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3D Printing in the Maritime Industry

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ABSTRACT

3D printing, also known as additive manufacturing, refers to a process in which materials, such as metal or plastic, are layered to create objects based on digital models. The maritime industry, traditionally conservative in its adoption of new technologies, has increasingly recognized the potential benefits of 3D printing. 3D printing is rapidly transforming the maritime industry by enabling on-demand production of parts, reducing lead times, and offering cost savings. As the maritime sector seeks to enhance efficiency, reduce costs, and improve sustainability, 3D printing is emerging as a powerful tool that has the potential to revolutionize shipbuilding and repair processes. This paper studies the integration of 3D printing in the maritime industry.

KEYWORDS: *3D printing (3DP), additive manufacturing, AM, maritime industry*

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INTRODUCTION

The maritime industry is experiencing a transformative shift due to emerging 3D printing technologies. Developed in the 1980s as a method for rapid prototyping, 3D printing has evolved from creating small-scale models to producing full-scale components used in highly specialized fields such as aviation, medical equipment, and now maritime. From customized parts to large, intricate designs, 3D printing is now a viable alternative to traditional manufacturing methods such as casting, molding, and machining. The technology allows for the creation of complex components and structures by adding material layer by layer, rather than subtracting it from a larger block. The design involves using layers of material, which can include plastics, metals, ceramics, and even composite materials. 3D printing technology is slowly but surely making its way into the maritime industry after practically becoming a mainstream function across many sectors and businesses. There is presently a favorable trend in the business for the use of 3D printing in the maritime sector [1].

WHAT IS 3D PRINTING?

3D printing (also known as additive manufacturing (AM) or rapid prototyping (RP)) was invented in the early 1980s by Charles Hull, who is regarded as the father of 3D printing. Since then it has been used in manufacturing, automotive, electronics, aviation, aerospace, aeronautics, engineering, architecture, pharmaceutics, consumer products, education, entertainment, medicine, space missions, the military, chemical industry, maritime industry, printing industry, and jewelry industry [2].

A 3D printer works by “printing” objects. Instead of using ink, it uses more substantive materials–plastics, metal, rubber, and the like. It scans an object–or takes an existing scan of an object–and slices it into layers, which can then convert into a physical object. Layer by layer, the 3D printer can replicate images created in CAD programs. In other words, 3D printing instructs a computer to apply layer upon layer of a specific material (such as plastic or metal) until the final product is built. This is distinct from conventional manufacturing methods, which often rely on removal (by cutting, drilling, chopping, grinding, forging, etc.) instead of addition. Models can be multi-colored to highlight important features, such as tumors, cavities, and vascular tracks. 3DP technology can build a 3D object in almost any shape imaginable as defined in a computer-aided design (CAD) file. It is additive technology as distinct from traditional manufacturing techniques, which are subtractive processes in which material is removed by cutting or drilling [3]. A digital design, material, and a 3D printer are all you need to print a 3D product. Figure 1 shows how 3D printer works [4].

3D printing has started breaking through into the mainstream in recent years, with some models becoming affordable enough for home use. Many industries and professions around the world now use 3D printing. It plays a key role in making companies more competitive. The gap between industry and graduating students can be bridged by including the same cutting-edge tools, such as 3D printing, professionals use every day into the curriculum. There are 3D printed homes, prosthetics, surgical devices, drones, hearing aids, and electric engine components. As shown in Figure 2, 3D printing involves three steps [5]. A typical 3D printer is shown in Figure 3 [6].

3D PRINTING IN MARITIME INDUSTRY

3D printing, also known as additive manufacturing, involves the process of joining materials layer by layer to create objects based on 3D model data. The allure lies in the manifold benefits 3D printing brings, such as reduced costs, minimized delays, rapid design changes, digital precision and symmetry capabilities based on CAD designs, bespoke parts production, and expedited delivery times. The integration of 3D printing in the maritime industry presents several benefits that could reshape the way ships are built and maintained. Because of the way 3D printers work, the only material consumed in printing a part is exactly what is needed.

When it comes to 3D printing in the maritime industry, we need to consider three scenarios [7]:

- 3D printing for rapid prototyping;
- 3D printing spare parts ashore, for delivery to ships; and
- 3D printing spare parts on board ships.

3D printing for rapid prototyping of designs is already well-established and in widespread use across maritime-adjacent industries. Over the next few years, we can expect to see increases in both 3D printing parts ashore for delivery to ships, and printing small spares on board. Ships carrying appropriate 3D printers have the potential to print small replacement parts like impellers, valves or pipe fittings on board.

EXAMPLES OF 3D PRINTING IN MARITIME INDUSTRY

Here are some of examples of 3D printing application in maritime industry [8]:

1. 3D Printed Submarine Prototype
2. 3D Boat Propeller
3. Spare Parts for Nautical Racing
4. Creating Map for the Arctic Seafloor
5. Sail Boat Spare Parts
6. Navy Drones
7. Yacht
8. Chain Mail fo Ship
9. Current Turbines
10. Rebuilding Coral Barriers

APPLICATIONS OF 3D PRINTING IN IN MARITIME INDUSTRY

3D printing technology allows for the creation of complex parts, prototypes, and even entire structures, both onshore and onboard ships, potentially revolutionizing shipbuilding, maintenance, and supply chains. Its applications are diverse, spanning from shipbuilding and maintenance to optimizing supply chain logistics. Common application areas include the following [8,9]:

- *3D Scanning*: Scanning of an actual model of a ship is possible — thanks to 3D laser scanning. This process includes converting the actual ship into a CAD file. It is helpful especially if you need to examine the physical appearance of the ship. Roaming around the ship will take tons of time. It is easier to analyze the ship if they are on your computer. There is no limit on how large you can scan the ship.
- *3D Designing*: Designing the model of the ship is hard when you are just doing it in a blueprint. You need to manually change all dimensions. Besides that, you have to make sure that all the changes are compatible with the materials. There are a lot of 3D designing software that you can use to analyze the design of the ship.
- *3D Printing:* After scanning and designing, you will need to see the finished product. A 3D printer will reproduce the CAD model out of your computer. Additive manufacturing is much faster compared to the traditional way of reproducing a ship. Besides being faster, 3D printing is also more flexible compared to mold casting. You can use every material available for production.
- *3D Reverse Engineering*: This allows you to identify the function of a technology. It is helpful in recreation of some technology with lost blueprints. You have to manually do the process before the existence of 3D technology. Maritime

industry can benefit a lot with this service. 3D reverse engineering also helps in innovation of any technology. If you have a CAD file of the model, it is easier to tweak design and see if it will work.

- *3D Rapid Prototyping*: 3D printing is a valuable tool for prototyping and design verification. If you want to test your model to see if it works, then you need to create a rapid prototype. 3D rapid prototyping allows you to see the actual ship before doing a mass production. This will save you from a lot of expenses if you proceed immediately with mass production.
- *Shipbuilding:* Traditional boat manufacturing processes, marked by significant costs, long lead times, enormous waste, and design limitations, are gradually being displaced by innovative solutions that harness the potential of additive manufacturing. In shipbuilding, 3D printing is used to create intricate parts such as propellers, engine components, and hull sections that would otherwise require complex and costly manufacturing processes. By employing 3D printers, shipyards can produce custom components more quickly and economically, reducing waste and allowing for faster assembly times. All you need to do is program it and you can reproduce the needed parts anywhere. Figure 4 shows an example of 3D printing of an entire boat [10], while Figure 5 shows University of Maine 3D printed boat, the largest 3D printed boat [11].
- *Maintenance and Repairs*: One of the most significant uses of 3D printing in maritime operations is its ability to facilitate on-demand repairs. 3D printing offers the ability to produce replacement parts on-demand, even in remote locations. Shipping companies often face logistical delays when ships need repairs while at sea or docked far from supply depots. With a 3D printer onboard, crews can produce critical replacement parts in real-time, minimizing downtime and costly delays. Additive manufacturing also reduces your need for any storage facilities. This facility keeps all the mold and supply you need for the maintenance of ships. AM is used to create a wide variety of parts in the maritime industry, including hull components, propellers, rudders, spare parts, and even entire structural assemblies. Figure 6 shows 3D printed boat hull [12].
- *Military Applications*: 3D printing in the maritime industry spans private, commercial, and military applications. The US Navy, for example, has been at the forefront of adopting 3D printing technology for maritime applications. The Navy is actively adopting 3D printing for producing parts on warships, including submarines and aircraft carriers, to reduce reliance on traditional supply chains and improve operational flexibility. In 2019, the Naval Sea Systems Command (NAVSEA) approved the use of 3D-printed metal parts for submarines, focusing on critical components such as valves and pumps. This effort aims to reduce downtime and improve the availability of parts during missions. University of Maine produced the largest 3D-printed boat for the military. Another example of a military navy that has resorted to onboard 3D printing is China's navy. In Europe, the British and Dutch navies have announced their intention to rely on 3D printing devices to improve their operational capabilities by reducing costs and streamlining logistics processes. Figure 7 shows a 3D printer at the U.S. Naval Postgraduate School [13].

BENEFITS

The adoption of 3D printing in the maritime industry comes with a host of remarkable benefits. The three-dimensional process helps save cost and space. Businesses are harnessing this technology to produce custom marine vessel components with speed, cost-efficiency, and minimal waste. 3D printing has the potential to reduce waste, costs, and emissions. Other benefits include [8,14]:

- *Cost Savings*: 3D printing saves money, reduces the carbon footprint of supply chains, uses fewer resources, and is convenient for ships and crews. Shipbuilding and maintenance are expensive endeavors, but 3D printing allows companies to produce parts in small, customized batches without the need for expensive molds or tooling. With the elimination of transportation costs from a shore-based parts manufacturer to the port and vessel, there are considerable savings.
- *Minimal Delays*: As wait times for a specialist part to be manufactured and transported to the port are reduced, delays of cargo, which result in huge costs and have a massive knock-on effect on the supply chain, are kept to a minimum.
- *Reduced Lead Times*: Time is money in the shipping industry, and long lead times for essential parts can lead to significant losses. 3D printing reduces the time needed to create custom or replacement components, enabling near-immediate production and minimizing vessel downtime. With 3D printers located at ports, delays can be kept to a minimum. Spare parts for ships can be produced on the spot, as opposed to

them being transported from a manufacturer inland.

- *Speed and Efficiency:* 3D printing enables rapid production of parts, reducing lead times and allowing for faster project completion. This is particularly beneficial in shipbuilding, where delays can be costly. The technology also streamlines the supply chain, as parts can be produced locally, reducing the need for transportation and associated delays.
- *On-Demand Production*: The ability to produce parts on-demand is a game-changer for the maritime industry, particularly in remote locations or during extended voyages. 3D printing allows for the rapid production of replacement parts and components, reducing downtime and ensuring that ships can remain operational without waiting for parts to be shipped from distant suppliers.
- *Sustainability:* Although the sea route is already far more environmentally friendly than the air trade route, efforts are nevertheless underway to improve the environmental footprint. Sustainability is a growing concern in maritime operations, where fuel consumption and material waste contribute to environmental degradation. 3D printing enables shipbuilders to use only the required amount of material, reducing overall waste by up to 90%. 3D printing is inherently more sustainable than traditional manufacturing methods, as it generates less waste and allows for the use of recycled materials.
- *Design Freedom:* 3D printing provides shipbuilders with greater design freedom, enabling the creation of complex geometries and structures that would be challenging or impossible to achieve with conventional methods. The technology allows for the creation of complex geometries and customized parts, opening up new possibilities for design and innovation in shipbuilding and marine equipment. With the ability to produce parts locally, the maritime industry can become less dependent on global supply chains and more resilient to disruptions.
- *Customization:* Ships often require specialized components tailored to specific operational needs. 3D printing enables shipbuilders to produce custom parts with relative ease, allowing for greater flexibility in design and functionality. This customization can lead to improved performance and efficiency in various maritime applications.
- *Lightweight Structures*: Any material used in maritime part production needs to be light, capable of withstanding heavy impacts without damage, not absorb water, be naturally resistant to marine growth, equally distribute weight, and possess a degree of resistance to corrosion. 3D printing allows for the creation of lightweight structures by optimizing material usage. This is particularly important in shipbuilding, where reducing weight can lead to improved fuel efficiency and lower operating costs. By using advanced materials and innovative design techniques, 3D-printed components can offer significant weight savings without compromising strength or durability.

CHALLENGES

In spite of the clear benefits, the adoption of 3D printing in maritime manufacturing is not without challenges. Not all 3D printing techniques are suitable for all materials, and certain materials need specific printers designed for those materials. There are technological shortcomings and difficulties regarding 3D-printers' operations. A printer works at its own pace and thus cannot do overtime. There can be issues with ability to replace large parts or ones built with different materials. Other challenges include [10,13]:

- *Material Limitations:* Although the range of materials available for 3D printing is expanding, there are still limitations in terms of material properties, particularly for high-strength metals and composites. Certain high-strength, corrosion-resistant materials critical to maritime applications, such as specific steels and alloys, remain difficult to print at scale. Research is ongoing to develop new materials suitable for maritime environments.
- *Certification and Standards:* The maritime industry is heavily regulated, and the adoption of 3D printing requires establishing standards and certifications for printed parts, and ensuring that 3D-printed parts meet international safety and durability standards is essential. Certification processes for additive manufacturing are still in development, which can delay the widespread adoption of 3D printing for critical components.
- *Investment and Training:* The initial investment in 3D printers, as well as the specialized training required to operate them, can be prohibitive for smaller shipping companies.
- *Quality Control:* Quality control of printed components is a challenge. Regulating the quality of printed components is still a hurdle that needs to be addressed before widespread adoption.

Ensuring the quality and consistency of 3D-printed parts is critical, particularly for components that must meet stringent safety and performance standards. The industry is working on developing standardized testing and certification processes to ensure that 3D-printed parts meet the required specifications.

- *Legal Concerns*: In the marine industry, the main legal concerns focus on insurance, type-approval, and intellectual property law. In general, if key parts are type-approved it would not impact insurance premiums, so the primary legal concern is that of protecting intellectual property.
- *Intellectual Property Rights*: Protection of designs and patents in the context of 3D printed parts is another area of concern.

CONCLUSION

3D printing in the maritime industry is gradually becoming popular. 3D printing saves money, reduces the carbon footprint of supply chains, uses fewer resources, and is convenient for ships and crew. Limitless possibilities are waiting once the maritime industry and 3D printing work together. 3D printing is poised to revolutionize the shipbuilding industry, offering significant benefits in terms of cost, efficiency, and innovation. As technology matures, 3D printing will likely become a standard tool in the maritime industry's arsenal.

The future of 3D printing in the maritime industry is bright and filled with potential, with ongoing advancements in materials, technology, and processes expected to drive further adoption. In the future, we may see 3D printing used not only for spare parts and small components but also for the construction of entire ship sections. More information about 3D printing technology in the maritime industry can be found in the books [15,16].

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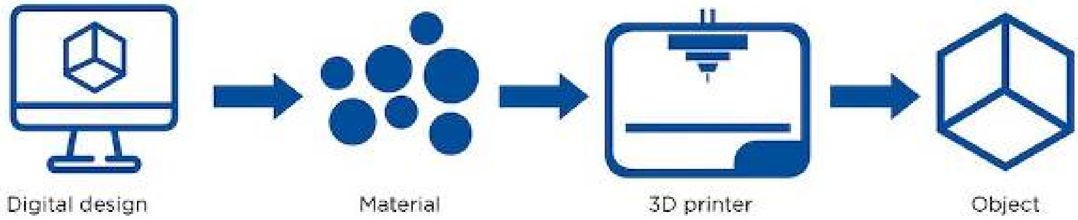

Figure 1 How 3D printer works [4].

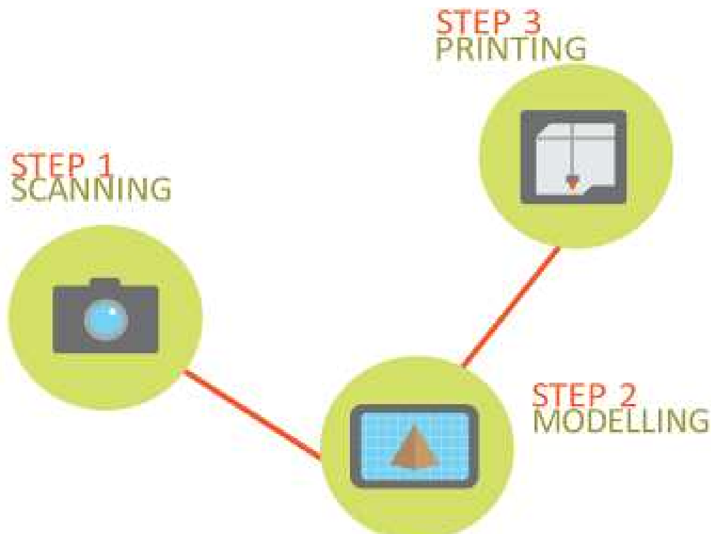

Figure 2 3D printing involves three steps [5].

Figure 3 A typical 3D printer [6].

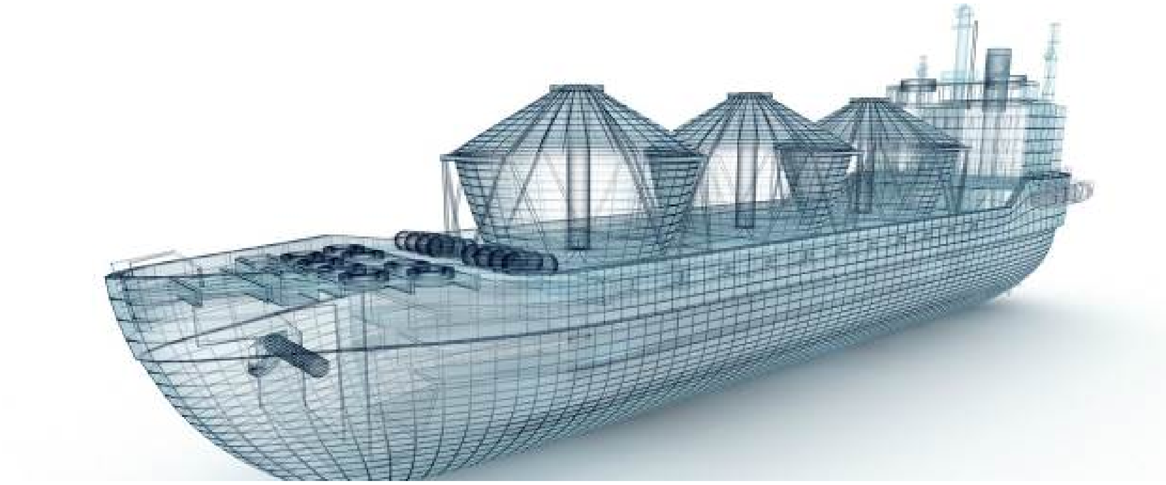

Figure 4 3D printing of an entire boat [10].

Figure 5 University of Maine 3D printed boat, the largest 3D printed boat [11].

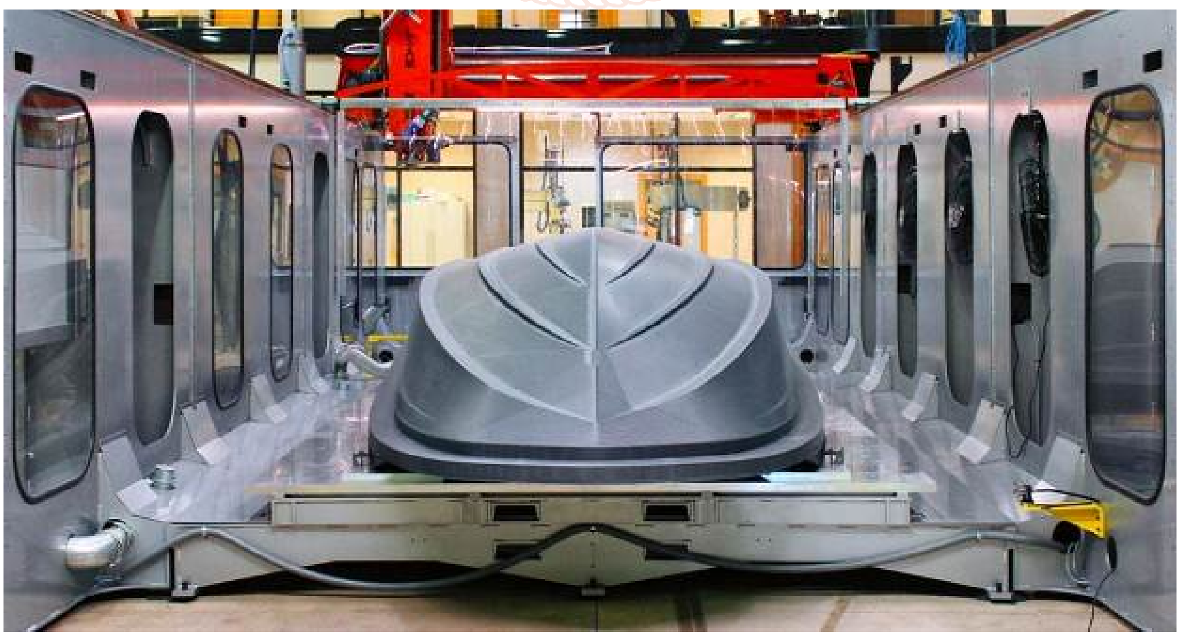

Figure 6 3D printed boat hull [12].

Figure 7 A 3D printer at the US Naval Postgraduate School [13].