, which is often done using CAD. If significant technological challenges are faced during the design phase, it can result in delays and increased costs as the designers and government strive to find solutions to the problems. However, digital models allow for more detailed design work to be done earlier in the requirements development phase[65], as well as enabling verification of Concept of Operations models to be rerun once detailed models are finished.

INTEGRATE WAR GAMING WITH TECHNICAL DESIGN

24. War-gaming provides an inexpensive and repeatable way to test future naval force concepts and requirements. However, it often lacks the detailed physical models required to develop system requirement documents, so its value remains limited to document-based outputs. To evaluate future system requirements, the Navy has historically relied on war-gaming to develop concepts of operations and engineering designs, but these activities have tended to occur in isolation. While physical testing infrastructure is costly and has long development timelines, war-gaming centers are not located near the infrastructure, hindering designers' ability to quickly integrate war-gaming lessons into system design.[66]

25. The soloed approach to naval system design can be overcome through digital engineering. By integrating digital models into hybrid live, virtual, and constructive (LVC) environments, we can merge the intensive efforts associated with prototyping and the flexibility of war-games. Digital models enable the creation of detailed representations of the physical world that can be evaluated repeatedly by both war-gamers and engineers at lower costs than physical prototypes. This approach permits the evaluation of changes in technical requirements against a system's ability to meet operational needs, and requirements developed from digital systems can be provided to contractors with increased confidence that the delivered system will meet the fleet's needs.

MODERN SHIP DESIGN SYSTEM

26. As passenger and cargo ships continue to grow larger, handling them at ports becomes more challenging and poses safety risks such as fire and container accidents. Moreover, meeting environmental regulations further complicates the construction of new ships. Several start-ups are creating software that enables shipbuilders to virtually design, optimize, and simulate ships as a way to tackle these problems. German start-up, Naval Architect, has built a cloud-based platform that employs digital twin technology to design ships. The platform performs feasibility studies, creates 2D and 3D visualizations, enables effective collaboration across departments, and offers analytical tools to track projects and estimate weight, time, cost, and other parameters. By using the software-as-a-service (SaaS) platform, designers can create digital ship models with both geometrical and non-geometrical information in a single unified location, providing shipbuilders with 3D digital ship models throughout the ship's lifecycle.[67] Similarly, French startup, Syroco, offers a decision-making platform based on digital twin technology to improve ship propulsion systems. Syroco integrates all aspects of a vessel and its operational setting in its digital twin models to generate hydro and aero efficiency and behaviour models of propulsion systems. This facilitates the ability of ship manufacturers to examine the simulated effect of alternative propulsion systems like sails, wings, and hybrid engines on performance, emissions, and operating expenses, empowering them to make informed choices prior to their application in real-life situations. At the core of Syroco Efficient ship, a digital twin serves as a virtual representation of a real-world ship and is used for simulation of efficiency and performance in a variety of configurations. The digital twin also provides an additional level of control over all efficiency parameters, helping to save fuel, reduce emissions, and achieve compliance. Overall, these start-ups offer innovative solutions to the challenges faced by shipbuilders and provide them with the necessary tools to design more efficient, safe, and environmentally-friendly ships.[68]

27. As the amount of parametric data such as wind, weather, ocean currents, and others increases, designing a ship is becoming more challenging. To address this, the shipbuilding industry is turning to AI to optimize the design and process. Ports and shipyards are also incorporating AI-based predictive analytics to manage the surge in ship traffic. To automate ship navigation and simulate operational conditions, startups are developing AI-based solutions. Xyzt.ai, a startup based in Belgium, provides a big data location intelligence platform that can analyze large volumes of shipping data. The platform uses machine learning (ML) algorithms to analyze AIS data, IoT sensor data, and ocean wave data to provide vessel builders and operators with analytical insights. The spatio-temporal data of vessels, such as their location, velocity, and operational metrics, are monitored by the maritime analytics software of the platform through visualization and analysis. Maritime engineers can utilize xyzt.ai's software to optimize vessels, taking into consideration different factors such as maintenance, lifespan, and operating conditions.[69] Clearbot, a startup based in China, provides AI-powered intelligent tools for marine services.The self-driving boat, which operates autonomously, can carry a payload of 200 kg and has the ability to collect a maximum of 15 L of oil. The electric-powered boat generates accurate data reports to track environmental sustainability goals (ESG) metrics while also reducing labour and fuel costs. By improving hazardous environment cleanups, Clearbot's AI-based solution benefits the environment and reduces costs.[70]

TECHNOLOGICAL ADVANCEMENT AND FUTURE OF SHIPBUILDING

28. Technology plays a crucial role in the growth of any industry, and the shipbuilding industry is no different. In fact, shipbuilding is experiencing a rapid transformation through the use of advanced technologies that aim to effectively tackle challenges like environmental pollution and rising fuel costs.[71] Currently, the shipping industry hasdeveloped several potentially revolutionary technologies that have the potential to shape the future of shipbuilding.

a. **3-D Printing Technology** . The shipbuilding industry is revolutionizing at an accelerated pace, thanks to the advancement of technology. One such technology that has shown great potential in the industry is 3D printing. 3D printing enables the printing of tangible objects in three dimensions using a digital copy or framework. The technique involves cutting the desired object's framework into thin slices and then reconstructing these slices by an additive process to create the real object layer by layer. With this technology, even complex structures can be fabricated with ease.[72] While there are numerous 3D printing processes invented so far, only a few are commercially sustainable and affordable. The technology is currently used in various industries to manufacture scientific equipment, small structures, and models. Recently, NSWC Carderock used its 3D printer to fabricate a model of the hospital ship USNS Comfort (T-AH 20), using CAD drawings of the ship model. Further development of this technique could help the industry in building complex geometries of ships such as bulbous bows with ease. The possibility of using 3D printers to quickly replace ship parts for repair purposes is also being researched.

b. **Ship building Robotics**. The shipbuilding industry is looking towards robotics as a way to improve efficiency while keeping workers safe from hazardous tasks such as welding. In addition, the industry is facing a shortage of skilled labor, which further highlights the importance of robotics. Robots are capable of handling a wide range of tasks in shipyards, including welding, blasting, painting, and heavy lifting. For instance, the Geoje shipyard in South Korea uses robotic systems for 68% of its production processes, enabling it to launch approximately 30 ships annually. While robots were initially designed for welding, inspection and pipe cleaning robots have also emerged, along with spider robots that autonomously crawl over vessel surfaces to blast off rust and contaminants in preparation for painting. Hyundai Heavy Industries (HHI) has developed mini welding robots and is planning to incorporate robotics in shipbuilding. These developments indicate that the shipyards of the future will be smart and digital, with robotics playing a significant role in the shipbuilding process.

c. **Ballast Free Ship Design**. The concept holds promise in tackling the issue of ballast water disposal that leads to the discharge of non-native species, creating several ecological problems. The design includes a network of longitudinal pipes from the bow to stern in the ship's hull, facilitating the constant flow of local seawater, which prevents the transfer of contaminated water or water from one ecosystem to another. While this technology is still in the experimentaland developmental phase, if it passes testing successfully, a ballast-free design will undoubtedly be the future of shipbuilding.

d. **LNG Fueled engines**.Lately, Liquefied Natural Gas (LNG) is gaining popularity as an alternative fuel for ships due to its eco-friendliness. This is why the market for LNG-fueled ship engines is emerging and its prospects are promising. Compared to diesel engines, LNG engines reduce CO_2 emissions by 20-25%, cut NO_X emissions by almost 92%, while SO_X and particulate emissions are almost entirely eliminated. Furthermore, the new generation of ship engines needs to comply with the TIER 3 restrictions of 2016 by IMO. Therefore, LNG is the best solution available at the moment, and the industry acknowledges it. The major ship engine designers, including Mitsubishi, Wartsila, Rolls-Royce, and MAN Diesel & Turbo, are busy developing LNG-fueled engines. Rules for LNG for Ships" have been issued by classification societies, who are also involved in this matter. Recently, Deen shipping has developed the world's first new-built LNG-fueled tanker, a 6,100 dwt dual-fuelled chemical tanker named 'MTS ARGONON,' which sails on dual fuel, 80% LNG & 20% diesel. Classed by Lloyd's Register, it is an eco-friendly fuel and is also cheaper than diesel, saving the ship a considerable amount of money over time. In addition, a LNG-powered escort tug with LNG engine support from Rolls-Royce marine has been developed by BB. If these indications are any indication, most of the future ships will be powered by LNG, contributing to green shipping.[73]

e. **Solar & Wind Powered Ships**. It's quite alarming to think about the day when we exhaust all of our oil and gas reserves. Although sailing ships of the past may not return, the shipbuilding industry is working tirelessly to develop new technologies to utilize renewable energy sources like wind and sun to power ships. One impressive example is the Turanor, the world's largest solar-powered ship, which circumnavigated the globe without using any fuel and is currently being usedfor research. While relying exclusively on solar or wind power alone may not be feasible at the moment, we cannot dismiss the possibility of their future use with further technological advancements. Recently, many innovations have been introduced to help large ships reduce fuel consumption by incorporating solar panels or rigid sails. One such device is the Energy Sail, developed by Eco Marine Power, which enables ships to harness energy from wind and sun to decrease fuel costs and greenhouse gas emissions. This technology is exclusively designed for shipping and can be installed on various types of vessels ranging from oil carriers to patrol ships.

f. **Buckypaper.** The shipbuilding industry is now exploring the potential of buckypaper as a material for ship construction. Buckypaper is composed of carbon nanotubes and each tube is 50,000 times thinner than human hair. Compared to traditional shipbuilding materials such as steel, buckypaper is much lighter - only 1/10th the weight of steel - yet it has the potential to be 500 times stronger and 2 times harder than diamond when it is formed into a composite.[74] By using buckypaper, ships could become more energy efficient and require less fuel, as well as be resistant to corrosion and flame. Interestingly, buckypaper has already been researched as a potential construction material for airplanes, and it may not be long before it is used in shipbuilding as well.

g. **Integrated Electric Propulsion**. Integrated electric propulsion technology is an advanced system that uses gas turbines, diesel generators, or both to generate three-phase electricity that powers electric motors to turn propellers or water jets. This innovative system uses electric transmission instead of mechanical transmission, which eliminates the need for clutches and reduces or eliminates the use of gearboxes. Several advantages come with this technology, includingthe freedom to place the engine, quieter ships, and reduced weight and volume. Future warships, such as the Royal Navy's HMS Queen Elizabeth and the US Navy's Zumwalt Class Destroyers, will utilize integrated electric propulsion technology.

h. **Fresh Water Free Energy System**. The shipping industry incurs more than half of its operational costs in fuel expenses. Furthermore, energy and water are interdependent; water is needed for energy production, and conversely, energy is essential for water supply delivery. Throughout the energy production lifecycle, such as mining, processing, and electricity generation, water is necessary, and the energy sector is among the largest consumers of water resources after irrigation in various regions.[75] In modern times, German submarines use fuel cells or reactor cells that were adapted from the American Apollo space program. These technologies can be applied to small commercial vessels since they only require fresh water as fuel and emit minimal pollution with hydrogen being the byproduct. Only the hydrogen needs to be stored or discharged.

i. **Immersive Technology**. Creating ship designs involves a complex process that includes ideation, design, construction, and support for maintenance and training. Traditional methods of reviewing these stages using 2D drawings and designs can be time-consuming and slow down the shipbuilding process. However, new startups are using Augmented Reality (AR) and Virtual Reality (VR) to develop 3D virtual models of designs and avatars of users, speeding up the process. This technology enables engineers to perform ergonomics reviews, reachability studies, and maintenance operations while also checking for possible collision points between virtual humans and 3D virtual ship models. Immersive technologies foster better communication between different teams, improving project delivery time and quality. Exxar Cloud, a US-based startup, offers a no-code VR and AR software solution for design collaboration. It lets ship designers and builders conduct design reviews in VR and monitors production and inspections with AR. This solution also integrates with a variety of 3D

CAD applications like SOLIDWORKS, Navisworks, Catia, Creo, Solid Edge, and Siemens NX to stream 3D CAD data into Exxar's Reality Visualization engine. With this software, there are fewer delays in shipbuilding, as it reduces rework and improves project efficiency, ultimately leading to better client satisfaction.[76]

j. Green Ships. Global trade is heavily reliant on maritime transportation, especially for container shipping which involves large volumes of goods. However, this comes at a cost to the environment due to the pollution caused by ships which can negatively impact the ocean ecosystem and contribute to global warming. Startups are working towards finding solutions that reduce this environmental impact by developing alternative clean fuels and renewable energy to power ships. In addition to this, shipbuilders are incorporating sustainable materials and software into the components of ships to increase fuel efficiency and comply with international environmental regulations. Amogy, a US-based startup, offers an energy system that uses ammonia as a renewable fuel to decarbonize ocean transportation, resulting in an emission-free, high-energy-density power source. The use of ammonia also reduces costs and requires less storage space than other options like liquid hydrogen and liquefied natural gas. Amogy utilizes existing ammonia production and distribution infrastructure from the agriculture industry to power ships. Another startup, Marine Performance Systems, has developed a patented fluidic air lubrication system called FluidicALthat lubricates ship propellers using air. The system generates micro air bubbles that cover the ship hulls, reducing friction when sailing and increasing fuel efficiency. With up to 240,000 micro air bubbles generated per second per meter, the system has the potential to improve the environmental impact of ships while enhancing their performance.

k. Cybersecurity. Modern ships are equipped with numerous IoT sensors that help with navigation, inventory management, and equipment monitoring. As ship size increases, the importance of these sensors also increases. However, with the increase in the number of sensors on a ship, the potential for cyber vulnerabilities also increases. This can lead to voyage delays, information loss, or even damage to ship equipment. To address this issue, startups are developing cyber risk management solutions to protect IT systems and devices on ships. One of the areas that face significant vulnerability is the sensors' connections to the internet, which is why some startups focus on endpoint security software. ShipSafe IT suite, an AI and AR-based cybersecurity and vessel inspection solution, has been developed by ShipSafe Maritime Technologies, a Canadian startup, as an example. This solution provides endpoint strength management, reduces unnecessary alerts and false positives, and enables task scheduling through policy-based automation. Moreover, it automates time-consuming network tasks and simplifies the effort of onboard cybersecurity personnel in securing vessel operations and client environments.[77] Another startup, Cydome, from Israel, offers a maritime cybersecurity platform that protects vessel operations. It provides a real-time map of assets connected to ships' networks and conducts automated, built-in cybersecurity checkups, thereby validating ongoing compliance with maritime regulations. Cydome also analyzes a large number of data points for cyber risk mitigation and alerts ships in real-time in case of unauthorized access. These solutions help ship owners and operators in securing their vessels and ensuring the safe operation of their assets.[78]

l. Advanced Materials. Shipbuilding can benefit from the application of advanced materials such as carbon composites, aluminum, and other innovative materials, resulting in enhanced structural characteristics and cost-effectiveness. With the incorporation of composite materials in shipbuilding, it is possible to reduce maintenance downtime as they provide high resistance to corrosion. Furthermore, the integration of smart materials can bring down the fuel expenses while increasing the load-bearing capacity by reducing the overall weight of the ship. Many startups are focusing on creating sustainable materials that have high durability and promote circular economies. These startups are exploring sustainable and alternative polymers and composites that are relatively unused in the maritime industry. An Italian startup, Northern Light Composites, offers an eco-friendly alternative for shipbuilding by utilizing sustainable plastic materials. Their proprietary technology Composite is a composite based on a thermoplastic matrix of natural or mineral fibers and an Atlas HPE recyclable core, made from natural fibers and eco-sustainable flax fibers and resins that are biologically decomposable. They also use Basaltex fibers for structural components that can't be realized with vacuum infusion processing, reducing environmental pollution from discarded fiberglass boats.[79] A patented, scalable, and cost-efficient method for enhancing the toughness of epoxy resins has been developed by TriboBlend, a startup based in Spain. Their technology can improve the performance of (nano)particulate, polymeric, and composite materials through ultra-high pressures and shear rates on liquid phase materials and mixtures to induce physical and/or chemical modifications. The performance of coatings, crucial for preventing corrosion in ships, is also improved by TriboBlend's technology.[80]

m. **Internet of Things (IoT).** Internet of Things (IoT): The Internet of Things (IoT) is transforming the way manufacturers operate by providing access to machine data and integrating different systems. However, in industries such as shipbuilding, the information flow is complex and scattered across different points, creating challenges in terms of connectivity and data aggregation. Furthermore, shipyards are inherently hazardous workplaces, with workers operating in proximity to dangerous equipment. To address these issues, IoT technology is being integrated into shipbuilding processes to enhance safety and improve efficiency. SOL-X, which is a startup based in Singapore, concentrates on utilizing the Industrial Internet of Things (IIoT) to enhance the safety and welfare of workers in ships. Its SAFEVUE.ai solution uses IIoT and AI to improve situational awareness for workers across hazardous operations. Additionally, SAFEVUE.ai Crew Protect, a wearable device, provides real-time assistance in emergencies and features geofencing of hazardous work zones. The solution finds application in the maritime, oil & gas industries, and other hazardous environments.[81] A network protocol that gathers and analyzes information about the crew and surroundings of a vessel has been created by Sealution, a startup from Belgium. The network of IoT devices collects and processes data and feeds it to a central database to gain a comprehensive overview of processes, performance, and irregularities on board. The solution uses a room module for signal transmission and a central module for data exchange, increasing connectivity below deck, reducing safety risks to crews, and eliminating the need for manual inspections of cargo containers.IIoT technology is transforming the shipbuilding industry, providing enhanced safety and efficiency through real-time monitoring and data analysis. Startups like SOL-X and Sealution are developing innovative solutions that leverage the power of IIoT and AI to improve safety, increase productivity, and optimize shipbuilding processes.[82]

CONCLUSION

29. The role and mission of defense forces specially navy, present and planned size and composition of the naval force, annual warship procurement strategy and plan, the prospective affordability of government, the capacity of localand global shipbuilding industry to execute the navy's shipbuilding plans, and proposals on the basis ofdecommissioningsurvivingwarships and finally new technology are the deciding factorsof future warship building. Advanced technology and warship building skill play pivotal role for future warship building. Naval research and development program is a continuous practice and which is designed to facilitate decision-making process. Global powerful navies spend more in this field. This paper has made limited and discussed the issues briefly due to hold the attraction of readers to avoid boarding, though the subject was very diversified and vast. It will help student, researchers, warship builder and stake holder to thing further and contribute more in the field of warship technology.

30. Collecting paper documents in binders that require manual updates for even minor design changes is an integral part of the conventional ship design process. This results in warehouses full of paperwork for a single class of ships. However, with the use of digital models, all the necessary information can be stored on a single drive. Digital models have a long lifespan and can be continuously updated with real-world data, making them a critical feature for continued verification of designs and requirements.In order to meet the evolving needs of future armed forces in general and navy in particular, it is necessary to adopt a more mission-focused design approach. This involves synchronizing, managing, and coordinating concepts, activities, technologies,

requirements, programs, and budget plans to guide decision-making for the end-to-end mission. This is in contrast to the recent platform-centric design concept, which failed to integrate the departments in broader warfare concepts. By utilizing digital models and adopting a mission-focused approach, armed forces specially navy can ensure they are well-equipped to meet the challenges of modern warfare.

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