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Identification of architectural and engineering faults in ship design and remedial measures

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Abstract

Every year several ships sink in the ocean because of storms and other reasons. The ship design system must be integrated inter-communicating with all components of the system. The design of architecture, civil engineering, electronic sub-systems, mechanical engineering, metallurgical engineering, and more especially the telecommunications must be formulated in one unified system. This paper tries to classify the ship-design and faults of the systems and sub-systems and how to be updated for safety. Moreover, it focuses on various architectural and engineering faults in ship design during manufacturing. The ship design is required to be flexible to accommodate new updates after factory-made. Naval architecture relies on mechanics, material strength, and structure design. The mission of a ship is determined by its deployment, cargo, cruising radius, operating, maximum speed, mobilization, passengers, and safety. A strong computerized telecommunication system is essential for all ships, integrated architecture with all devices electronic sub-systems. All the devices used in ship design must be consistent and in conformity with applicable disciplines of engineering and telecommunications to form unified and integrated system. The strong system operated via satellite is required to be installed for safety. The Geographical Information System (GIS) and Global Climatology system help ports and ship navigation of the locations, hazards, high winds, and storms. As a final point, the results are reported as the recommendations.

Keywords: Center of gravity of ship; Ship weight; Buoyancy; Ship propeller; Online storm maps.

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1. Introduction

Naval architecture and ship designers require extensive involvement in engineering fields, economics, construction materials, and latest methods to estimate ship performance, predict costs, and construct parts, such as bow, bulkheads, Charpy test, coupon, davits, grain structure, ice field, lumen, stern, and wireless. Malik, *et al.* (2021), discussed several adverse factors in Bermuda Triangle in Atlantic Ocean. Also highlighted results from Hubble telescope observations. This reveal Van Allen Belts are the most impactful source of high-intensity particles, flocks, herds, heavy clouds, and swarms. Malik, *et al.* (2021) stressed the need and importance of navigation maps of strong winds and storms. According to Moyst and Das (2005), a ship's frequent design changes and rework pressures lead to increased costs and duration. The ship builders should understand the design process and its integration to improve design quality and reduce design changes' impact on manufacturing and construction. A better strategy is to eliminate design quality issues and rework.

The impact of complexity on competitiveness in ship design discussed the use of archived data from 100 Norwegian design projects, which measures the magnitude and directionality varying among different factors (Ebrahimi *et al*., 2020). Brett (2020) reviewed characteristics, sources, and drivers and discusses pertinent difficulty factors in ship design; the work aims to improve affordability. Furthermore, the impact of complexity on affordability in the ship design are discussed, with the magnitude and directionality varying among complexity factors (Ebrahimi *et al*., 2021). The findings suggested enhancing complexity management in designing process.

The basic idea presented relates to engineering factors in designing process and its operation by Rumawas (2016). He introduced a model for integrating human factors into designing, focusing on existing knowledge, implementation of principles, relationships, standards, crew well-being and performance. Muckle (1951) has discussed various basic naval architectural ship designs. Furthermore, Garcia Agis *et al.* (2020), focused on the issue to overcome and making efficacy in ship design procedures. Watson (2002) represented increasing demand for commercial activities at sea for rapid development of ships. Therefore, construction and operation rules, practical "ship design" must be addressed, regarding merchant, naval ships, cargo, passenger, and service crafts.

Nejad *et al.* (2021) recommended the serious monitoring of ship propulsion systems, because this is a grave aspect leading to ship sinking. As stated by Andrews (2020), early design decisions are crucial. Ship owners often make deliberate errors, disregarding material degradation or manufacturing alterations that exceed the novel-design assumptions. He has further pointed out several issues confronting the errors which occur during designing the ship architecture. Moreover, Sulligoi *et al.* (2016) has tackled an important issue regarding installation of power systems controlled by electronic circuit and telecommunication system.

2. Historical Aspects

Titanic sinking is a renowned disaster, causing curiosity and speculation. Various theories have emerged, with the most probable theory being the most dominant, based on evidence from expeditions to the site. Many scientists have widely deliberated upon the unfortunate Titanic sinking in the ocean (Hill, 1996; Gannon,1995; Sanford, 1994). Titanic had 2200 passengers on board including crews, when struck with iceberg on April 14, 1912, resulting in its sinking in less than three hours. The Titanic's hull steel collapsed due to high Sulphur content, low water temperatures, and impact loading from the iceberg collision, causing the ship to split open and crack. The rivets, used to fasten the plates, elongated due to water stresses, breaking caulking, sealing and allowing water inside the ship. Bassett (2000) described the details of this accident and reasons of failures. He also summed up technical and engineering grounds and things regarding ship sinking particularly that of the Titanic. Moreover, Gannon (1995) discussed the reasons of sinking of Titanic. Garzke *et al*. (1994) provided very useful information about the structural failure, with reference to Titanic’s failure.

The structural and other errors in designing of the ship will wisely depicted by the learned producer. The Titanic's sinking was exacerbated by:

- Inadequate design of its watertight compartments, allowing water to flood damaged areas, causing the ship to pitch forward, spill over, and increase sinking rate.
- The ship's damaged hull compartments flooded, causing it to pitch forward and spill over into adjacent ones, causing the bow to contain water, increasing sinking rates.
- The Titanic disaster was caused by advanced shipbuilding technology surpassing engineers' understanding that substandard material was used in manufacturing of ship.

3. Materials and methods

The maritime industry can significantly reduce ship sinking risks through continuous training, technological advancements, and best practices, fostering a culture of safety. The analysis methods used herein are based on the conceptual and descriptive analyzing the issues.

3.1. Major reasons for ship sinking

Marine accidents involve multiple factors, requiring investigations, safety measures improvement, technology advancements, training, and regulations to mitigate risks and ensure the safety of the maritime industry. The cargo issues, collisions, design flaws, equipment failure, fire, grounding are the most important subjects. Ship structures affected by severe weather conditions, human error, structural failure, and flooding. The other reasons are variation of buoyancy and weight along the length of the ship, incorrect vertical position of center of gravity, vertical position of metacenter, problems in watertight closures, and wave-making resistance.

Ship design is a complex field that often faces design errors, which can be catastrophic or lead to ship sinking. Errors frequently occur after ships leave into the water, underscoring the necessity for risk mitigation procedures and ethical guidance. The changing nature of ship design practice requires designers to balance the ability of computer-driven precision with the demands of performance.

Addressing mechanical engineering errors in safety design must be ensured, which is of pivotal and crucial importance. The naval architect is the sole ship-designer, responsible for creating new designs, while ensuring balance and logic having overall design insight vision. The architect finalizes the design considering fundamental aspects of ship safety, confirming a cohesive and balanced ship design. Naval architect errors can sink ships and computers can make mistakes. The designers must trust others, believe in potential errors and don't exceed their competence and experience. Another frequent reason of ship sinking is Rogue waves, which attack ships from the side without intimidation, have been a cause of numerous ship disasters.

3.2. Drawbacks in ship designing which leads to sinking

Modern ship design adheres to international standards and regulations to mitigate risks. Advances in technology, materials, and construction techniques enhance safety and reliability. Incident investigations identify design-related factors and recommend improvements to prevent future incidents. Design failures in large ships can lead to ocean sinking due to vulnerabilities in architecture, materials, or construction, with various design-related issues contributing to such incidents. Poor stability design can cause a ship to capsize or heel excessively, compromising equilibrium, especially in adverse weather or cargo operations. Structural weaknesses in a ship's hull, such as materials, welding, or construction, can lead to hull failures, compromising the ship's buoyancy and allowing water to enter. Bulkheads are crucial for dividing ships to prevent flooding, but inadequate design or improper construction can lead to rapid water spread within the vessel. Ballast tanks are essential for ships running light with a high hull out of water, as they provide added inertia, weight, and mass to help navigate waves and waves. These tanks can be filled with fresh water or reserve fuel, often used in inaccessible areas. Ballast systems are crucial for adjusting a ship's draft and stability, but improper design or operation can lead to stability issues and affect seaworthiness. Freeboard refers to the vertical distance from the waterline to the main deck, and insufficient freeboard can cause instability and potential flooding during rough seas.

3.3. Major mechanical engineering faults

Fault in many of sinking ships has been the propulsion system failure in the last five years which must be monitored and detected at early stage. Current practices must be to focus on performance monitoring, regulatory codes, and marine machinery research, while addressing extreme environmental conditions like the Arctic and Antarctic. Following the Titanic disaster, ships were fitted with double-sided hulls and raised transverse bulkheads to prevent minor punctures and prevent water spills. Safety regulations mandate the use of wireless technology for large ships, minimum lifeboat capacity, and ice patrols to alert nearby ice fields following ship sinking.

3.4. Structural stability and weight of the ship

A ship's large weight displaces a large volume of water, resulting in a buoyancy force greater than its own weight, preventing it from sinking in water. A ship's weight causes it to displace a significant volume of water, resulting in a buoyancy force greater than its own weight, thus preventing sinking. The bow, bulkheads, Charpy impact test, coupons, davits, grains, ice fields, luminous flux, stern, and wireless are essential components of a ship's structure. However big ships sink when water enters into the ship. The Archimedes principle and law of buoyancy force are the basic science principles which apply to the ship manufacturing to avoid ship sinking. Numerous ships are lost due to the loss of granular cargoes like crushed ore and mineral sands. Cargo ships sink because of vibrations from engine and sea can increase water pressure, leading to cargo liquefaction, causing vessel stability by shifting or slouching solid bulk cargo inside the hold, which sometimes leads to instability and hence sinking.

3.5. How to avoid sinking of big ships in ocean

In order to follow up and obey the International Maritime Safety Standards, adherence to the International Maritime Organization (IMO), classification societies provide international safety guideline. Implementation of Advanced Navigation Systems in ships enhance situational awareness, reduce collision risk and prevent groundings or navigation errors. The Cargo Management Overview system helps for implementing proper cargo stowage and securing, maintaining ship stability and prevents cargo-related accidents. During emergency “communication protocols operations” establish clear protocols for crew, shore-based personnel, authorities and facilitate efficient coordination. The crew training and proficiency must be continuous and followed as ongoing process to ensure comprehensive training including emergency response drills. It also guarantees readiness for various situations and sound decision-making. Effective emergency response plans are crucial for a coordinated and efficient response in case of an accident.

The task of regulatory compliance involves ensuring compliance with international and national maritime regulations and standards through regular inspections and audits by relevant authorities. Similarly, regular inspections, maintenance, and repairs are conducted to ensure that the ship's structural integrity, propulsion systems, and critical equipment are in good condition. Recently, developed systems for weather monitoring linked with satellite communication system utilize advanced meteorological tools and services to monitor weather conditions. It can enable ships to anticipate severe weather and implement preventive measures. Maintaining a watertight integrity system by regularly inspecting and preserving compartments, hatches, and doors can minimize flooding risks in case of collisions or other incidents. Catching fire in ship is usual feature in marine life, therefore, there must be strict fire prevention measures include proper storage of flammable materials, regular equipment checks, and crew training in firefighting techniques. It is important to conduct comprehensive risk assessments before each voyage, considering factors such as route planning, weather conditions, and potential hazards. Passenger safety measures, such as lifeboat drills, passenger briefings, and adequate lifesaving equipment, should be implemented and are mandatory and applicable for passenger ships.

3.6. Installation of ship communication system linked with satellite

Communication at sea involves information transfer between ships or shores through sound, visual, radio, or electronic signals. They include flag, flashing light, Morse symbols, voice, and radiotelegraphy. Shipboard communications include internal telephone systems, voice pipes, and portable transceivers. Moreover, with engine orders from the bridge via phone or telegraph, and over short distances through visual or sound signals. Having a suitable communication in sea is of pivotal and essential ability. Maritime communications, encompassing safety, navigation, commercial, and miscellaneous purposes. As stated by Sulligoi, *et al.* (2016), research has progressed from traditional hand flags to modern equipment for radio, wireless telegraphy, radiotelephony, and satellite communications. Radio communications utilize single-sideband modulation (SSB) or single-sideband suppressed-carrier (SSB-SC). It is a refined form of amplitude modulation, to efficiently transmit information like audio signals using transmitter power and bandwidth. Ships now utilize various technologies and devices, including SSB transmitters, walkie-talkie sets, Very High Frequency (VHF) receivers, transceivers, telex, fax, and satcoms. They are used for communication using computers. The novel idea of electrical propulsion in marine systems involves and is facilitated by power electronic converters, making them crucial for electrification of large ships.

4. Results and Discussion

Based on this research study methods, some outcomes are represented in this part. The following organizations are of immense importance for consultation regarding various issues and reason of failure leading to ship sinking. Furthermore searching special keywords like "ship sinking", "maritime safety", "accident investigations", and "naval architecture" can explore specific incidents or topics of interest from following resources.

In order to prevent large ships from sinking in ocean, effective design, maintenance, operational procedures, and safety regulations are crucial. Following points regarding Safety Standards and Navigation Systems are important to adhere to before commencement of a voyage. In Table 1 a few measures are listed.

Marine Accident Investigation Branch and National Transportation Safety Board are responsible for investigating maritime accidents and international maritime authorities frequently provide detailed analyses of collisions and their causes. Visit international government maritime agencies's websites to access research findings and reports on maritime safety, UK Maritime and Coastguard Agency and Australian Maritime Safety Authority.

Table 1. Important instruction for ship management and design engineers

No.	Instructions
1	Adherence to safety standards
2	Advanced navigation systems
3	Cargo management
4	Communication protocols
5	Crew training
6	Emergency response plans
7	Passenger safety measures
8	Regular maintenance
9	Regulatory compliance
10	Risk assessments
11	Risk Control

The IMO and MAIB (Marine Accident Investigation Branch) regularly publish reports on incidents of grounding, highlighting factors contributing to these incidents and lessons learned. The IMO and European Maritime Safety Agency (EMSA) are responsible for reducing maritime accidents and marine pollution from ships. They frequently report flooding incidents and implement prevention measures, ensuring transparency and safety in the maritime industry. Lloyd's Register and the American Bureau of Shipping set standards for ship design and construction to prevent structural failures, while marine safety organizations provide investigation reports. The industry publications provide very useful information. Explore publications from classified societies, industry associations, and maritime engineering organizations, which often contain research papers and technical articles on ship safety.

The World Meteorological Organization (WMO) is a UN agency responsible for analyzing Earth's atmosphere, ocean interactions, climate, and water resource distribution. The WMO and Naval Historical Center (NHC), along with other meteorological agencies, provide crucial information on extreme weather conditions and potential maritime safety risks. The MAIB, in collaboration with the Department for Transport, investigates marine accidents involving UK vessels globally and all vessels in UK territorial waters. United States Coast Guard (USCG) and MAIB investigations offer insights into human error-related accidents, offering recommendations for improving crew training and procedures. Reports from maritime safety organizations, classification societies, and equipment manufacturers can reveal incidents of equipment failure and suggest improvements in design and maintenance practices. The IMO establishes guidelines for safe cargo transport, with maritime authorities reporting incidents related to improper handling and stowage. Ship design standards, industry publications, and maritime safety organizations can identify design flaws and suggest improvements in ship architecture. The collection of data from spaceborne scatterometers now makes it possible to trace high winds over the ocean globally. Figure 1 and Figure 2 are illustratine and self explanatory.

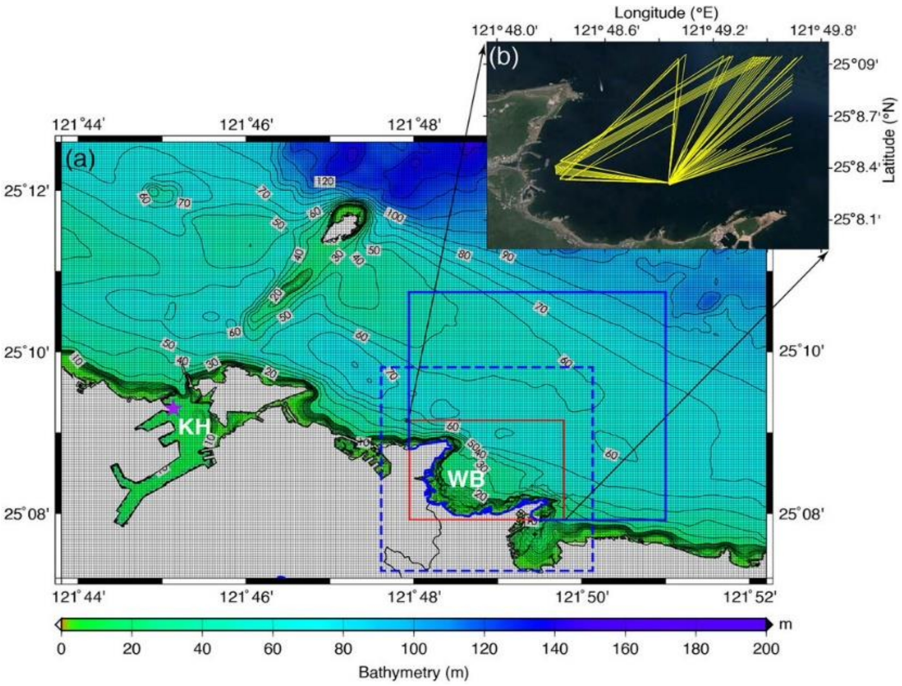

Figure 1. Wind map Mapping High Sea Winds from Space: A Global Climatology [Source: AMS American Metrological Society]

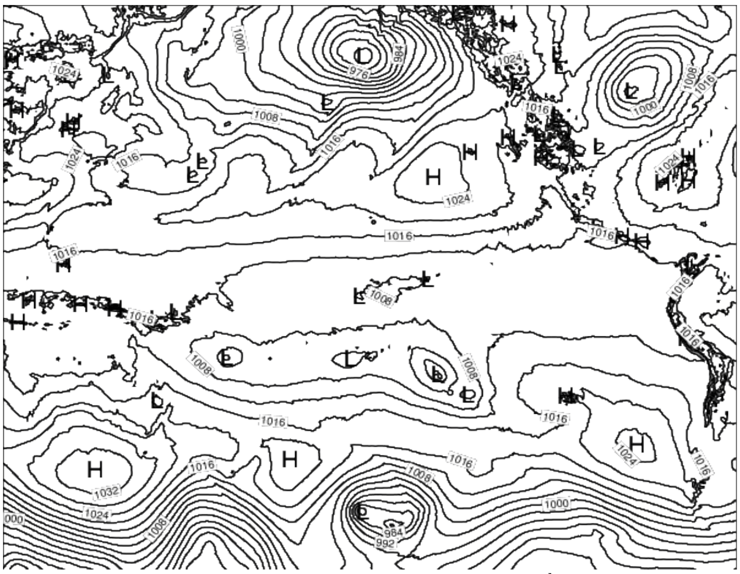
Figure 2. Pacific-Ocean Weather Map for 15 days recorded on 9th February 2024, [Source: weather forecast.com]

David (2015) highlighted several issues about maritime transport and ballast Water management and proposed their solutions. The matters regarding ship weight/ship design and buoyancy calculation procedure as well as calculation of friction/resistance is explained by Roh and Lee (2018). The matter regarding propulsion devices has been outlined and discussed by Sulligoi (2016). The most important issue in ship designing is the determination of forces, loads and moments required for design process, which keeps it stable is discussed by Hirdaris (2014). Sutulo and Guedes Soares (2011) present the prediction of maneuvering in ship design model regarding performance. Muckle (1951) has discussed various important terminologies and aspects such as machinery material, shipbuilding side spaces stability and causes of important problems occurring in ship design. Papanikolaou (2014) wrote about initial ship design processes and usual steps involved. Wahid *et al*. (2020) has focused on aluminum alloys in ship architectural design, their features, presentation, and complications from a manufacture viewpoint.

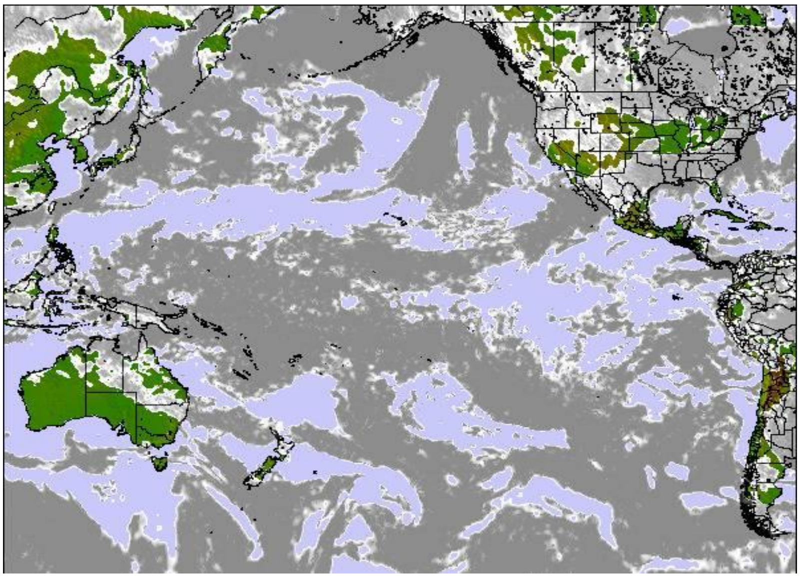

Figure 3. Clouds covering Atlantic Ocean on 8th February 2024, [Source: weather forecast.com]

Table 2. Important scientific and engineering considerations for ship designing

No.	Feasible concepts to be adhered for ship design
1	Archimedes' principle
2	Buoyancy in ships
3	Buoyancy, gravity, density, and water displacement
4	Center of gravity's vertical orientation
5	Compromises necessary
6	Computing friction resistance
7	Concept of the metacenter
8	Contract design stage
9	Determination of forces and moments
10	Detrimental effects of discontinuities
11	Efficiency of propulsion
12	Geometry and correlated effects
13	Hydrostatic and hydrodynamic loads
14	Hydrostatic forces
15	Indexes of metacentric stability
16	Metacenter's vertical position
17	Laws and regulations for safety
18	Metacentric stability
19	Scantlings and strength calculations
20	Ship weight and buoyancy computation

Table 2, denotes essential scientific and engineering factors for ship design, along with feasible concepts to be followed. Moreover, Table 3 represents crucial devices for ship stability, which architects and engineers should consider during ship design. Table 4 outlines crucial safety factors for post-ship manufacturing and design, focusing on engineering and architecture for comprehensive safety consideration.

Table 3. Required devices in ship-design

No.	Devices of pivotal importance for ship stability
1	Achieving level attitude or trim
2	Action of propulsion devices
3	Ballast tanks
4	Cavitation
5	Combined passenger and cargo ships
6	Dynamic stability of route
7	Features related to general arrangements per ship type
8	Four fundamental hull categories
9	Heel when turning
10	Impact of maneuverability on action of the propulsion device
11	Jointing, connections, and attachments
12	Model experiments
13	Preliminary design stage
14	Preparation of requirements
15	Propeller general design and placement
16	Resilience in narrow and shallow waterways
17	Resistance and propulsion
18	Rudders and planes
19	Separation resistance
20	Ship design procedure
21	Ship form for minimum resistance
22	Ship hull
23	Ship propeller

Table 4. Safety factors required after ship manufacturing

No.	Post ship-design matters regarding safety
1	Combination of dynamic wave stresses and calm-water
2	Floodable length and subdivision
3	Mechanical evaluations of models and ships
4	Ships in waves
5	Static Stability of a Ship
6	Stopping and Reversing
7	Strength and stiffness
8	Strength of ships
9	Structural configurations
10	The chaotic wake of a boat.
11	Turbulent water flow
12	Turning and steering
13	Weight and buoyancy variations along the ship's length

Conclusion

The architectural and engineering ship design must be in conformity with international standards. The emergency plans to avoid ship sinking, risk assessment and risk management techniques are of crucial importance. A fracture because of catastrophic failure in structural materials occurs at high speeds without plastic deformation, due to low temperature and high impact loading. The Titanic's wrought iron rivets failed due to brittle breakage and high influence loading from heavy storms, causing the rivet heads to pop off a normal failure. Regulatory agencies set safe waterline depths for ships which must be followed. Larger ships increase cargo and passenger capacity, increasing risk of accidents. Reduced maneuverability and factors like natural conditions, technical failures, route conditions, ship-related issues, human errors, and cargo-related factors contribute. The effective ship design, periodical maintenance, following operational and standard measures leads to safety. Proper cargo management, updated telecommunication network through satellite and crew training are very crucial elements to adhere.

References

Andrews, D. 2020. Design errors in ship design. Journal of Marine Science and Engineering, 9(1): 34. https://doi.org/10.3390/jmse9010034

Bassett, V. 2000. Causes and Effects of the Rapid Sinking of the Titanic. Vicki Bassett College of Engineering University of Wisconsin. engr.psu.edu

David, M. 2015. Vessels and ballast water. Global Maritime Transport and Ballast Water Management: Issues and Solutions, 2015:13-34.

Ebrahimi, A., Brett, P. O., Erikstad, S. O., and Asbjørnslett, B. E. 2021. Influence of ship design complexity on ship design competitiveness. Journal of Ship Production and Design, 37(03): 181-195.

Ebrahimi, A., Brett, P. O., Erikstad, S. O., Asbjørnslett, B. E., and Garcia Agis, J. J. 2020. Ship design complexity, sources, drivers, and factors: A literature review. International Shipbuilding Progress, 67(2-4): 221-252.

Gannon, R. 1995.What Really Sank the Titanic. Popular Science, 246(2): 49-55.

Garcia Agis, J.J., Brett, P. O., and Erikstad, S. O. 2020. How uncertainty influences decision-making effectiveness in conceptual ship design processes. International Shipbuilding Progress, 67(2-4): 141-172.

Garzke, W.H., David K.B., and Saniford, A. 1994. The Structural Failure of the Titanic, Oceans Conference Record (IEEE), 3: 138-148.

Hill, S. 1996. The Mystery of the Titanic: A Case of Brittle Fracture? Materials World, 4(6): 334-335. https://doi.org/10.3390/jmse9010034

Hirdaris, S. E., Bai, W., Dessi, D., Ergin, A., Gu, X., Hermundstad, O. A., and *et al*. 2014. Loads for use in the design of ships and offshore structures. Ocean engineering, 78, 131-174

Malik, A.A., Siddique, F., Asad, M., and Waqar, A. 2021. Dominant factors having adverse effects on Bermuda Triangle region. Research in Marine Sciences. 6(3): 1014-1032.

Moyst, H., and Das, B. 2005. Factors affecting ship design and construction lead time and cost. Journal of ship production, 21(03): 186-194.

Muckle, W. 1951. Modern Naval Architecture. W.P. Griffith & Sons London.

Nejad, A. R., Purcell, E., Valavi, M., Hudak, R., Lehmann, B., and *et al*. 2021. Condition monitoring of ship propulsion systems: State-of-the-art, development trend and role of digital Twin. In International Conference on Offshore Mechanics and Arctic Engineering (Vol. 85178, p. V007T07A005). American Society of Mechanical Engineers.

Papanikolaou, A. 2014. Ship design: methodologies of preliminary design. Springer.

Roh, M. I., and Lee, K. Y. 2018. Computational ship design. Springer Singapore.

Rumawas, V. 2016. Human factors in ship design and operation: Experiential Learning. PHD thesis. Norwegian University of Science and Technology, Faculty of Engineering Science and Technology Department of Marine Technology.

Sulligoi, G., Vicenzutti, A., and Menis, R. 2016. All-electric ship design: From electrical propulsion to integrated electrical and electronic power systems. IEEE Transactions on transportation electrification, 2(4), 507-521.

Sutulo, S., and Guedes Soares, C. 2011. Mathematical models for simulation of manoeuvring performance of ships. Marine Technology and Engineering, 661-698.

Wahid, M. A., Siddiquee, A. N., and Khan, Z. A. 2020. Aluminum alloys in marine construction: characteristics, application, and problems from a fabrication viewpoint. Marine Systems & Ocean Technology, 15: 70-80.

Watson, D. G. 2002. Practical ship design (Vol. 1). Elsevier.