Effects of Energy Efficiency Design Index on Resistance, Hydrostatics and Ship Design Using Hughes-Prohaska Method

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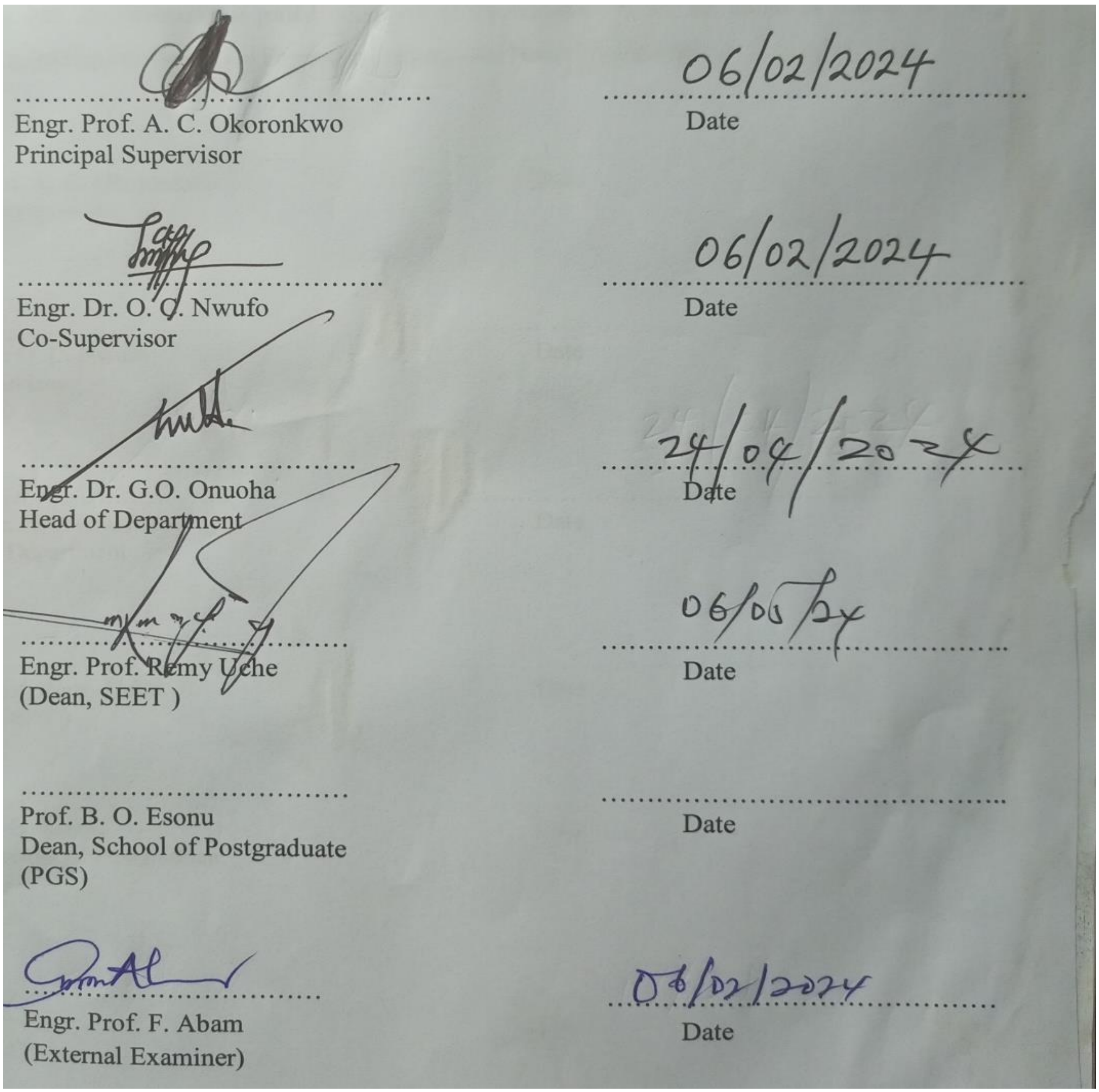
CERTIFICATION

This is to certifiy that this work “Investigation of the Effects of Energy Efficiency Design Index on Resistance, Hydrostatics and Ship Design Using the Hughes-Prohaska Method” was carried out by CHUKU, Azubuike John (Reg. N0: 20174080428) in partial fulfillment of the requirements for the award of Master of Engineering (M.Eng.) in Mechanical Engineering, (Energy and Power Engineering).



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DEDICATION

This Dissertation is dedicated to God Almighty whose mercy, grace and inspirations unquantifiable led to the successful completion of this programme.

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NOMENCLATURE

Symbol	Description	Unit
S	Wetted surface area	m2
Vs	Ship speed	m/s2
υ	Kinematic Viscosity	
C_{Ts}	Ship resistance coefficient	-
C_{Tm}	Model resistance coefficient	-
R_{TS}	Ship total resistance	N
P_e	Ship Effective power	kW
All_P_{MCR}	Allowable power	kW
ρ	Density	Kg/m3
η_x	Efficiency factor for allowable power	-
R_{Tm}	Model total resistance	N
H	Hull form	-
Fn	Froude Number	-
Rn	Reynold's Number	-
d	Water depth	m
T	Vessel draft	m
C_B	Block coefficient	-
L_M	Length of the model	m
L_S	Length of the ship	m
B	Breadth	m
C_F	non-dimensional conversion factor between fuel consumption measured in g and CO2 emission also measured in gram based on carbon content.	
MEi	Main Engine	kW
AEi	Auxiliary Engine	kW
Vref	Ship speed	(knot)
Dwt	Deadweight or capacity	Tonne
P	Power of the main and auxiliary engines, measured	kW
PME(i)	75% of the rated installed power (MCR) for each main engine	kW
PPTO(i)	75% output of each shaft generator installed	kW
PPTI(i)	75% of the rated power consumption	kW
P_{eff}(i)	75% of the main engine power reduction due to innovative mechanical energy efficient technology	
$PAE_{eff(i)}$	Auxiliary power reduction due to innovative electrical energy efficient technology	

PAE	Auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation.
SFC	Specific fuel consumption, measured in g/kWh, of the engines. The subscripts ME(i) and AE(i) refer to the main and auxiliary engine(s), respectively.
fj	Correction factor to account for ship specific design elements. fj should be taken as1.0.
fw	Non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed. fw should be taken as one (1.0)
$f_{eff}(i)$	Availability factor of each innovative energy efficiency technology. $f_{eff}(i)$ for waste energy recovery system should be 1.
fi	Capacity factor for any technical/regulatory limitation on capacity, and can be assumed one (1.0) if no necessity of the factor is granted.

ABSTRACT

In this study, the investigation of the effects of energy efficiency design index on resistance, hydrostatics and ship design was successfully carried out. The aim is to determine how much the current Energy Efficiency Design Index (EEDI) formulations improve or conflict with ship design, vessel resistance, and hydrostatic laws. Parametric case studies of a Roll-on Passenger (Ro-Pax), Tugoat, and Reefer vessel are conducted for this reason. This group of vessels was picked because of how much energy they use naturally. To determine the impact of EEDI law on these three types of boats, Ship speed, Water Line Length (LWL), Beam (B), Draft (T), L/B ratio, B/T ratio, and Prismatic Coefficient (Cp) were examined. The results of the towing tank-model resistance tests were extrapolated to the three big ships, after the Hughes-Prohaska technique was used to evaluate the overall ship resistances and effective power of each of the models. In order to calculate the effective power, permissible power, and EEDI achieved, the resistance values previously extrapolated for the big ships were used. Based on correlation analysis of the data, the results indicate that there was an almost 89% agreement between the EEDI referenced and the EEDI attained. When the Hughes-Prohaska method's resistance data was verified against test data from an existing vessel model, an average error of 2% and a maximum error of 4% were discovered. It was deemed permissible to make this mistake. Effective power per unit displacement was plotted against each relevant parameter to examine the implications of EEDI on ship design, resistance, and hydrostatics. This is being done to ascertain the behavior of the EEDI attained. Additional findings showed that, with constant specific fuel consumption (SFC) and altering speed from 12 knots to 24 knots, the attained EEDI is proportional to the power (kW)/dead weight (tonne) ratio. It has been shown that at low speed, longer ships perform better on EEDI. However at higher speed, longer ships modify the L/B ratio, B/T ratio, draft, hydrostatic coefficients, increase resistance, and ultimately increase the ship's energy consumption. Further evidence suggest that in order to lower the EEDI, it is necessary to lower the pragmatic coefficient, optimize the hull, and decrease ship speed. In this instance, the 14% decrease in EEDI would be caused by the 13% sacrifice made to ship speed at the design stage. The graphs that were produced show that a ship may operate more efficiently and have a less environmental effect when the EEDI decreases.

Keywords: Energy Efficiency Design Index (EEDI), Ship parameters, Hughes-Proshaka, , Model Resistance Test.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The two major problems facing marine transportation today are energy consumption and environmental pollution, yet the industry is nevertheless vital to the global transportation system because of its enormous trade volume (seaborne trade) and cheap cost per unit of transportation. According to Faitar et al. (2016), over 70% of global commerce by value and over 80% of global trade by volume are transported by water and handled by ports throughout the world. The business will continue to grow as globalization intensifies, and although while shipping is already the most effective method of transporting cargo, more can be done, according to the industry. The basis for good transformation is laid by better designs and optimized engines. The International Maritime Organization (IMO) has defined new requirements for increased efficiency throughout all phases of a ship's lifespan in collaboration with key stakeholders. The Energy Efficiency Design Index (EEDI), one such indicator, is the ideal illustration of this challenging objective (Hon et al., 2019). The performance of a ship's sailing is determined by the compatibility of the ship, engine, and propeller. This also has an impact on the economy and emissions of the ship. To better understand the interaction between these three parts and to advance the fundamental matching theory, some research on the ship-engine-propeller matching has been conducted (Ogar et al, 2018, Qin et al, 2003 and Molland et al, 2017). Additional exports must be asked in order to reduce and slow down CO_2 emissions in light of past data on air pollution caused by CO_2 emissions and the fact that maritime transport is a "green transport" in comparison to other modes of transport (Chuku et al, 2023).

International groups have voiced grave concern about air pollution given that maritime transportation is a transnational business activity. As a result, there are now several worldwide anti-pollution legislation, with the most recent ones concentrating on air pollution (MEPC, 2009).

It must be highlighted that the flag nations are responsible for enforcing all international laws. The vessels under such flag states are thus not required to comply with the international regulations if the flag states do not ratify the regulations and/or agreements. In any event, the port authorities where the moored vessels are located might demand adherence to the global laws. Because of this, it is often simple to apply international laws (Borkowski et al., 2011). As a result, the International Maritime Organization (IMO) has taken on a pertinent role and is acting quickly to address it (IMO, 2010). Therefore, reducing the carbon fuel consumption on board (which is mostly caused by propulsion and on-board electricity generation) is one of the key strategies to cut greenhouse gas emissions, more effective energy utilization results in lower CO_2 emissions.

After being made required at the 62nd MEPC conference in July 2011, Energy Efficiency Design Index has recently gained prominence in the marine sector.At that conference, it was resolved that starting on January 1, 2013, all new ships must meet the EEDI's minimal requirements. It becomes both intriguing and frightening for the majority of ship owners, shipping businesses, and ship design firms (Esmailian et al., 2017).

The International Maritime Organization (IMO) developed the Energy Efficiency Design Index (EEDI) as a technical tool to increase the energy efficiency of ships. The achieved EEDI value of a ship must be lower than the required EEDI value as calculated by the EEDI reference line, which is the global fleet average for a specific ship type adjusted by the necessary reduction factor (Mersin, 2020). Although the overall number of ultra large tugboat ships (ULCS) has greatly expanded over the past few years, the Required EEDI calculation for tugboat boats currently does not adequately account for their existence in the global fleet. As a result, the EEDI requirements are typically rendered largely irrelevant for the construction of ULCS, however they may be challenging to satisfy in the case of smaller tugboat carriers. Most applications for matching ship propulsion systems focus on propelling effectiveness and fuel cost while neglecting environmental effects. Due to their detrimental effects on maritime transportation, consideration of EEDI or other emission indices should be introduced to the matching process (Molland, et al., 2017). The EEDI value, on the other hand, is only determined as a verification after the matching design to make sure the ship complies with the EEDI regulations. The mere objective of the propulsion system matching with propulsive efficiency would not be adequate to the ship design and operation due to the increasingly strict EEDI regulations. Early ship propulsion system design would require the involvement of EEDI, i.e., potential EEDI advice on design parameters during system matching. In order to study the impact of EEDI on ship engine propeller matching, a matching process integrating the propulsion system matching theory and EEDI computation is devised in this work. The ship engine propeller matching platform is built and calibrated using the sea trial data of a 38800 DWT (deadweight tonnage) general-cargo carrier. After model formulation and analysis, it is possible to determine the inversely proportional relationship between EEDI and open water propeller efficiency (Taskar et al., 2015). The three major inputs used in matching are ship speed, propeller diameter, and ship effective power. By adjusting each of these three factors independently, it is possible to forecast not only the trend but also the magnitude of the change in EEDI.

1.2 Statement of Problem

Some researchers avoid the Hughes-Prohaska resistance and power prediction method due its time consuming factors, rigorous experimental procedures and cost of running experiments in the towing tank despite the obvious revelation that the current method of using the Holtrop and Mennen method is only theoretical, relatively unreliable and as such could pose great risks on ascertaining a vessel's energy efficiency design index. Hypothetically, the level of unreliability of the Holtrop-Mennen method suggest that the resistance and power predicted therefrom disfigures any analysis on energy efficiency design index of ships and therefore, inform wrong policies to be imposed. The number of ships in the global commercial fleets has increased overall during the past ten years, and with more emissions comes a greater environmental burden. The International Maritime Organization (IMO) proposed the energy efficiency design index (EEDI) criteria to restrict greenhouse gas (GHG) emissions from maritime vessels (IMO, 2010). A sophisticated formula is used to determine EEDI, which stands for energy efficiency of the ship, and it is calculated as the ratio of the ship's potential CO_2 emission to its available capacity for conveying useful weight, payload, and cargo. In order to comply with the EEDI laws, stricter standards are consequently put on the propulsion and hydrodynamic design of ships, especially those conventional ones. The hydrostatic analysis constantly plays crucial roles in the design, building, and management of ships, ensuring that they sail safely while maintaining the appropriate speed. In order to comply with IMO regulations and simultaneously be able to design ships with adequate capacity to carry deadweight or payload (cargo), the early ship design stage investigations on the influence of EEDI on the key hydrostatic parameters are helpful.

1.3 Objectives of Study

The main objective of this study is to analyze the effects of energy efficiency design index on resistance, hydrostatics and ship design using the Hughes-Prohaska method. Other specific objectives are;

i. To prepare models of geometrical and hydrodynamic similarity with the large ships being tested for; conduct model resistance tests using ship models at the towing tank facility of the Centre of Excellence in Marine and Offshore Engineering of the Rivers State University;
ii. To apply the results from the model tests in (i) above using Hughes-Prohaska methods to predict the Total Resistance and Effective Power of the Ropax, Tugboat and Refeer boats to be operated in the Gulf of Guinea;
iii. To carry out detailed analysis on ship design parameters such as resistance, breadth, draft and length for the determination of attained EEDI values for the different ship types;
iv. To validate EEDI attained and the Allowable Power obtained using the reference line values for each of the ship types;
v. To develop a program using Microsoft Excel that will be used to analyze the EEDI of vessels of varried specifications.

1.4 Justifications of the study

With the state of the economy and the environment as it is now, energy efficiency has gained more and more importance. The goal of this dissertation is to map the current status of energy efficiency for ships operating in the Gulf of Guinea, both on a ship-by-ship and industry-wide basis. Model resistance tests for the three boats employed in this project's case study will be the initial area of attention, followed by a review of the shipping industry's regulatory environment with regard to energy efficiency. The operations carried out on ships with the intention of reducing their consumption and emissions come next. These actions vary from adjustments to the design to changes to the operational procedures. The possible innovations that the industry could put into practice on a larger scale to improve the overall sector's efficiency will come after that. Finally, a summary of the key challenges to putting these steps into action will be looked at. While the present guidelines are only a short-term fix and some of the most notable advances need more research, the ongoing work raises this industry's potential for progress.

This study has the added benefit of expanding the amount of knowledge already available about how energy-efficient ships are, but more importantly, it will provide ship designers and operators a better understanding of the relationship between hydrostatics and energy efficiency. Researchers who require it as a source of information for more research in this field or on related topics would greatly benefit from the study.

1.5 Scope of the study

The focus of this study will be restricted to assessing how the energy efficiency design index affects the hydrostatics and ship design of just Ropax, Tugboat, and Reefer boats operating in the Gulf of Guinea. The primary focus of this study will be on the International Maritime Organization's (IMO) perspective on the creation and application of the EEDI index. The chosen ship classes, which are the biggest and use the most fuel in shipping, will be covered by the EEDI implementation in this effort. This research excludes ships using hybrid, steam, and diesel-electric propulsion systems.

CHAPTER TWO

LITERATURE REVIEW

2.1 Review of the Concept

2.1.1 The Ship

According to Ogar et al. (2016), a ship is a huge boat that navigates the world's seas and other suitably deep rivers while transporting goods, people, or supporting specific tasks like fishing, research, or defense. Based on factors including size, form, cargo capacity, and function, ships may often be separated from boats. Ships have aided in scientific advancement, migration, colonialism, trade, and conflict. Following the 15th century, new crops brought to and from the Americas by European mariners had a huge impact on the increase of the global population. The biggest share of global trade is carried out by ship.

Depending on the time period and the context, the word "ship" has either simply denoted a huge vessel or, more precisely, a sailing ship with three or more square-rigged masts (Jack, 2011). More than 49,000 commercial ships totalling about 1.8 billion dead weight tons were in operation as of 2016. 43% of them were general-cargo carriers, 13% were tugboat ships, and 28% of these were reefer vessels (IMO, 2017).

The field of naval architecture is both intriguing and challenging. It is intriguing due to the wide range of floating structures and the numerous compromises required to produce the best useful result. It is difficult since protecting the crew members and the maritime environment requires a significant financial investment in a ship. The range of shapes that a ship might assume can be appreciated by just visiting a busy port. This variance results from the various demands made on them and the operating circumstances. There are therefore a variety of fishing boats, from tiny local boats that operate during the day to ocean-going ships with equipment to deep-freeze their harvest. There are ships to harvest the other treasures of the deep, including the mining of minerals and the extraction of gas and oil for use as energy sources. Reefer vessels come in a variety of sizes, from little coastal craft to enormous superReefer vessels (Eyring et al., 2009). Grain, coal, and ore are among the General-Cargo commodities carried by other enormous ships. Ferries are available to transport people between ports that may be just a few kilometers or a hundred distant. There are tugs for hauling ships across oceans or guiding them into ports. The port would not be able to operate without the dredgers, lighters, and pilot boats. There will be a variety of warships in a naval port, including enormous aircraft carriers, cruisers, destroyers, frigates, patrol boats, mine countermeasure vessels, and submarines. In addition to function variety, hull shape variety exists. The great majority of ships have a single hull and maintain their weight through displacement. Multiple hulls are preferable in some applications because they offer spacious deck spaces without being overly long. In some instances, utilizing dynamic forces to sustain a portion of the weight while moving might result in faster speeds. Examples include planning craft, surface effect vessels, and hydrofoil craft. Air cushion vessels give an amphibious capability and allow for navigating shallow water. Combinations of these specialized forms will be used in some crafts. The variation extends beyond form and content (Bondia et al. 2016). Steel, wood, aluminum, and other types of reinforced polymers are among the materials utilized. The wind may be employed as the propulsion method to move the ship across the water, however mechanical propulsion is typically used for bigger craft. Diesel engines, steam turbines, gas turbines, fuel cells of some kind, or a combination of these may produce the driving force. Through mechanical or hydraulic gearing, or by employing electric generators and motors as intermediates, the power will be transferred to the propelling unit. The propulsor itself is often some type of propeller, sometimes ducted, although it might also be an air or water jet. There will be several other systems on board, including ways to control the ship, ways to produce electricity, hydraulic power for winches, and other systems for handling cargo. With several thousand people on board and spending weeks at sea, a ship might resemble a floating village. It requires electricity, ac, a sewage treatment facility, galleys, bakeries, stores, restaurants, movie theaters, dance floors, music halls, and swimming pools. All of these factors, along with the ship's overall layout, must be put in place for the planned duties to be completed by the ship quickly and effectively. A ship must float, move, be able to survive in a very harsh environment, and be able to endure an acceptable amount of accident, therefore the naval architect has additional challenges beyond those faced by building and town designers. The naval architect is the one who "orchestrates" the design, utilizing the knowledge of many other professions to find the optimum solution for a variety of needs that are frequently at odds. Naval architecture is a combination of science and art. Science is used to ensure that the spacecraft moves at the desired speed, is sufficiently stable and sturdy to resist the rigors of the hostile environment through which it travels, and other things. In order to create a product that is not only visually beautiful but also capable of carrying out its role with maximum effectiveness, efficiency, and economy, it is necessary to carefully combine the many aspects at play. A ship is a significant investment that takes several years to construct and is anticipated to stay in service for at least twenty-five years, making naval architecture a difficult career. The majority of the time, it is a component of a larger transportation system and must be appropriately integrated with the other components of the whole system. The size of the ship that can be accommodated will be constrained by the terrain and facilities at some ports, and it may even be necessary for it to carry specific equipment for loading and unloading cargo. The tugboat ship is one illustration of this. Tugboats can be used to transport goods from the plant where they are made. These standard-sized tugboats are transported by road or rail to a port with specialist handling gear, where they are loaded with cargo. They are discharged into land transportation at the target port. Tugboats enable ships to load and unload cargo more quickly and securely while requiring much less time in port. Port costs are decreased, and the ship is put to better use. To satisfy the demands of the operator, the designer must build the best ship feasible. In order to achieve this, he must understand how the ship will be utilized and foresee potential changes in those demands and usage over time. So flexibility in the design is required. The most admired ships throughout history have consistently been those that were flexible. The safety of the ship, the crew, and the environment are paramount. The design must be secure during routine operations and not too prone to error or accident. No ship can be completely secure, thus a designer must make deliberate choices on the amount of risk that is deemed acceptable in the broad range of situations where the ship would be expected to find itself. The chance that the conditions provided for will be exceeded must always be considered, together with any potential repercussions, and only accepted if determined to be unavoidable or acceptable (Chen et al., 2015). Acceptable in the sense of being deemed appropriate by the owner, operator, the general public, and last but not least by the designer, who bears the primary duty. Even in cases where someone else's negligence resulted in an accident, the designer ought to have been aware of the risk and taken precautions to lessen the effects. For instance, the ship must have a decent probability of surviving a collision or at the very least staying afloat long enough for people to be evacuated safely. This necessitates the use of a variety of life-saving tools. A tragic illustration of what might happen when things go wrong is the Estonia's sinking in 1994, which resulted in a significant loss of life. Materials that might harm the environment if accidentally discharged are sometimes carried on cargo ships. Large oil spills' effects are frequently mentioned in the media. Perhaps even more dangerous substances exist. The bunker fuel in ships poses a risk, and the Lorries on board ferries may be carrying hazardous goods. It is obvious that individuals who design, build, and manage ships have a significant duty to the general public. They will probably face consequences if they fall short of the standards expected of them. Governments have established a number of requirements that vessels flying their flag or visiting their ports must abide by over time due to concerns about the safety of people and property. Worldwide shipment necessitates adherence to international regulations.

2.1.2 Types of ships

Having so many different categorization criteria makes ships challenging to categorize. A categorization based on the kind of propulsion divides ships into sailing ships, steamships, and motor ships. Sailing ships are only powered by their sails. Steam engines are used to move steamships. Internal combustion engines are used in motor ships, which also include vessels driven by a mix of sail and internal combustion. Other classification requirements for ships include the number of hulls: monohull, catamaran, and trimaran. Categories like dinghy, keelboat, and icebreaker are given by the shape, size, and purpose (Faitar et al., 2016). Steel, aluminum, wood, fiberglass, and plastic make up the hull. The kind of propulsion system employed, including sails, mechanical, and human-propelled (such as ancient triremes). Triremes of Ancient Greece and ships of the line of battle in the 18th century were examples of the era during which the vessel was utilized (IMO, 2012). The ship's place of origin; many boats have ties to specific places, such the pinnace of Northern Europe, the gondolas of Venice, and the junks of China.

According to Paulet and Presles, another approach to group ships and boats is based on their intended usage. This system consists of commercial, fishing, leisure, and racing boats in addition to military and commercial ships. The first four of those categories are used to categorize ships in this section, along with sections for lake and river boats and other types of ships.

Cargo ships, passenger ships, and special-purpose ships are the three basic categories into which commercial vessels or merchant ships may be separated.

Dry and liquid cargo is transported by cargo ships. Dry cargo can be pushed onboard as in roll-on roll-off ships, loaded directly into a general cargo ship in break-general-cargo, loaded in intermodal tugboat as aboard a tugboat ship, or transported in general-cargo by general-cargo carriers (Livanos et al., 2014). On Reefer vessels, such as Reefer vessels that may carry both crude and finished products of oil, chemical liquid cargo is often transported in General-Cargo. Other than chemicals and LPG/LNG, reefer vessels may also carry vegetable oils, while smaller shipments may be transported on tugboat ships with tank tugboats. Small river ferries to enormous cruise ships are all different sizes of passenger ships. This category of ship includes ferries, which transport people and vehicles on brief journeys; ocean liners, which transport people from one location to another; and cruise ships, which transport people on leisurely journeys that frequently include returns to the port of embarkation. Special-purpose boats are employed for purposes other than transportation. Examples include icebreakers, cable ships, research vessels, pilot boats, rescue boats, pilot boats, and pilot boats. Full hull shapes are common on commercial ships to increase cargo capacity. Although aluminum can be used on speedier ships and fiberglass on the smallest service vessels, steel is often the material utilized for hulls. On bigger commercial boats, deck officers and marine engineers may also be present. Commercial vessels typically have a crew led by a captain. If appropriate, special-purpose vessels frequently include specialist crews, such as scientists on research vessels (Molland et al., 2017). A single propeller driven by a diesel or, less frequently, a gas turbine engine commonly powers commercial vessels. Pump-jet engines may be used on the quickest ships.

A navy uses naval vessels for military operations. There have been several varieties of naval ships. Surface warships, submarines, and support and auxiliary ships are the three main types of modern naval vessels. The seven primary categories of modern warships are: amphibious assault ships, cruisers, destroyers, frigates, corvettes, and aircraft carriers. The difference between cruisers, destroyers, frigates, and corvettes is not exact; several navies may have different definitions for the same ship. Battleships were employed throughout the Second World War and on occasion afterward (the final battleship was struck from the U.S. Naval Vessel Register in March 2006), but carrier-borne planes and guided missiles rendered them obsolete. According to Taskar et al. (2015), assault submarines and ballistic missile submarines make up the majority of military submarines. The main functions of the diesel/electric submarine up until the conclusion of World War II were anti-ship warfare, the insertion and removal of clandestine operatives and armed units, and information collection. Submarines were also able to efficiently chase one another when the homing torpedo, superior sonar systems, and nuclear propulsion were developed. Submarines now have a significant and long-ranged capability to strike both land and sea targets with a variety of armaments, ranging from cluster bombs to nuclear warheads. This capability was made possible by the development of submarine-launched nuclear and cruise missiles. Many different types of support and auxiliary vessels are also found in the majority of fleets, including minesweepers, patrol boats, offshore patrol vessels, replenishment ships, and hospital ships that are used as medical treatment facilities. Cruisers and destroyers are examples of fast battle ships with fine hulls that increase speed and maneuverability. In addition to having weaponry, they frequently have cutting-edge electronics and communication systems.

A subgroup of commercial boats, fishing vessels are often tiny and are governed by separate laws and classifications. Architecture, the kind of fish they capture, the technique employed to catch them, where they came from geographically, and technical elements like rigging may all be used to classify them. Around 4 million boats made up the world's fishing fleet as of 2004. Among these, 1.3 million were decked ships with interior spaces, while the remaining 1.8 million were open ships (Tokuşlu, 2019). Two-thirds of the open vessels were conventional crafts driven by sails and oars, while the majority of decked vessels were automated. More than 60% of all big fishing vessels in use today were produced in Japan, Peru, Russia, Spain, or the United States. The average fishing vessel is not much bigger than 30 meters (98 feet), however larger ships for tuna or whaling can reach heights of 100 meters (330 feet). The catch may be prepared for market and sold more rapidly after the ship arrives at a port on a fish processing vessel. particular purpose ships require particular equipment. For instance, stern-trawlers have a back ramp, trawlers have winches and arms, and tuna seiners have skiffs. A total of 85,800,000 tons of fish were taken in the marine capture fisheries in 2004 (84,400,000 long tons and 94,600,000 short tons). According to Wärtsilä et al. (2017), anchoveta constituted the greatest single capture at 10,700,000 tons (10,500,000 long tons; 11,800,000 short tons). Alaska pollock, Blue whiting, Skipjack tuna, Atlantic herring, Chub mackerel, Japanese anchovy, Chilean jack mackerel, Largehead hair tail, and Yellow fin tuna were all among the top ten marine species caught that year.

Commercial fishing is also done for species including salmon, shrimp, lobster, clams, squid, and crab. Many techniques are used by commercial fishers nowadays. One is fishing using nets, such as entangling nets, lift nets, beach seines, purse seines, and gillnets. Trawling, especially bottom trawling, is an additional. In techniques like long-line fishing and hand-line fishing, hooks and lines are employed. Use of fishing traps is another technique.

A weather ship was a vessel that was positioned in the ocean to serve as a platform for meteorological measurements of the surface and higher atmosphere for marine weather forecasting. Four radiosonde releases took place each day, and surface weather measurements were made hourly. It was also intended to facilitate transatlantic flights and search and rescue efforts. The idea of weather ships was first put out by the aviation community in 1927, and it was shown to be so helpful during World War II that the International Civil Aviation Organization (ICAO) developed a global network of weather ships in 1948, with 13 of them being provided by the United States (Xie, 2011). This number was ultimately reduced to nine. Their sailors often spent three weeks at a time at sea before returning to port for 10-day intervals. As weather ships did not avoid weather systems as other ships tended to do for safety concerns, their findings proved to be useful in studies of wind and waves. They were useful for keeping track of storms at sea like tropical cyclones. Forecasts for the Great Storm of 1987 began to reflect negatively on the departure of a weather ship. Due to the ships' high cost, weather buoys began to primarily replace them starting in the 1970s. The international community's agreement to the employment of weather ships came to an end in 1990. On January 1, 2010, Polar Front, also known as weather station M (or "Mike"), ceased operations as a weather ship. A fleet of volunteer merchant ships that are engaged in ordinary economic activity continue to observe the weather from the sea (Zakaria and Rahman, 2016).

2.1.3 Energy Efficiency Design Index (EEDI)

The International Maritime Organization (IMO) has implemented Annex VI of the MARPOL 73/78 agreement and developed a new regulation to reduce air pollution from ship emissions in accordance with the goals outlined in the UN Framework agreement on Climate Change and the Kyoto Protocol. These new regulations focused on energy efficiency measures for new ships and lowering green gas emissions from shipping for existing ships (Tokuşlu, 2019). In order to improve the energy efficiency of new ships during the design stage, the International Maritime Organization

(IMO) approved a new measure with a set of technological innovation and performance requirements in 2011. By using less fossil fuels and emitting fewer greenhouse gases, this new metric, known as the Energy Efficiency Design Index (EEDI), seeks to minimize CO_2 emissions and environmental damage on a worldwide scale. All new ships that are 400 GT or bigger must use EEDI. The new ships will be more energy-efficient according to this new measure thanks to their optimized hulls, engines, propellers, etc. As early as the design phase, EEDI mandates minimal energy consumption and CO_2 emission for unit load per ton/mile in various ship types and models (IMO, 2011). The ship is more energy-efficient and emits less CO2 when its EEDI rating is lower. Recent research have shown that energy-efficient techniques for ships are all practical and helpful for lowering CO_2 emissions.

The energy efficiency of a vessel is determined using the EEDI. Based on a complicated algorithm that takes into account the ship's emissions, capacity, and speed. The EEDI contrasts the benefits of shipping for society and the environment (Shi et al., 2010). The EEDI formula accounts for particular design elements and requirements, such as the usage of energy recovery, low carbon fuels, ship performance in waves, and the requirement for ice fortification of certain ships. It is still up for debate how some design elements, such electric propulsion, should be handled. A constant value for the EEDI exists and will only change if the design is modified. The EEDI, expressed in units per nautical mile, may be viewed as less significant or useful for specific ship types. This shows that the units in which the EEDI is measured may need to be modified to accommodate specific ship types and ship sizes, and that the EEDI may not be practically relevant to all ship types. This is supported by the potential requirement for a minimum size threshold. Large cargo ships, which are responsible for a substantial portion of emissions, can be covered, nevertheless (MEPC, 2011).

A ship's energy efficiency and environmental impact are inversely correlated, and the lower the EEDI, the better. They want to finish the current EEDI regulations and provide appropriate reference lines for boats that aren't currently taken into account. Again, if we assume a 25-year vessel life, the vessels built up until phase 0 will continue to emit at the same rate until 2038 (no reduction is required). In addition, it can take 10 years or longer to notice the actual impact. International shipping will only be impacted by EEDI "as and when older, less efficient tonnage is replaced by new, more efficient tonnage." Emission control instruments are advantageous in every aspect, even if EEDI is presently not a reliable emission indicator.

Ships built in 2015, 2020, and 2022–2025 will have to comply to even higher requirements, hence it is essential for ship owners and operators to be aware that EEDI criteria would constantly tighten. Despite the fact that there were initially a number of exclusions, the list of ship types to which the EEDI does apply is constantly expanding (Zakaria and Rahman, 2016). The most recent changes, RoPax, indicate that cruise ships with diesel-electric propulsion and LNG carriers with diesel-mechanic or diesel-electric propulsion must abide by the prescribed EEDI constraints.

Nevertheless, based on the results of the initiative's initial phase, the IMO intends to broaden the EEDI in the future to include additional types of ships. For ship operators, staying current with these developments will be essential.

The maximum EEDI that can be attained is the required EEDI, which depends on the kind and size of the spacecraft. Over three phases, beginning with a reference line value in 2013 and concluding in 2025, the limitation will be gradually reduced. The reference line for the required EEDI for vessels constructed after 2000 is a function of the EEDI (Longva et al., 2010).

The EEDI analyzes a ship's energy consumption while at sea, taking into account both the crew's accommodation requirements and the energy required for propulsion. Energy used for ballasting, navigating, or maintaining the cargo is not taken into account.

2.1.3.1 Certification of EEDI Design Stage

An EEDI Technical File comprising the essential data for the verification and other pertinent background papers must be submitted by a Ship Owner or Shipbuilder to a verifier (Administration or its RO) for the preliminary verification at the design stage. According to the EEA (2013), the EEDI Technical File, which must be created by either a ship owner or a shipbuilder, must at the very least contain the following.

i. Dead weight and shaft power of main and aux. engines;
ii. Ship speed on deep water in the maximum design loaded conditions at the 75% of the maximum continuous rate (MCR) for the main engine;
iii. Specific fuel consumption (SFC) of the main engine at 75% MCR and auxiliary engines;
iv. Principal particulars, overview of propulsion system and electricity supply system on board;
v. Estimation process and methodology of the power curves at design stage;
vi. Description of energy saving equipment; and calculated value of the Attained EEDI.

After validating the achieved EEDI at the design stage, the verifier is required to submit a report on the preliminary verification of EEDI. Stage of Sea Trials A copy of the NOx Technical File, the final displacement table, the measured lightweight, or a copy of the survey report of deadweight, must all be submitted by the ship owner prior to the sea trial. The verifier must be present for the sea testing to verify (IMO, 2009):

i. Propulsion and power supply system;
ii. Particulars of the engines;
iii. Other relevant items described in the EEDI Technical File;
iv. Draft and trim, sea conditions; and Ship speed, shaft power of the main engine.

The verifier is to issue the report on the verification of EEDI after verifying the attained EEDI after the sea trial and it is proposed to issue an International Energy Efficiency (IEE) certificate.

2.1.4 Energy Efficiency and Environment

Since the late 1980s, the IMO has concentrated on preventing air pollution. The reduction and regulation of greenhouse gases (GHGs) released by ships has recently received attention, according to IMO (2008). The Marine Environment Protection Committee (MEPC) has recently talked about two primary activities. Review of the CO2 Operational Index Guidelines comes first. The second, important to this project, entails creating a required Design CO2 Index for new ships. According to IMO (2008), a worldwide agreement on certain topics should be reached by December 2009, and the new regime should take effect by 2012. The main idea of the index is to create a method of measuring the energy efficiency of a vessel already at the design stage. The index has a future objective of being a fair base for comparison, thus providing a baseline for requiring a minimum efficiency standard for new ships to be included in upcoming IMO conventions. This common base varies with the ship size and type, IMO – MEPC (2008). The definition of efficiency, in this case, has been proposed by IMO (2008) as Efficiency = Environmental Cost / benefit for the society. Here, the benefit to society is defined as the matching transportation work, while the environmental cost is defined as the CO2 released by the ship. The distance sailed times the load capacity determines this task. According to IMO (2008), the IMO methodology additionally takes into account the following ship operating conditions:

i. Continuous operation at 75% of the MCR (using the total installed power).
ii. Considers only the “Sailing” states in the continuous period of time (24/7/365). Transport work based on full cargo capacity utilization.
iii. Sailing continuously at service speed.
iv. A number of correction factors (ice class, shaft generator, heat recovery, etc).

Delivering items is the sole task you should complete during the entire time. However, this definition of the index only includes ships whose primary function is to convey passengers and goods. Other significant ship types, such as icebreakers, tugboats, offshore supply boats, and others, do not meet this criteria. For the vast majority of non-transport boats, the notion of taking a proportion of the total installed power into account is also unfeasible. For instance, AHTS ships may contain several power system redundancies that are only to be activated in certain circumstances. The vessel's energy efficiency will be impacted both directly and indirectly by safety elements like oil recovery and firefighting systems, some of which are likely to need higher volumes, areas, and power capacities. In order to take into consideration more than just the transportation duty that a ship may have, an index that wants to handle all sorts of ships, including the non-transport ones, has to have a distinct definition of usefulness to society. Even the IMO has previously acknowledged the impossibility of having a single work unit for all cargo ships. For instance, RoRo employs g/GTkm (g/distance) whereas Reefer vessels use g/tonkm (g/ton.forcedistance).

2.2 Review of past work

The Energy Efficiency Design Index (EEDI) Performance of a Tugboat Ship was examined by Tokuşlu in 2020. He learned that The International Maritime Organization (IMO) had passed a new policy to stop air pollution from ship emissions that focused on lowering green gas emissions from shipping for current ships and energy efficiency measures for new ships. The Energy Efficiency Design Index (EEDI) is a metric mandated by this new legislation. By burning less fossil fuels and emitting fewer greenhouse gases, this new metric seeks to lower CO_2 emissions and worldwide environmental damage. All new ships that are 400 GT or bigger must use EEDI. In this study, the energy efficiency performance of one of the tugboats in the Turkish maritime commerce fleet was examined. An energy-efficient rating for the ship was discovered. In order to increase a ship's energy efficiency throughout the short, medium, and long terms, several doable suggestions have been made. This study was the first to concentrate on the energy efficiency of a tugboat ship.

The implementation of the Energy Efficiency Existing Ship Index (EEXI) is primarily aimed at enhancing the energy efficiency of newer ships compared to older vessels, with the overarching goal of expediting the global fleet replacement to align with the International Maritime Organization's (IMO) strategy to reduce Greenhouse Gas (GHG) emissions in the maritime sector. This paper begins by providing an overview of the swift development and acceptance of the EEXI as a fresh mandate within the International Maritime Organization (IMO) to address the reduction of carbon intensity in existing ships. Furthermore, it emphasizes the noteworthy level of non-compliance within the current global fleet, necessitating attention that is at least as critical as that given to the Energy Efficiency Design Index (EEDI). Finally, the paper delves into an examination of potential measures for improving a ship's EEXI performance, followed by a detailed discussion of the technical challenges associated with EEXI implementation. These challenges include considerations related to Engine Power Limitation (EPL), the assessment of minimum propulsion power, power reserve, and the determination of reference speed (Liu et' al. 2021).

The Influence of EEDI (Energy Efficiency Design Index) on Ship Engine Propeller Matching was examined by Ren, Ding, and Sui in 2019. They discovered that tougher standards are imposed on the propulsion system design of conventional ships as a result of the world's stricter GHG (greenhouse gas) emission rules. Ship-engine-propeller matching, which is crucial to the design, building, and operation of ships, accounts for the majority of their total CO_2 emissions. In the first part of this study, a platform for matching ship propulsion systems based on the ship-engine-propeller matching concept and its use with the WinGD 5–52 marine diesel engine have been examined. It is crucial to comply with the energy efficiency design index (EEDI) legislation used to determine the ship's CO_2 emissions, and ship-engine-propeller matching must be done taking EEDI into account. In order to examine the link between EEDI and ship-engine-propeller matching, a technique is created that combines the system matching theory and EEDI computation. This procedure can offer the matching results as well as the associated EEDI value. A thorough study was also carried out to determine the link between EEDI and system matching factors including ship speed, effective power, and propeller diameter, reflecting the trend and magnitude of EEDI while altering these three parameters. The system matching parameters that satisfied the various EEDI stages showed the initial value selection in the matching process to serve as a guide for the design of ships, engines, and propellers in accordance with the EEDI requirements.

Hassan et al. (2020) investigation of the use of the energy efficiency design index and its effects on Reefer vessel design. He learned that the Energy Efficiency Design Index (EEDI) measures how much carbon dioxide a ship releases in relation to the cargo it is carrying. As a requirement of the Kyoto Protocol, the international Maritime Organization (IMO) approved EEDI in order to decrease the emission of Green House Gases (GHGs) by shipping. As of January 1, 2013, all new ships with a gross tonnage of 400 or more must meet the EEDI's basic standards. All new ships must meet this index's minimum energy efficiency standard, which is stated in tonnes of CO_2 emitted per "Capacity Mile." The article sought to determine how EEDI affected the hydrostatics and design characteristics of Reefer vessel ships. The current IMO formulation and guidelines are used to compute EEDI. The final presentation of the data showed how altering ship design factors including length (LWL), beam (BMLD), draught (T), and prismatic coefficient (CP) affected EEDI and hydrostatics. Since there have been objections to this index from the start, an attempt is also made to examine the objections to the EEDI formulation, guidelines, and reference line.

The feasibility of extending the Energy Efficiency Design Index to handle non-transport vessels was looked into by Gaspar and Ekrikstad in 2020. They discovered that the present environmental concerns need attempts to increase the marine industry's energy efficiency, necessitating design changes to new ships. At this time, the emphasis is on transportation boats, and the International Maritime Organization (IMO) plans to introduce an obligatory energy efficiency design index by the end of 2009. Longer ahead, it's probable that more types of vessels—like offshore support vessels—will be added. A different index calculation approach than the one that the IMO has actually recommended will be needed due to the nature of both the construction and operation of these vessels.

The criticality of shipping operations in global trade requires a comprehensive understanding of its sustainability. This depends on the integrity/performance of the ship structure and vital systems, such as the ship propulsion engine. The current research paper presents the application of an adaptive machine learning formalism, the Bayesian network, for failure assessment of a ship propulsion engine considering nonlinear and nonsequential failure interactions. The model captures critical failure influencing factors and their complex interactions to predict the failure probability of the ship energy system. Sensitivity and uncertainty analysis was carried out to establish the degree of influence of vital failure influencing factors as they affect the ship propulsion engine's reliability and the associated uncertainty in the prior data processing. The model is tested on the propulsion engine of an ocean going vessel to forecast the likelihood of failure based on the logical dependencies among failure causative factors. Two scenarios were analyzed based on canonical probabilistic algorithms, and the results show that upon evidence on the three critical failure modes, the ship propulsion engine failure likelihood increased by 11.8%, 8.2%, and 9.4%, respectively. The model shows an adaptive/dynamic capability to capture new failure information and update the system's failure probability. The proposed approach provides a condition monitoring tool and early warning guide for integrity management of critical ship energy systems (Chuku et'al., 2023).

The Marine Energy Efficiency Design Index (EEDI) is recognized as an effective stratagem to measure the level of carbon emissions from ships at home and abroad. It will play an important role in the assessment of carbon emissions from the shipping industry, especially under the current and future improvement goal of carbon neutrality. Various green technologies to lessen the carbon emissions of ships have been demonstrated and applied. Hybrid power system is one of them. Compared with traditional direct propulsion, it can considerably diminish the energy consumption and carbon emissions of ships. Constructed on the characteristics of the hybrid power system, this paper carefully and firstly examines the power categories of the hybrid power system during ship navigation. Then, according to the principle and elements of EEDI calculation method, it puts forward the key problems that should be solved in ship EEDI calculation of hybrid power system.

Then, according to different hybrid procedure categories, it also puts forward the calculation method of EEDI of each power mode and the calculation technique of acquired EEDI of hybrid ship. Finally, the calculation and analysis of a 7500DWT hybrid bulk carrier show that the EEDI calculation method for hybrid ships suggested in this paper is scientifically justifiable (Zhifang Wang *et al*, 2021).

They examined some of the major shortcomings of the present methodology in this work and suggested an expanded model as a replacement that takes into consideration the unique properties of these vessels. A number of functions connected to the vessel's primary missions were outlined under the suggested model. The labor, or utility, displayed by these functions was then translated to a matching measurement of the function's need for direct and indirect electricity as well as the resulting CO_2 emissions. The last section included a case study of an anchor handling tug and supply vessel (AHTS), which included an index and key operating characteristics.

Based on the current reduction factor modification strategy, Ancic and Estan (2015) assessed the CO_2 emission from General-Cargo carriers.Other measures and some novel ideas were also considered, and each scenario's CO_2 output was assessed. Jack (2011) investigated how the energy efficiency design index (EEDI) affected the CO2 emissions of very large crude carriers (VLCCs). They discovered that, compared to no regulation at all, the adoption of EEDI would cause a modest rise in VLCC CO_2 emissions over the course of a market cycle. According to their findings, a $50 per ton CO_2 bunker tax would cut VLCC CO_2 emissions by more than 6% over the course of a market cycle without requiring the world to invest 30% more resources in a fleet of vastly increased, underpowered, and overdriven VLCCs.

Attah and Bucknall (2015) examined future LNG carrier powering alternatives in light of the Energy Efficiency Design Index (EEDI) and looked into the potential effects of the EEDI rule, which is set to go into effect in September 2015, on LNG design. Because the Dual Fuel Diesel Electric (DFDE) propulsion currently proposed to be installed on the majority of future LNGC orders already achieves EEDI values that are compliant with the EEDI baseline, they found that the current EEDI reference baseline was insufficient to stimulate improvements in the design of future LNGCs. They also suggested ways to incorporate methane slip emissions into the EEDI calculations as they are now done.

In a novel method proposed by Longva et al. (2010), a needed index level (IR) was established by evaluating the cost-effectiveness of the available reduction options. They used eleven emission reduction strategies to examine the new panamax general-cargo carrier ship. On the basis of the feasible emission reductions and the cross-sector potential for attaining a worldwide reduction target, they came to the conclusion that the expenses imposed by additional restrictions might be justified. In the field of ship energy efficiency, Tien (2015) developed the EEDI Index for the Ropax carrier with ship name M/V Jules Garnier and suggested improvements to ship energy efficiency.

They suggested several actionable cost-cutting initiatives. EEDI for inland boats in Bangladesh was reviewed by Zakaria and Rahman in 2016. They evaluated the CO_2 emissions of 36 ferries, 70 Reefer vessels, 247 passenger ships, 526 cargo ships, and 526 cargo ships. Investigations on the impact of EEDI on vessel draft, fuel type, block coefficient, specific fuel consumption (SFC), and power have led to some workable ideas for how to improve the hull form of some current boats in order to lessen the negative impacts of CO_2 emission. Overall, all of these studies concentrated on the energy efficiency of both new and existing ships and demonstrated the usage of EEDI implementations in accordance with authorized changes.

In this paper, the authors recommend amendments to the current EEDI regulations, which includea an alternative EEDI formulation that does reflect a representative ship operational profile with multiple engine operating points, related to IMO's approach to NOx regulation. The proposed formulation targets to make EEDI calculations more realistic and representative with regard to fuel consumption and emissions performance at the design stage. An EEDI calculation based upon an operational profile is also important in view of the Carbon Intensity Index (CII), that has recently come into force, for the exploitation stage of ships. The paper also addresses the issue of underpowered ships by allowing for a larger engine margin to be selected for improved safety in adverse weather conditions without impairing carbon emissions. The authors provide an example of a benchmark chemical tanker to illustrate the proposed amendments, highlighting the benefits of a larger engine margin for both emissions and safety (Sui et’ al, 2023).

Lee et’ al.(2021) have introduced an innovative approach for estimating the Energy Efficiency Design Index (EEDI) by considering the integration of an Onboard Carbon Capture and Storage (OCCS) system on ships. The OCCS is designed to capture and store carbon dioxide (CO2) emitted from a ship's internal combustion engines, involving CO2 capture, liquefaction, and storage in a dedicated tank. The study also investigated the current state of greenhouse gas regulations for maritime vessels discussed at the International Maritime Organization. Their research includes a modified EEDI estimation formula and calculation method considering OCCS integration. Case studies on a container feeder vessel were conducted in compliance with EEDI regulations. The CO2 capture process utilized chemical absorption with an activated methyldiethanolamine solution, and the captured CO2 was liquefied using cold energy from liquefied natural gas and ammonia. To improve storage system efficiency, a prismatic pressure vessel was chosen for the CO_2 storage tank. The findings suggest that the required CO2 capture ratio in the process exceeds the actual EEDI reduction rate.

Gucma, Deja and Szymonowicz (2023) noted the following environmental and economic benefits of EEDI; Reduced GHG Emissions, Minimized Environmental Impact, Sustainable Maritime Fleet, Conceptual Solutions, Reduced Fossil Fuel Consumption and Feasibility Assessment.

The International Maritime Organization (IMO) has introduced three regulatory measures to enhance the energy efficiency of the global maritime fleet and reduce CO2 emissions. These measures include the Energy Efficiency Design Index (EEDI), the Energy Efficiency Existing Ships Index (EEXI), and the Carbon Intensity Index (CII). The EEDI, initially applied to newbuilds in 2013, became a reference point for energy efficiency standards with phased adoption and clear enforcement mechanisms. The EEXI has equalized power reduction onboard across vessels and brought older vessels in line with EEDI-compliant ones. The CII emphasizes operational efficiency, requiring collaboration among stakeholders for improved ratings (Fonden, 2023).

Amid contemporary economic and environmental challenges, this paper highlights the heightened emphasis on energy efficiency. It offers a comprehensive overview of energy efficiency within the maritime sector, encompassing individual vessels and the industry as a whole. The paper investigates the regulatory framework, explores ship-based measures to reduce fuel consumption and emissions, considers industry-wide advancements, and examines the hurdles in implementing these measures. While current standards are seen as interim, further research is needed for substantial improvements. Nevertheless, the ongoing efforts underscore the maritime sector's potential for optimization, making this review a valuable primer for studies seeking insights into the sector's energy efficiency status (Barreiro et’ al. 2022).

For several decades, the global shipping industry has been an integral part of the broader effort to decarbonize various sectors. The sector is now committed to a substantial reduction of emissions, aiming to achieve a 40% decrease by 2030 compared to 2008 levels. Regulatory mechanisms like the MARPOL 73/78 Convention, the Energy Efficiency Design Index (EEDI), and existing monitoring and management schemes, such as the Ship Energy Efficiency Management Plan and the Energy Efficiency Operational Indicator, are pivotal in measuring fuel consumption and engine emissions. The Energy Efficiency Existing Ship Index (EEXI), expected to be enforced in 2023, aligns with the broader decarbonization objectives set by the International Maritime Organization, targeting a 70% reduction in emissions by 2050, using the 2008 baseline. Achieving these targets may entail reducing ship speeds, considering fleet downsizing, and replacing older vessels with more efficient ones. These changes come with significant costs for the industry, affecting shipping expenses and, ultimately, consumer costs (Czermański, 2022).

2.3 Knowledge Gap

The studies of earlier research relied on theoretical calculations and assumptions rather than model resistance tests to ascertain the actual resistance and real effective power of ships. Additionally, prior research did not pay specific attention to the combined impact of design factors, resistance, and hydrostatic details on a ship's energy usage. This study highlights the elements needed to regulate shipping-related CO_2 emissions. And as such analytical comparison is done on fuel consumption, carbon emission, and total power needs as consequences of inadequate ship design parameters and hydrostatics because the fundamental formulation of EEDI is based on the ratio of total CO_2 emission per tonne.

Given that there is now much discussion on whether the implementation of the EEDI would actually cut CO_2 emissions or not, an attempt is therefore necessary to assess the criticism of the current EEDI formulation, guidelines, and reference data for different vessels.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Materials

3.1.1 Ship Selection

The chosen ship classes, which are the biggest and use the most fuel in shipping, are covered by the EEDI implementation in this effort. This research excludes ships using hybrid, steam, and diesel-electric propulsion systems. These following ship types were used for this analysis;

a. Roll-on passenger carrier (Ropax);
b. Tugboat and;
c. Reefer vessel.

The specifications of the vessels above are presented in table 3.1

3.1.2 Tool Selection

Microoft Excel software tool was utilized to compute the resistance, effective power, and propulsion power of the ship, followed by the EEDI, in order to comprehend the effects of EEDI on ship design parameters and hydrostatics. Making parametric evaluations for all sorts of ships that take into account the most recent EEDI formulations and IMO standards is achievable with this tool.

3.1.3 Ship Design Parameters

There are three parameters that keep boats and ships on (or just above) the water, viz; the weight of the water displaced, the lift created by the foil moving through the water rises with the speed of the vessel until the vessel is foil carried, which is important to know when designing ships and the total displacement of the vessel which pushes downwards on the water's surface. When the strength of the upward and downward forces are equal, a vessel is in balance.

A vessel's weight doesn't change when it is lowered into the sea, but the amount of water that is displaced by its hull does. The boat floats when the two forces are equal. The forces are the weight of the water displaced and the total displacement of the vessels. It floats without trim or heel if weight is distributed equally across the whole vessel.

Table 3.1: Specification of the various ship types that are used for this study

Ship Type	**Vessel Speed -V (knots)**	**Length (m)**	**Froude Number (Fn)**	**Beam (m)**	**Draft (T)**	**L/B**	**B/T**	**C_P**	**C_B**
Ropax carrier	12	94.5-	0.14-0.21	16.0-	4.67-	5.9	3.43	0.73	0.70
	24	200	0.15-0.29	30.64	6.10	6.5	5.01	0.78	0.72
Tugboat vessel	12	32.7-	0.13-0.20	12.82-	5.90-	2.6	2.20	0.60	0.57
	18	40.0	0.25-0.39	14.00	6.20	2.9	2.25	0.65	0.60
Reefer vessel	12	135-	0.12-0.16	20.60	5.22-	6.5	3.94	0.83	0.65
	24	200	0.18-0.24	30.64	6.10	5.9	5.01	0.88	0.70

Source: (Aniete, 2019)

3.1.4 Ship Hydrostatics Considerations

The hydrostatic performance of a vessel is highly dependent on its maneuvering waterways. The existence of the banks and bottom, as well as the presence of the other vessels, could have a significant influence on a ship’s hydrostatic behaviour. The parameters which determine a ship’s hydrostatic performance include; Vessel speed (Vs), Vessel draft (T), Ship beam (B), Prismatic

Coefficient (C_P) and Block Coefficient (C_B). In order to understand the effect of each parameter, a systematic parameter study is indispensable.

3.2 Method

3.2.1 Theory of Energy Efficiency Design Index (EEDI) of the Ship

To gauge a ship's energy efficiency, the International Maritime Organization (IMO) placed the EEDI into legislation. The projected CO_2 emissions generated per unit of travel during the ship design process are measured by a ship's EEDI; the lower the EEDI, the lower the CO_2 emissions. EEDI is based on a complex algorithm that considers the emissions, capacity, and speed of the ship. The International Council on Clean Transportation (ICCT)'s definition of EEDI states that it can be calculated, as shown by Equation (3.1), and Figure 3.1 shows the equipment's computing power. P stands for the individual engine power at 75% of Maximum Continous Rating (MCR), C for the CO_2 emission factor based on the fuel type used by the specified engine, SFC for the specific fuel used per unit of engine power, certified by the manufacturer, and f for the non-dimensional factors that were added to the EEDI equation to account for some particular existing conditions. Deadweight tonnage (DWT) of a ship is its capacity, and its maximum design load speed is Vref.

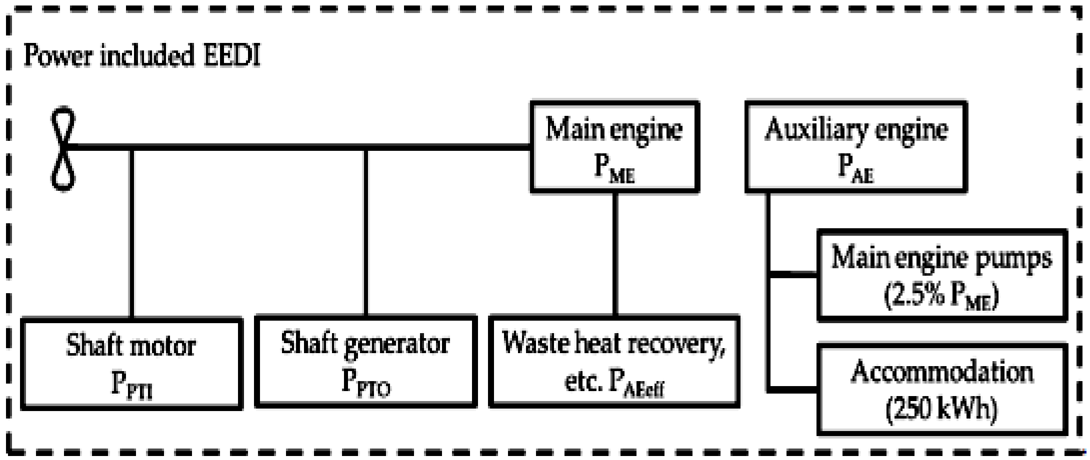

Figure 3.1. The power flowchart in the calculation of energy efficiency design index (EEDI).

3.2.1.1 Description of Energy Efficiency Design Index (EEDI)

The expression for determining emissions from the Main Engine is as seen in equation (3.1);

Emission from the Main Engine = $\left(\prod_{j=1}^{M} f_i\right) * \left(\sum_{i=1}^{nME} P_{ME(i)} * C_{FME(i)} * SFC_{ME(i)}\right)$ (3.1)

The expression for determining emissions from the Auxiliary Engine is as seen in equation (3.2);

Emission from Auxiliary Engine =$(f_{AE} * C_{FAE} * SFC_{AE})$ (3.2)

The expression for determining emissions from the shaft motor is as seen in equation (3.3);

Emission from shaft motor = $(\prod_{j=1}^{M} f_i) * (\sum_{i-1}^{nPTI} PTI(i) - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEeff(i)}\big) * C_{FAE*}SFC_{AE}$ (3.3)

The expression for determining efficient technology reduction is as seen in equation (3.4);

Effficient technology reduction = $\left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)$ (3.4)

The expression for determining capacity and reference speed is as seen in equation (3.5);

Capacity multiplied with the reference speed = $f * DWT\ Capacity * V_{ref} * f_w$ (3.5)

The expression for determining Energy Efficiency Design Index (EEDI) is as seen in equation (3.6);

$$\text{Energy Efficiency Design Index (EEDI)} = \frac{CO_2\ Emission}{Transport\ work}\left\{\frac{gCO_2}{Tonne*nautical\ mile}\right\} \tag{3.6}$$

$$= \frac{Power * Specific\ fuel\ consumption * CO_2 conversion\ factor}{Capacity * Speed}$$

Combining equations (3.1), (3.2), (3.3),(3.4) and dividing by equation (3.5);

$$= \frac{Emission\ from\ Main\ Engine + Emission\ from\ Auxiliary\ Engine + Emission\ for\ running\ shaft\ motor - Efficient\ Tech.\ Reduction}{Capacity * Reference\ Speed}$$

$$= \frac{\left(\prod_{j=1}^{M} f_i\right)*\left(\sum_{i=1}^{nME} P_{ME(i)}*C_{FME(i)}*SFC_{ME(i)}\right)+\left(f_{AE}*C_{FAE}*SFC_{AE}\right)+\left(\prod_{j=1}^{M} f_i\right)*\left(\sum_{i-1}^{nPTI} PTI(i)-\sum_{i=1}^{neff} f_{eff(i)}*P_{AEeff(i)}\right)*C_{FAE}*SFC_{AE} - \left(\sum_{i=1}^{neff} f_{eff(i)}*P_{eff(i)}*C_{FME}*SFC_{ME}\right)}{f*DWT\ Capacity*V_{ref}*f_w} \tag{3.7}$$

$$\left[\frac{k_w*\frac{g_{fuel}}{kwhr}*\frac{gCO_2}{g_{fuel}}}{Tonne*nauticalmile/hr}\right] \quad \left[\frac{gCO_2}{Tonne*nautical\ mile}\right]$$

Where;

C_F, non-dimensional Conversion Factor between fuel consumption measured in g and CO_2 emission also measured in gram based on carbon content.

Mei, Main Engine (kW)

AEi, Auxiliary Engine (kW)

V_{ref}, Ship speed (knot)

Dwt, Deadweight or Capacity (Tonne)

P, Power of the main and auxiliary engines, measured (kW)

$P_{ME(i)}$, 75% of the rated installed power (MCR) for each main engine (kW)

$PPT_{(i)}$, 75% output of each shaft generator installed (kW)

$P_{eff(i)}$, 75% of the main engine power reduction due to innovative mechanical energy efficient technology

$P_{AEeff(i)}$, Auxiliary power reduction due to innovative electrical energy efficient technology

P_{AE}, Auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation.

SFC, Specific fuel consumption, measured in g/kWh, of the engines. The subscripts ME(i) and AE(i), refer to the main and auxiliary engine(s), respectively.

Fj, Correction factor to account for ship specific design elements. fj should be taken as1.0.

fw, Non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed. fw should be taken as one (1.0)

$f_{eff(i)}$, Availability factor of each innovative energy efficiency technology. f_{eff}(i) for waste energy recovery system should be 1.

fi, Capacity factor for any technical/regulatory limitation on capacity, and can be assumed one (1.0) if no necessity of the factor is granted.

3.2.1.2 Conversion Factor, C_F

Fuel consumption in grams and CO_2 emissions, which are likewise measured in grams based on carbon content, are converted using the non-dimensional factor CF. The main and auxiliary engines are denoted by the subscripts MEi and AEi, respectively. CF is the fuel identified in the relevant EIAPP Certificate as the one utilized to calculate SFC. Table 3.2 provides the conversion factor values, or CF.

Table 3.2: C_F values for different types of fuel.

Type of fuel	Reference	Carbon content	C_F (t-CO2/t-Fuel)
Diesel/Gas Oil	ISO 8217	0.875	3.206
Light Fuel Oil (LFO)	ISO 8217	0.86	3.15104
Heavy Fuel Oil (HFO)	ISO 8217	0.85	3.1144
Liquefied Petroleum Gas (LPG)	Propane	0.819	3.0
	Butane	0.827	3.03
Liquefied Natural Gas (LNG)	Ethane	0.75	2.75

3.2.2 Hughes–Prohaska Method for Resistance and Effective Power Determination

The Hughes-Prohaska method for estimating the approximate resistance and power in displacement and semi-displacement vessels are extremely well known. The method is based on the hydrostatic theory and use coefficients found by a regression analysis of the outcomes of 334 tests on ship model. Since Ropax, Tugboat, and Reefers are displacement vessels, this strategy works well for them. This approach decomposes the total resistance coefficient as follows:

$$C_T = (1 + k) * C_{FO} + C_w \tag{3.8}$$

Where C_T is the total resistance coefficient, (1+k) is the form factor, C_{Fo} is the frictional coefficient and C_w is the wave resistance coefficient.

Both form factor (1 + k) and wave resistance coefficient C_w are assumed to be the same for model and full scale, i.e. independent of Reynolds's number (Rn). The model test serves primarily to determine the wave resistance coefficient. The procedure is as follows:

1. Determine the total resistance coefficient (C_{Tm}), in the model test from the ITTC 1957 method:

$$C_{Tm} = \frac{R_{T_m}}{\frac{1}{2}\rho_m * V_m^2 * S_m} \tag{3.9}$$

2. Determine the wave resistance coefficient C_w, same for model and ship:

$$C_w = C_{Tm} - C_{F0m} * (1 + k) \tag{3.10}$$

3. Determine the total resistance coefficient C_{Ts}, for the ship:

$$C_{Ts} = C_w + C_{Fos} * (1 + k) + C_A \tag{3.11}$$

4. Determine the total resistance R_{Ts}, for the ship:

$$R_{Ts} = C_{Ts} * 1/2 \rho_S V_s^2 S_s \tag{3.12}$$

The frictional coefficients C_{F0}, for flat plates are determined by Hughes' formula:

$$C_{F0} = \frac{0.067}{(log_{10} R_n - 2)^2} \tag{3.13}$$

The correlation coefficient C_A differs fundamentally from the correlation coefficient for the ITTC 1957 method. Here C_A does not have to compensate for scaling errors of the viscous pressure resistance. ITTC recommends universally $C_A = 0.0004$.

The Hughes–Prohaska method is a form factor method. The form factor (1+ k) is assumed to be independent of Froude number, F_n and Reynold's number, R_n and the same for model and ship (Melmet, 2013).

The form factor is determined by assuming:

$$\frac{C_T}{C_{F0}} = (1 + k) + \alpha \frac{F_n^4}{C_{F0}} \tag{3.14}$$

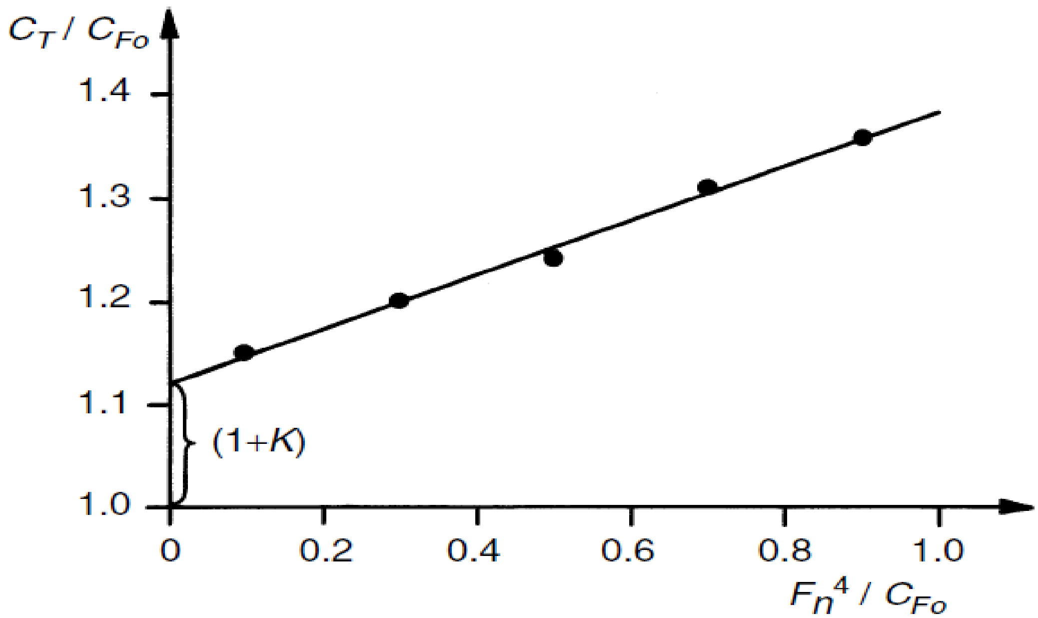

Figure 3.2: Extrapolation of form factor (Melmet, 2013)

Model test results for several Froude numbers (e.g. between 0.12 and 0.24) serve to determine ¸ in a regression analysis. For this analysis, assumption will be made to the effect that the form factor, 1+k = 1.12, 1+k = 1.16, and 1+k = 1.13 for Ropax, Tugboat and Reefer vessels respectively.

5. Determine the Effective Power of the Ship;

$$P_e = R_{TS} * V_s \tag{3.15}$$

The Allowable Power with respect to the Maximum Continuous Rating (MCR);

$$P_{MCR} = P_e * \eta_x \tag{3.16}$$

Where P_e is the effective Power, R_{TS} is the total ship resistance and V_s is the design vessel speed and η_x $is\ the\ efficiency\ factor\ for\ Power\ (energy\ generated)$.

3.2.3 Model Resistance Test at the Towing Tank

(i) Procedures for conducting model resistance test

The procedure for conducting Model resistance test at the towing tank of the Centre of Excellence of the Rivers State University, Port Harcourt is extracted from the manual and attached as APPENDIX C.

(ii) Method of estimating Model wetted surface area, Sm

In the absence of a detailed lines plan, it may be useful to estimate the wetted surface area based on a few dimensions. In this desertation, the Mumford's equation will be applied.

Mumford's Equation;

$$S = 1.7LT + C_B LB \tag{3.17}$$

Where; C_B is the block coefficient, L is the length over all of the model, T is the draft of the model and B is the breadth moulded.

(iii) Data of the Models used for the resistance test

Table 3.3: Shows the data of the different models used for the Model resistance test at the Towing tank facility. The data of the models are extrapolated and correlated for the big ships.

Table 3.3: **Data of the model used for the resistance test at the towing tank**

MODEL Particulars	Computed parameters	Units	Ropax	Tugboat	Reefers
Froude Number	Fr		0.14	0.13	0.12
Length of Ship	L	m	94.5	32.7	135
Beam of the Ship, B	B	m	16	14	20.6
Ship Speed, Vs	Vs	knots	12	12	12
Draft of the Ship, T	T	m	4.67	5.9	5.22
Ship Kinematic Viscosity at 15 degrees (1025kg/m2)_Seawater	υ	m2/s	0.00000119	0.00000119	0.00000119
Scale between model and ship	λ		1: 25	1: 25	1:25
Density of freshwater	ρ_{fw}	kg/m3	1000	1000	1000
Density of Seawater	ρ_{sw}	kg/m3	1025	1025	1025
Model Block Coefficient (C_B)	Same for Model & Ship		0.72	0.6	0.7

Model Kinematic Viscosity at 10 degrees (1025kg/m2)_Fresh water	υ	m2/s	0.00000135	0.00000135	0.00000135
Length of the Model, L_M (m)	$L_M = \frac{L}{\lambda}$	m	3.78	1.308	1.69
Model Beam, BM	$B_M = \frac{B}{\lambda}$	m	0.64	0.56	0.824
Model Draft, T_M (m)	$T_M = \frac{T}{\lambda}$	m	0.1868	0.236	0.2088
Model Speed, V_M	$V_M = F_r\sqrt{g.L_M}$	m/s	0.852527583	0.501494774	0.570040735
Model Wetted Surface area, S_M	$SM = 1.7LT + CB * L * B$	m^2	2.9422008	0.9642576	1.5746744
Ship Wetted Surface area, Ss	$S_s = S_M\lambda^2$	m^2	1838.8755	602.661	984.1715

3.2.4 Parameters for determination of reference values for the different ship types

If the design of a ship allows it to fall into more than one of the above ship type definitions, the required EEDI for the ship shall be the most stringent (the lowest) required EEDI. The Reference line values shall be calculated as follows:

Reference line value $= \ a * \ b^{-c}$

Table 3.4: Parameters for determination of reference values for the different ship types

Ship Type Defined in Regulation	a	b	C
Ropax Vessel	961.79	DWT of the ship	0.477
Reefer vessel	2218.80	DWT of the ship	0.488
Tugboat ship	73.22	DWT of the ship	0.201

(MEPC, 2016)

3.2.5 Reduction Factors (in percentage) for the EEDI Relative to the EEDI Reference line

Reduction factor to be linearly interpolated between the two values dependent upon vessel size. The lower value of the reduction factor is to be applied to the smaller ship size, n/a means that no required EEDI applies.

Table 3.5 Reduction factors (in percentage) for the EEDI relative to the EEDI Reference line

Vessel Type	Deadweight Category	Phase 0	Phase 1	Phase 2	Phase 3
	20,000 DWT and above	0	10	20	30
Ropax vessel	5,000 -20,000 DWT	n/a	0-10*	0-20*	0-30*
	55,000 DWT and below	0	10	20	30
	40,000 – 55,000 DWT	n/a	0-10*	0-20*	0-30*
Reefer vessel					
	5,000 DWT and above	0	10	20	30

Tugboat carrier	5,000 – 55,000 DWT	n/a	0-10*	0-20*	0-30*

*Reduction factor to be linearly interpolated between the two values dependent upon vessel size. The lower value of the reduction factor is to be applied to the smaller ship size. N/A means that no required EEDI applies.

3.2.6 Microsoft Excel

Microsoft created the spreadsheet program Excel for use with Windows. The calculating or computing capabilities, graphing tools, pivot tables, and the Visual Basic for Applications macro programming language were used to analyze data from the expirements and was further processed with relevant equations.

The data obtained from the experiments conducted are presented in tables 4.6 to 4.28 in Appendix A, while the results are presented in figures 4.1 to 4.23 in Chapter 4.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The results obtained from the study are presented in figures 4.1 – 4.23 and tables 4.1 – 4.5.

As previously mentioned, the effects of EEDI on ship design parameters and coefficients are examined for three different types of boats. Ropax, Tugboat, and Reefer vessels were picked as case studies because they are the most commonly utilized commercially for shipping the most commodities at sea and for vessel assistance at ports. As a result, they use the most energy and tend to pollute the marine environment the most unintentionally.

4.1.1 Results from the Model Resistance Tests carried out at the Towing tank and the effects of EEDI

The results of the various model resistance tests performed at the towing tank facility of the Centre of Excellence in Marine and Offshore Engineering of the Rivers State University, Port Harcourt, are shown in Table 4.1 in APPENDIX B. The ship to model ratio of 1:25 was used to extrapolate the model findings.

4.1.2 Effects of energy efficicieny design index (EEDI) on ship speed

Particulars considered for the analysis are as shown in the table 4.2. The values displayed in the table are initial computed values, other values can be found in the appendices.

Table 4.2: Change in ship speed

Ship Type	Ship Speed -V (knots)	Effective Power (Pe) (kW)	Displacement (Disp)(Tonne)	Pe/Disp
Ropax	12-24	5880	5000	1.176
Tugboat	12-18	2539	5000	0.5078
Reefer	12-24	5717.33	5000	1.14347

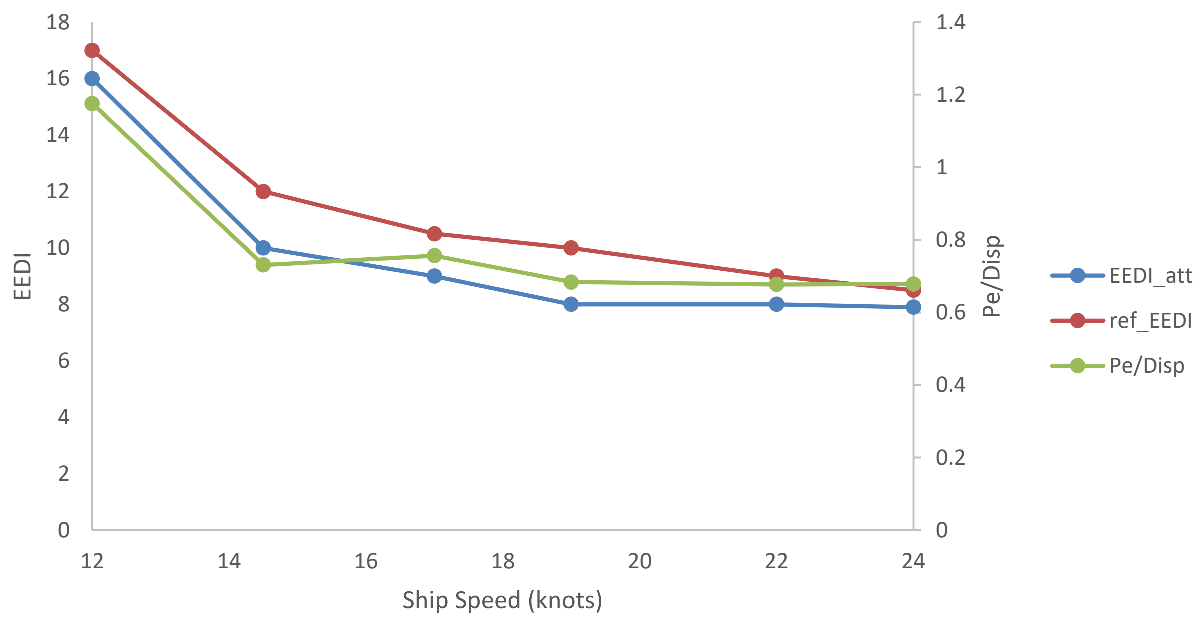

Figure 4.1: Effect of EEDI on speed of Ropax carrier from 12 to 24knots.

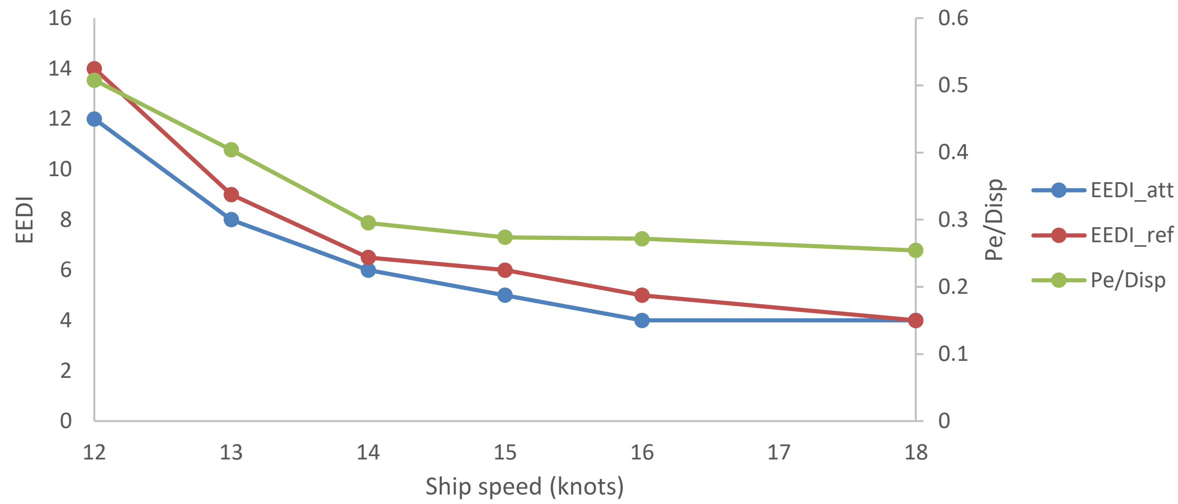

Figure 4.2: Effect of EEDI on speed of Tugboat vessel at 12knots to 18knots

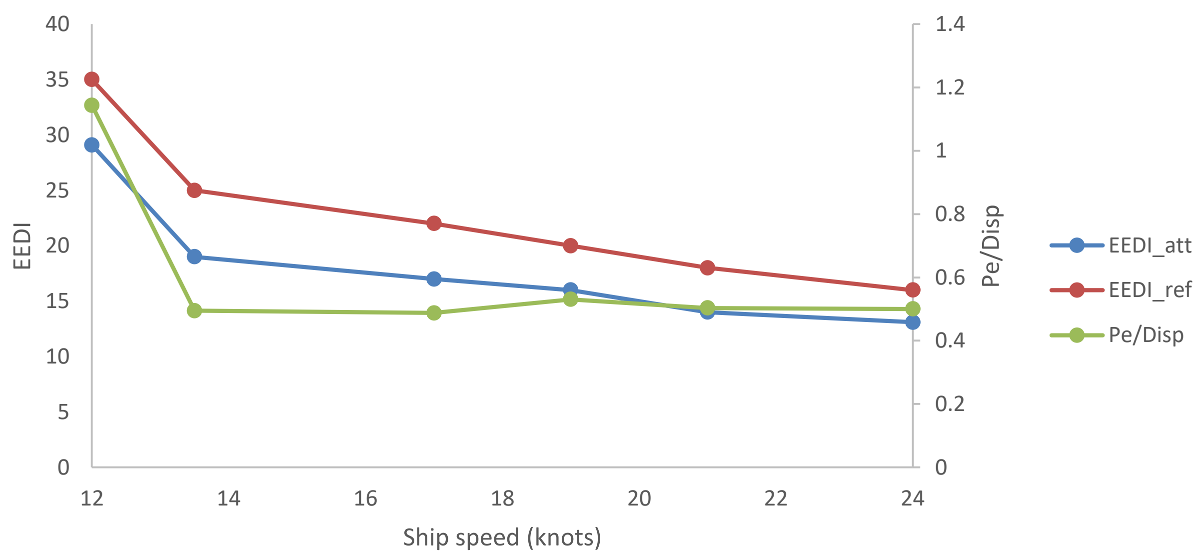

Figure 4.3: Effect of EEDI on Speed of Reefer vessel at 12knots to 24knots.

4.1.3 Effect of EEDI on Change in Waterline Length (LWL) of the ship considered for the analysis

Particulars considered for the analysis are as shown in table 4.3. The values displayed in the table are initial computed values, other values can be found in the appendices.

Table 4.3: Change in waterline length

Ship Type	Length (m)	Effective Power (Pe)	Displacement (Disp)	Pe/Disp
Ropax carrier	94.5 - 200	5880	5000	1.176
Tugboat ship	32.7 - 40	2539	5000	0.5078
Reefer vessel	135 – 200	5717.33	5000	1.14347

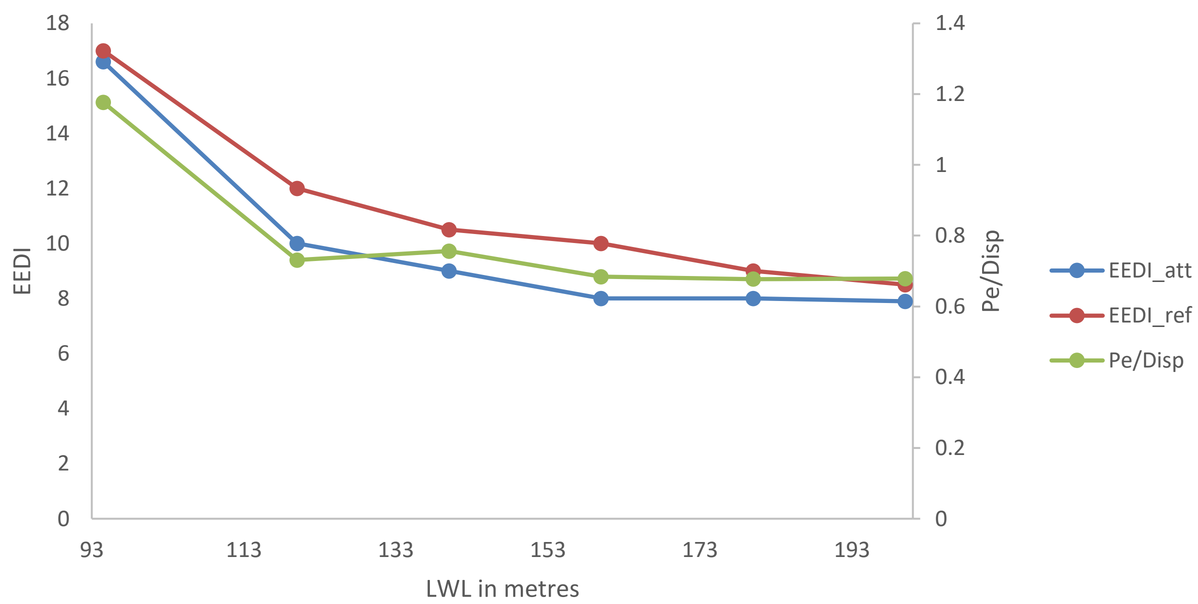

Figure 4.4: Effect of EEDI on Length of Ropax ship at 12knot Speed.

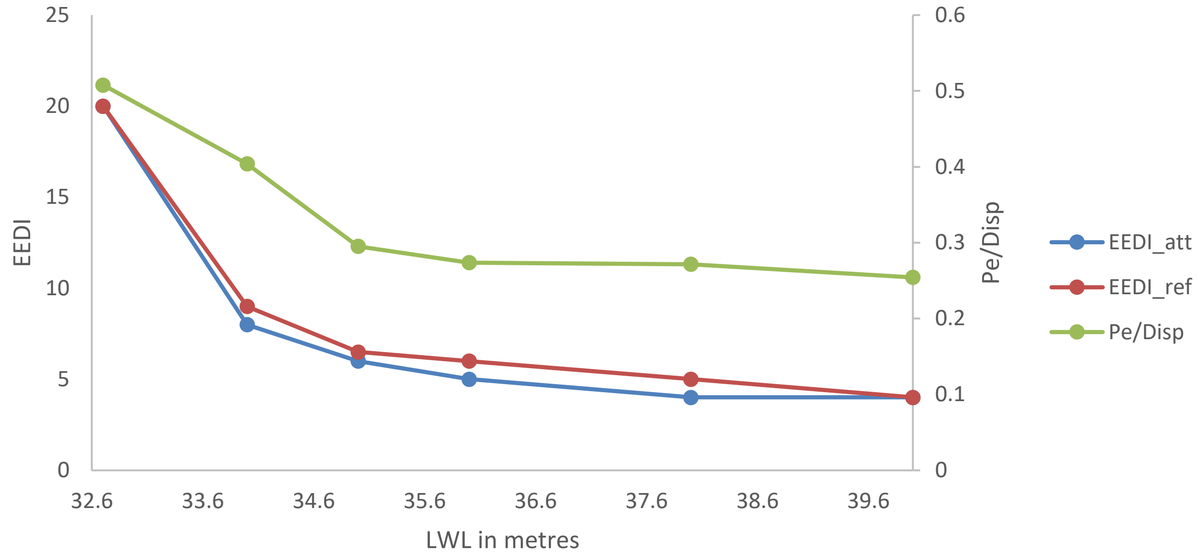

Figure 4.5: Effect of EEDI on length of Tugboat vessel at 12knot Speed.

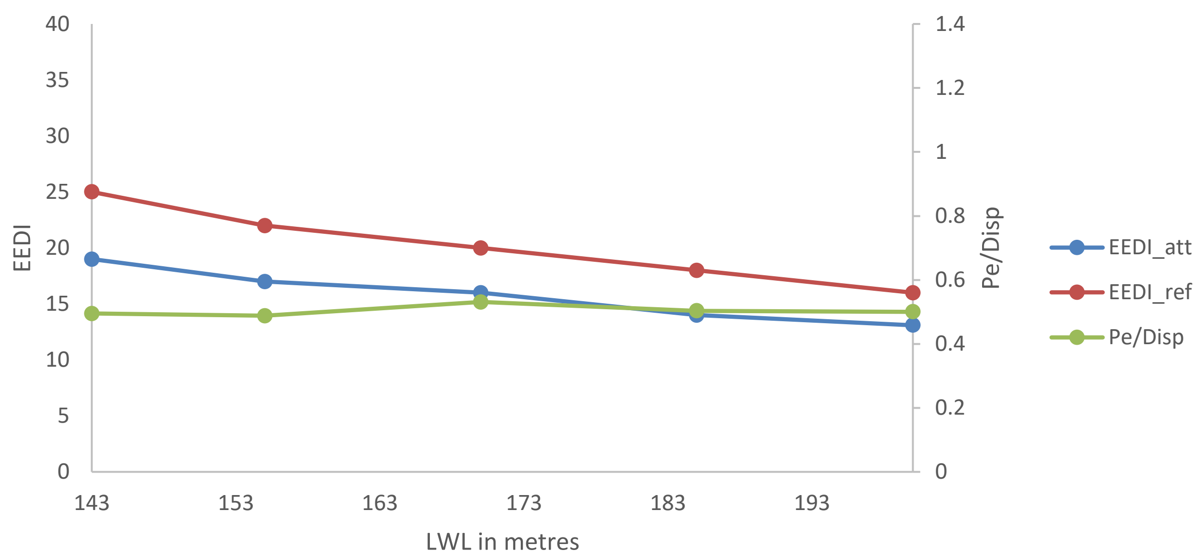

Figure 4.6: Effect of EEDI on length of Reefer vessel at 12 knot .

4.1.4 Effect of EEDI on Change in Beam of Ship Particulars considered for the analysis

The details taken into account for the analysis are shown in table 4.4. Other values can be found in the appendices; the values shown in the table are initial calculated values.

Table 4.4: Change in Beam

Ship Type	Beam (m)	Effective Power (Pe)(kW)	Displacement (Disp) (T)	Pe/Disp
Ropax ship	28.1 - 39.2	5880.0	5000	1.176
Tugboat vessel	22.2 - 33.3	2539.0	5000	0.5078
Reefer vessel	28.0 - 39.2	5717.33	5000	1.14347

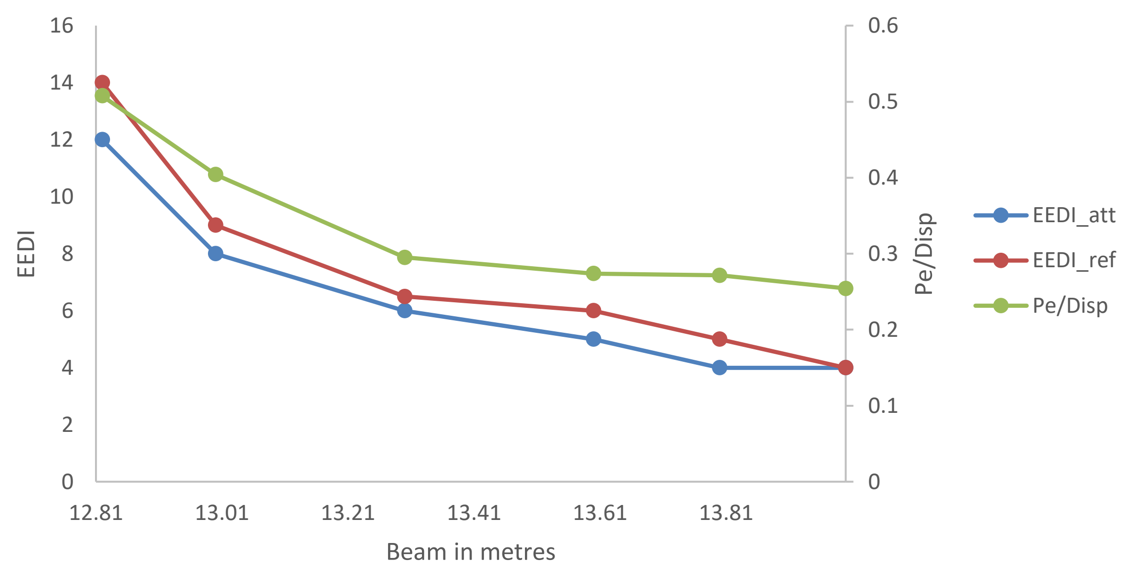

Figure 4.7: Effect of EEDI on Beam of Ropax at 12knot speed.

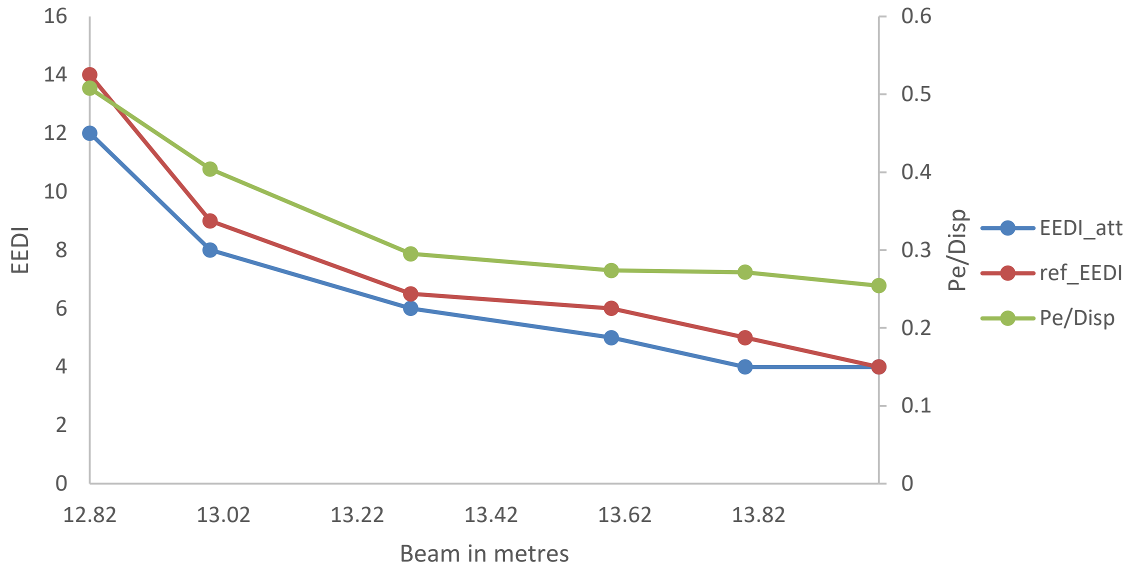

Figure 4.8: Effect of EEDI on Beam of Tugboat at 12knot speed.

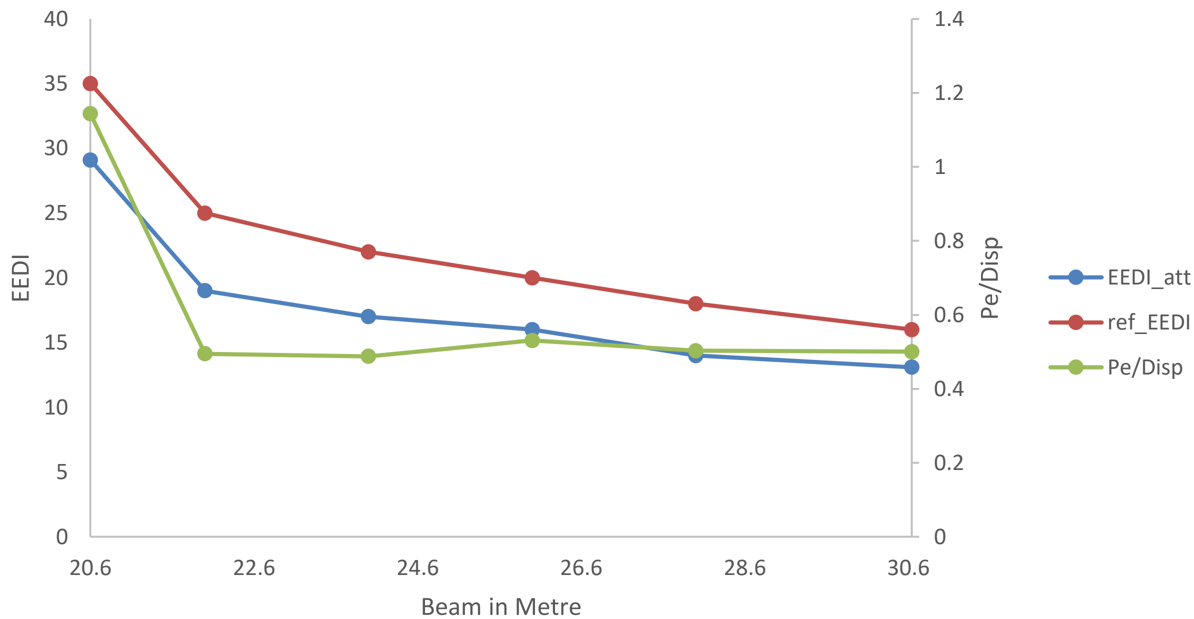

Figure 4.9: Effect of EEDI on the Beam of Reefer vessel at 12knot speed.

4.1.5 Effect of EEDI on Change in draft (T) of the ship types considered for the analysis

Particulars considered for the analysis are as shown in table 4.5. Other values are placed in the appendice section.

Table: 4.5: Change in Draft

Ship Type	Draft (T) (m)	Effective Power (Pe)(kW)	Displacement (Disp)(T)	Pe/Disp
Ropax ship	4.70 - 6.10	5880.0	5000	1.176
Tugboat vessel	5.90 - 6.20	2539.0	5000	0.5078
Reefer vessel	5.22 -6.10	5717.33	5000	1.14347

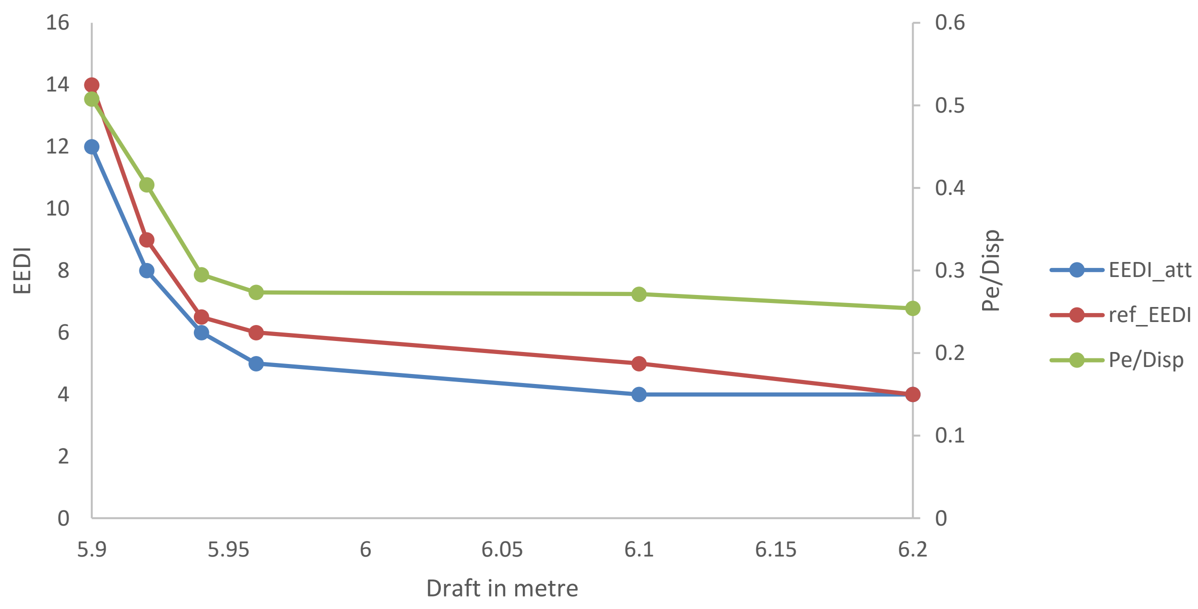

Figure 4.10: Effect of EEDI on Draft of Ropax at 12 knot speed.

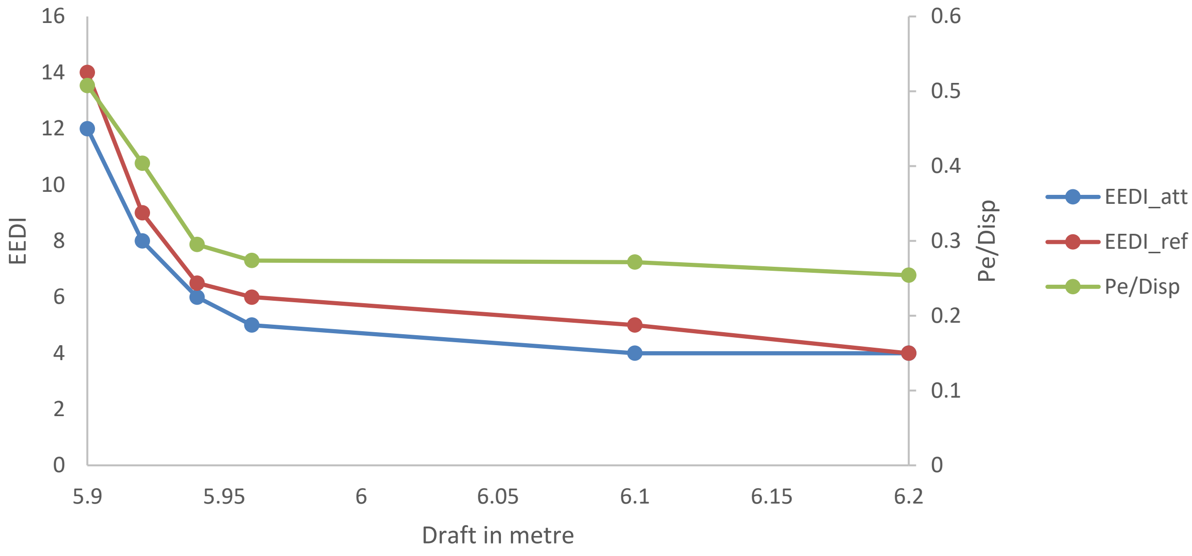

Figure 4.11: Effect of EEDI on Draft of Tugboat at 12 knot speed.

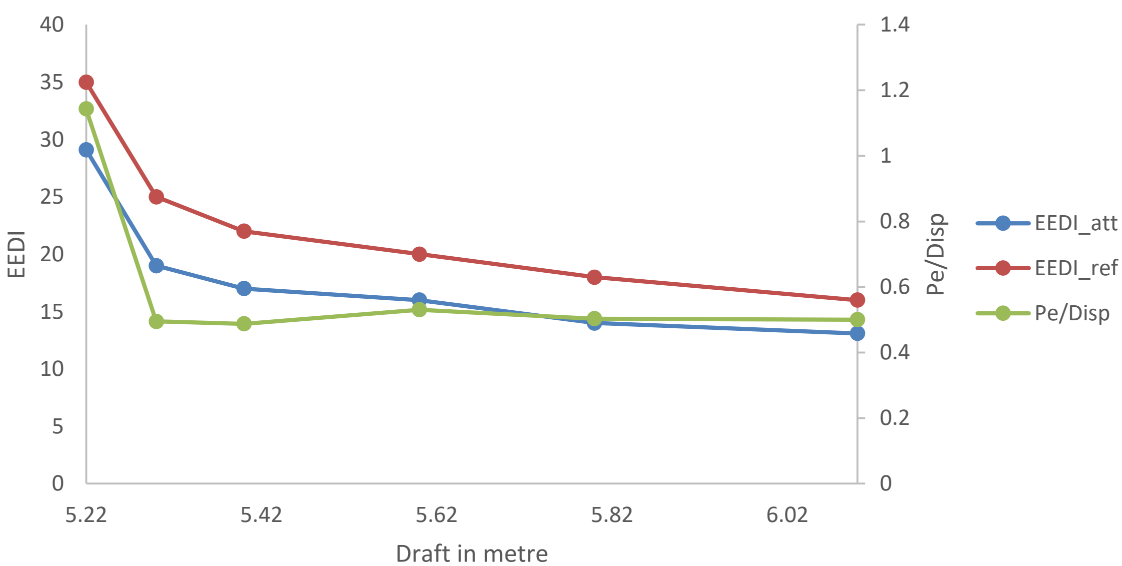

Figure 4.12: Effect of EEDI on Draft of Reefer vessel at 12 knot.

4.1.6 Effect of EEDI on L/B ratio of the ship types considered for the analysis

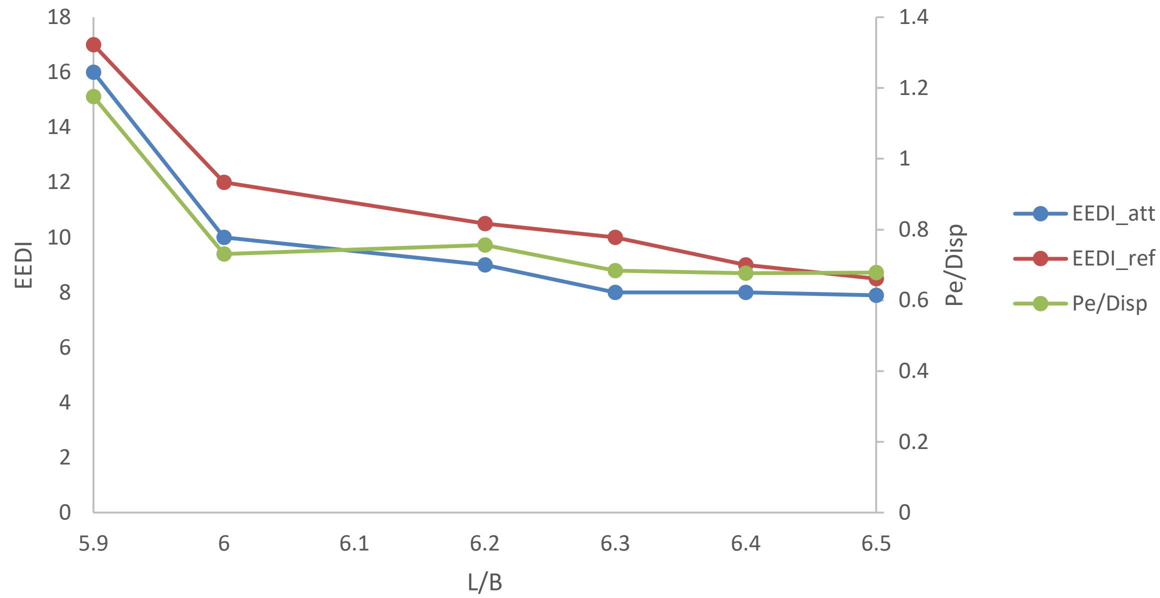

Figure 4.13: Effect of EEDI on L/B of Ropax carrier at the speed of 12 knots

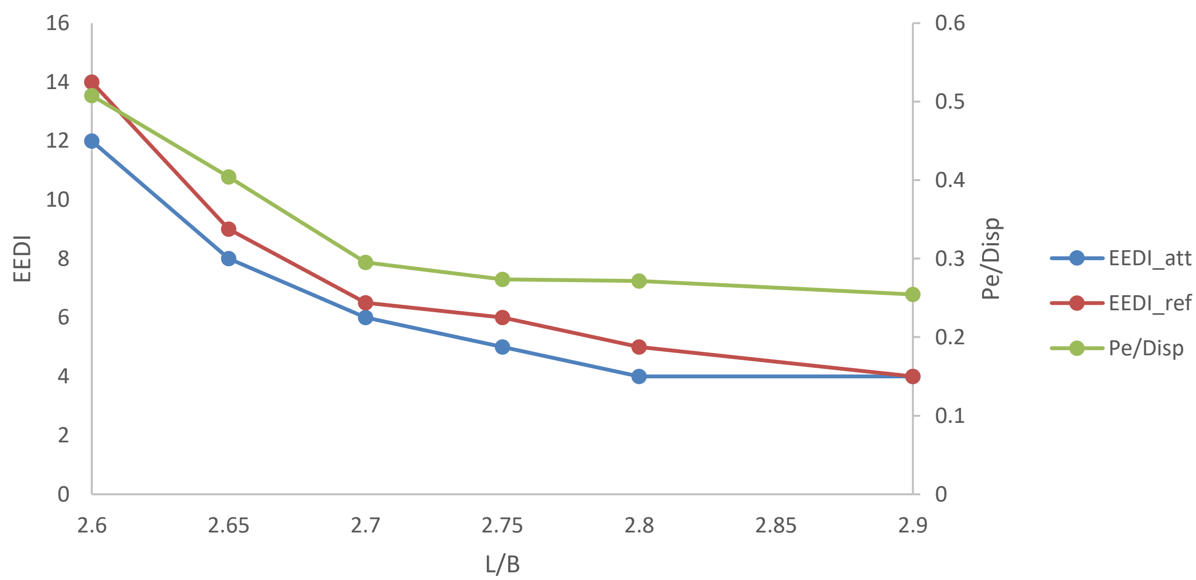

Figure 4.14: Effect of EEDI on L/B of Tugboat vessel at the speed of 12 knots.

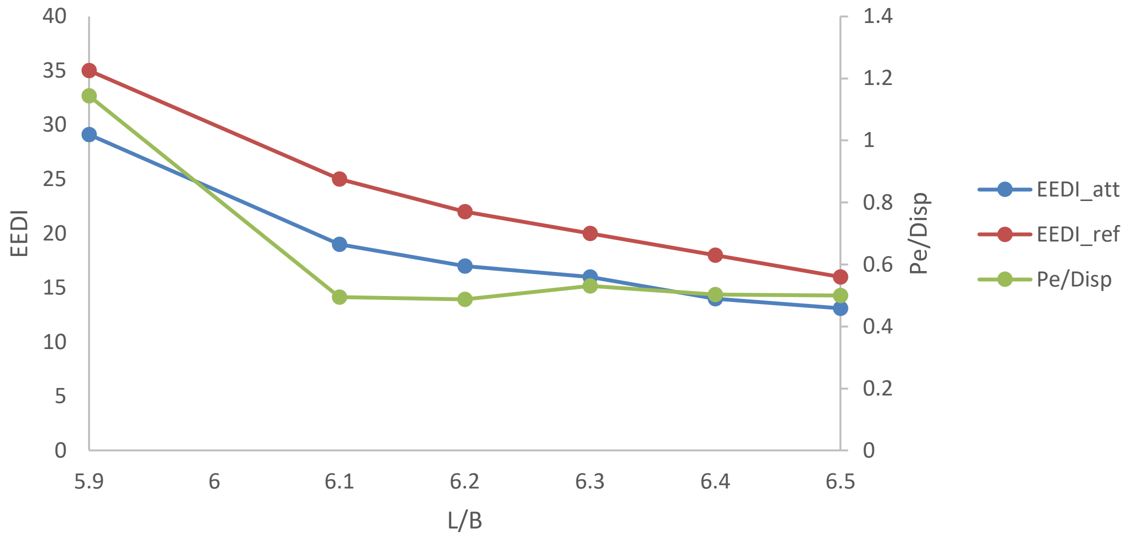

Figure 4.15: Effect of EEDI on L/B of Reefer vessel at 12knots

4.1.7 Effect of EEDI on the rate of Change in B/T ratio of the ship types considered for the analysis

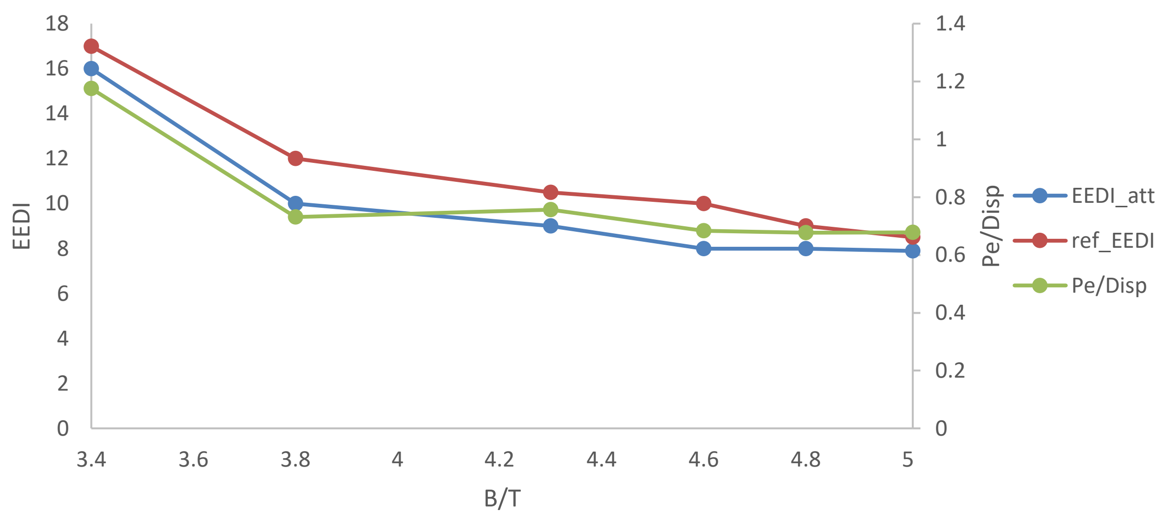

Figure 4.16: Effect of EEDI on B/T ratio of Ropax at 12 knot Speed.

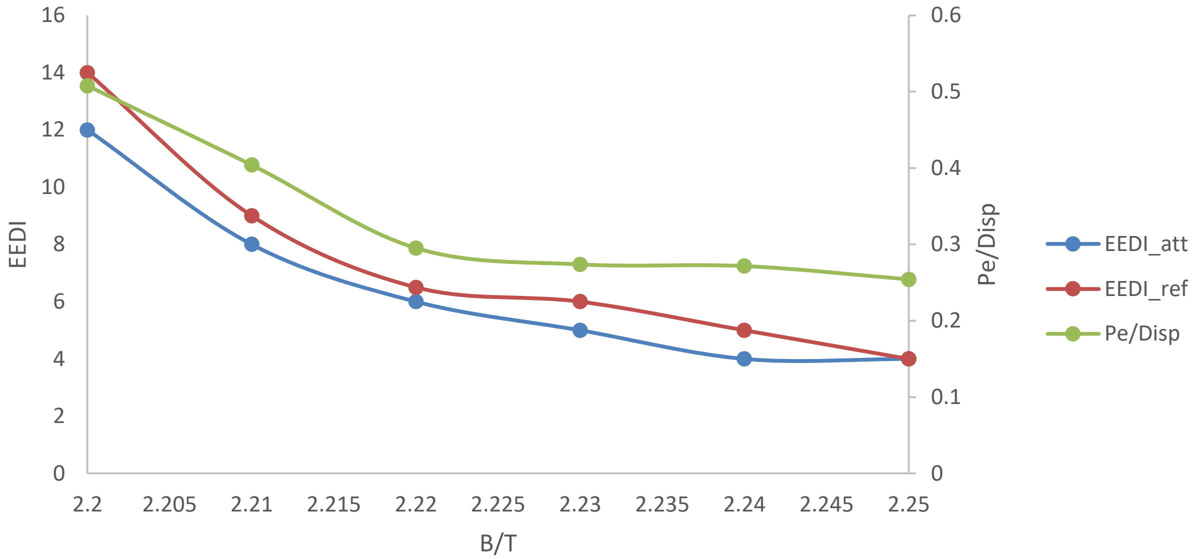

Figure 4.17: Effect of EEDI on B/T ratio of Tugboat at 12 knots Speed.

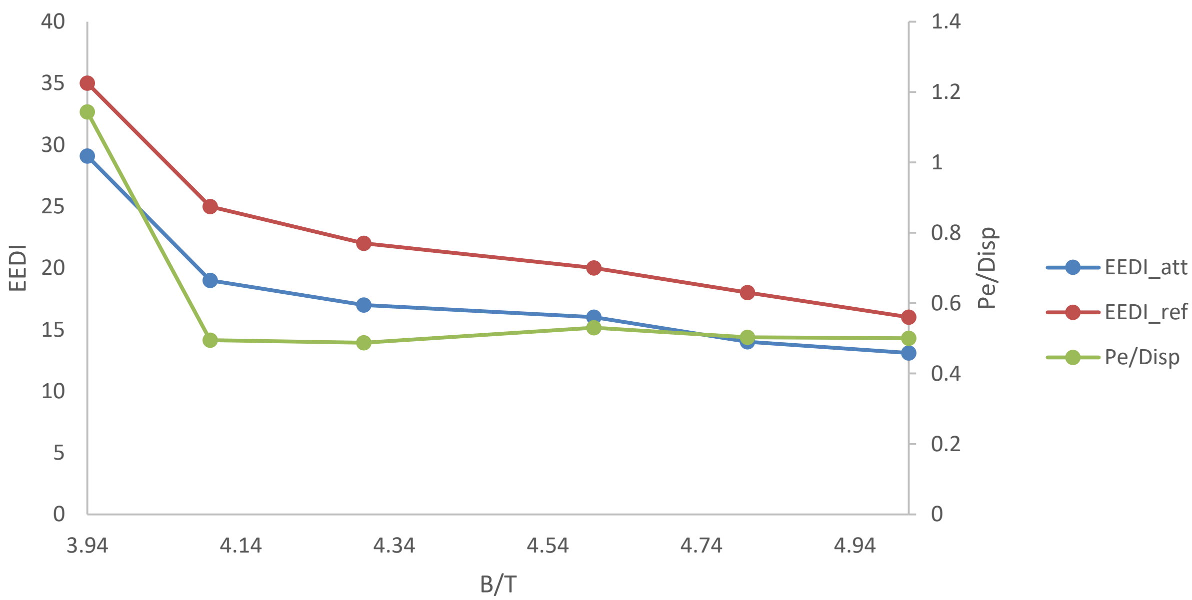

Figure 4.18: Effect of EEDI on B/T ratio of Reefer vessel at 12 knots Speed.

4.1.8 Effect of EEDI on the rate of Change in Prismatic coefficient, C_P of vessels

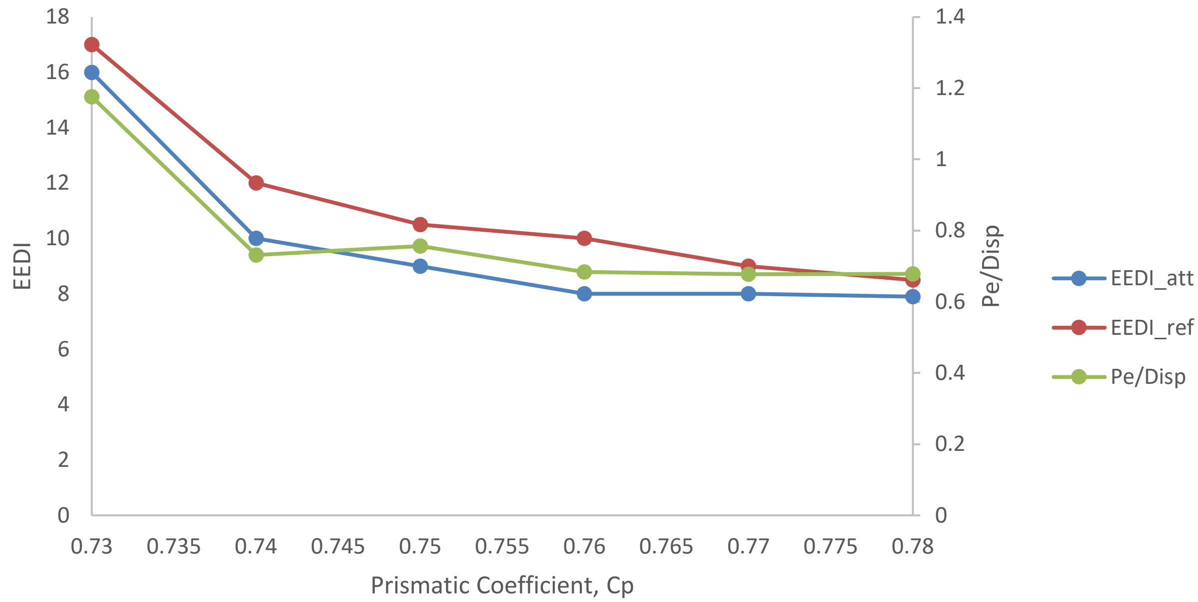

Figure 4.19: Effect of EEDI on Prismatic coefficient of Ropax at 12 knot Speed

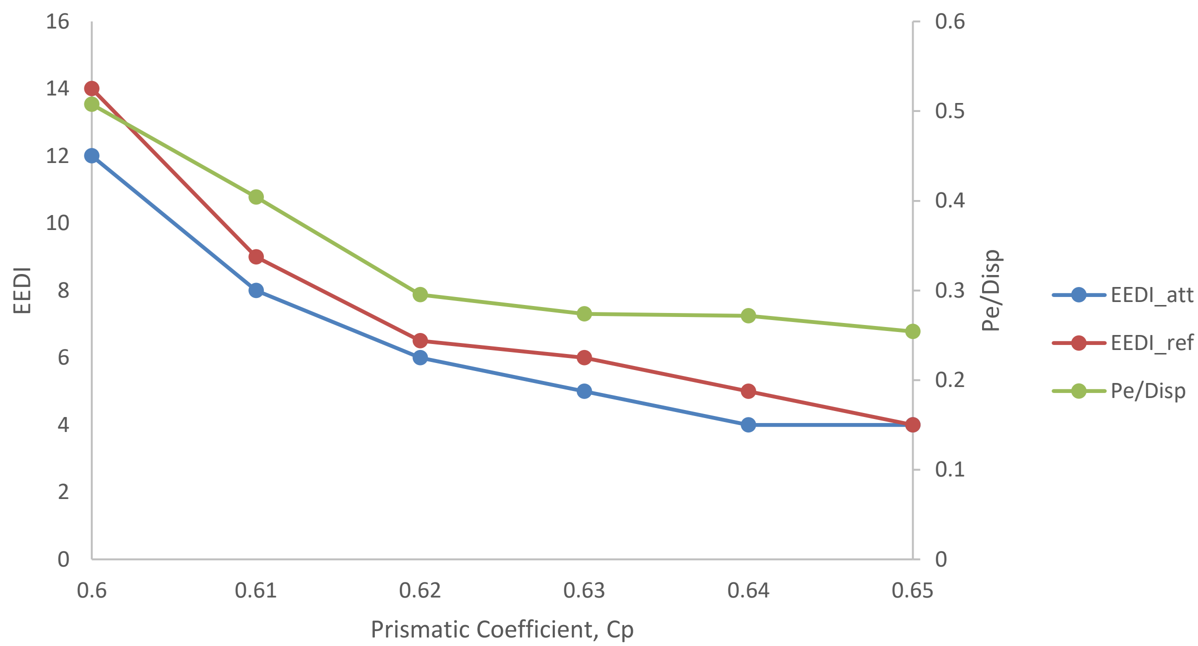

Figure 4.20: Effect of EEDI on Prismatic coefficient of Tugboats at 12 knots

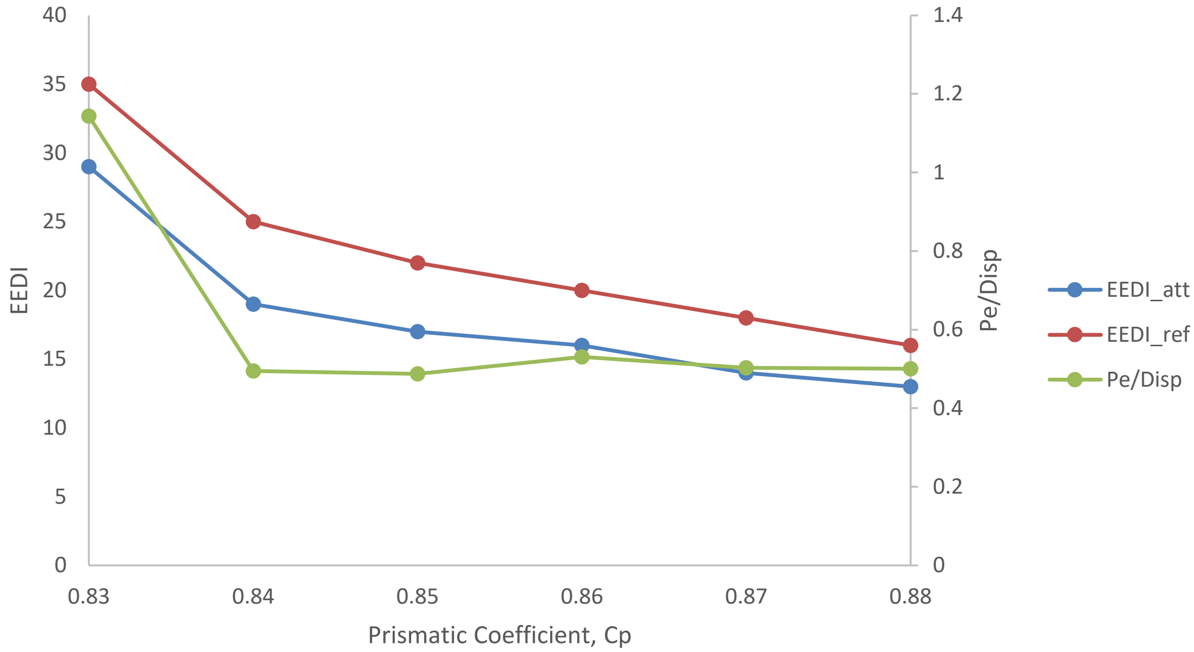

Figure 4.21: Effect of EEDI on Prismatic coefficient of Reefer vessels at 12knots Speed

4.1.9 Validation between the Present EEDI reference line and the EEDI attained in terms of CO2/Tonne-mile emission and in terms of Allowable Power

For various types of vessels, the maximum permissible power at the moment is shown in Figures 4.22 and 4.23 together with the EEDI reference line. It's quite intriguing to watch how closely the achieved lines for each of the ship types adhere to the reference line. The inclusion of highly specialized tonnage under the classification of Ropax ships is the cause of the significant dispersion and poor correlation of the reference line values.

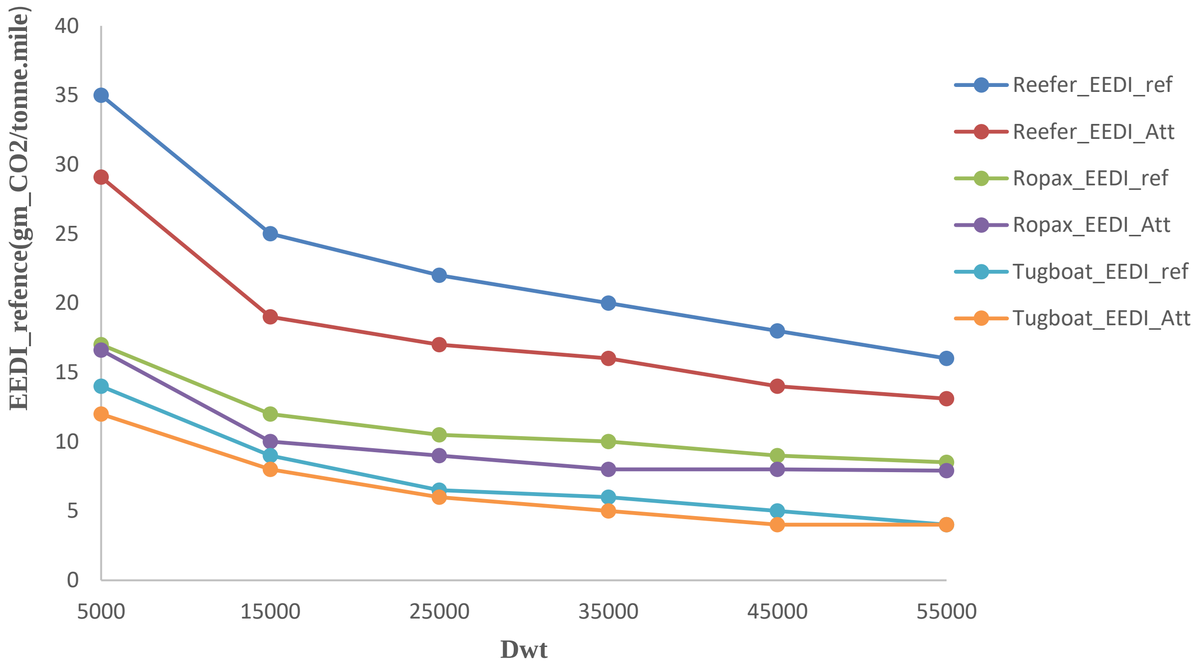

Figure 4.22: Validation of EEDI_reference and EEDI_attained as per CO_2/Tonne-mile emision for all vessel types.

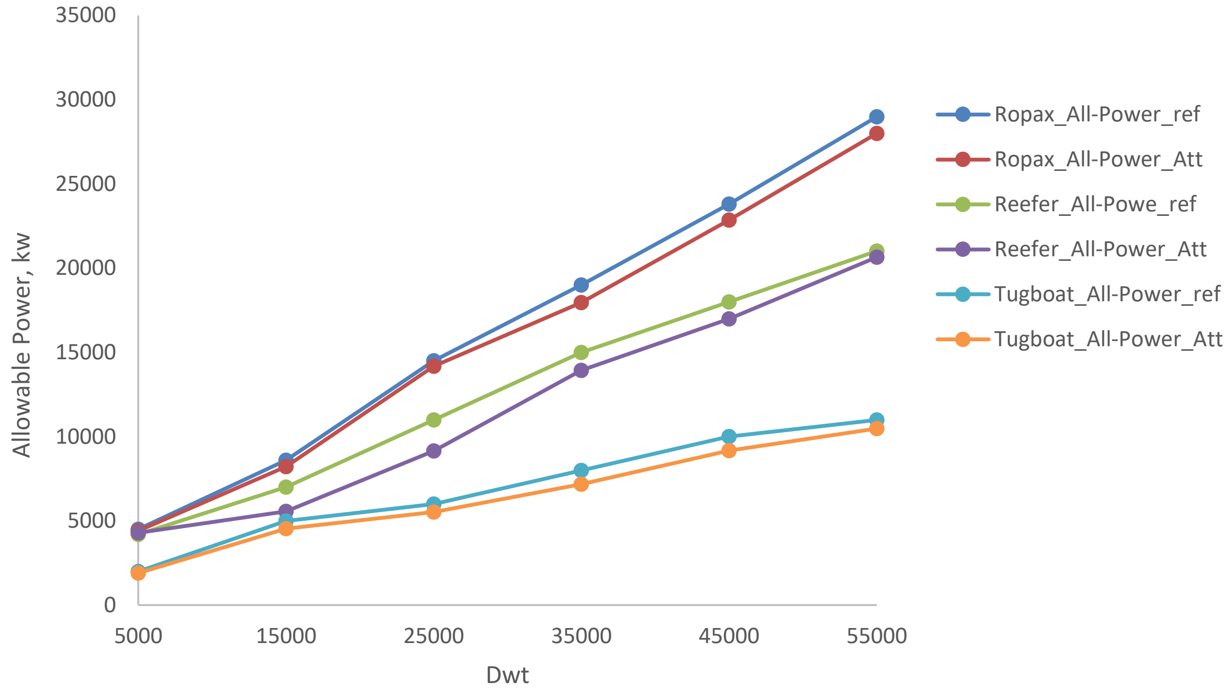

Figure 4.23: Validation of Maximum Allowable Power of EEDI reference and EEDI Attained for the three (3) vessel types

4.2 Discussion

When running at low speed inside or below 12 knots, it is evident that the EDDI for all of the vessels was improved due to their short length, breadth, draft, and prismatic coefficient. This is due to the observation that lowering these settings causes the EEDI achieved value to fall. In contrast, it is preferable to raise L/B and B/T at low speeds while lowering them at high speeds. The reason for this is because the current EEDI formula will encourage ship designers and owners to construct tiny ships (in terms of dimension) that operate at low speeds.

The influence of speed, length, beam, and draft have the biggest impact on EEDI, followed by the prismatic coefficient, which has a less significant impact on the aforementioned index, according to our analysis of the curves for various ship characteristics. Therefore, it was highlighted that the speed and length should be taken into account before the beam, draft, and prismatic coefficient if a designer wants to adjust the value of EEDI for a certain ship. To examine the variance in EEDI achieved and the Effective Power/Displacement curve with various ship design specifications, an Effective Power/Displacement curve is generated for each example.

This ratio truly includes every ship's hydrostatic impact. The fact that the EEDI formula used today does not violate the hydrostatic rules of naval architecture can be seen in the variation of EEDI obtained and the Effective power/Displacement curve with various ship specifications that revealed a similar trend.

4.2.1 The Effects of EEDI on ship design parameters of Ropax, Tugboat and Reefer vessels

The estimates made by EEDI for changing different design elements of the reefer, tugboat, and ropax vessels resulted in the numbers below. The objective is to demonstrate how various ship design details and coefficients were impacted by the energy efficiency design index. At 12 and 24 knots for Ropax and Reefer vessels and 12 and 18 knots for tugboat vessels, all design parameters were examined. Investigating the effect at both low and high Froude numbers is the goal.

4.2.2 Effect of energy efficicieny design index (EEDI) on the change in ship speed

The differences between reference EEDI (EEDI_ref) and Attained EEDI (EEDI_attained) are increasingly pronounced with increasing speed as seen in Figures 4.1, 4.2, and 4.3. The greatest speed that may be achieved is shown by the effective power and displacement ratio, which for ropax, tugboat, and reefer boats, respectively, intercepts the speed line at 15 knots, 13 knots, and 15 knots. At slower speeds, the impact of speed on EEDI achieved is noticeably less. The EEDI reference line and EEDI reached have comparable trends. There is no disputing the fact that EEDI performs best at low speeds.

4.2.3 Effect of EEDI on Change in Waterline Length (LWL) of the ship considered for the analysis

It is clear from Figures 4.4, 4.5 and 4.6 that the difference between the reference EEDI and the EEDI achieved reduces with length at 12 knot speeds, but grows with length at higher speeds. This is in part due to the fact that wave resistance increases at higher speeds. Smaller vessels (30-90 meters) are more affected by EEDI than big vessels, such as ropaxes and tugboats. Take note of the identical pattern between the EEDI achieved and Effective Power (Pe)/Displacement lines.

4.2.4 Effect of EEDI on Change in Beam of Ship Particulars considered for the analysis

According to Figure 4.7–4.9, at 12 knots of speed, the difference between EEDI ref and EEDI achieved diminishes with increasing breadth, but increases at higher speeds (18 and 24 knots). Effective Power (Pe)/Displacement line shows a similar pattern to EEDI achieved.

4.2.5 Effect of EEDI on Change in draft (T) of the ship types considered for the analysis

The gap between EEDIref and EEDI achieved, as seen in figures 4.10 and 4.12, reduces with increasing draft at 12 knot speeds but increases with increasing draft at faster speeds (12 and 24 knots). - Effective Power (Pe)/Displacement line shows a similar pattern to EEDI achieved. It is simple to conclude that a little draft is preferable at low speeds and vice versa.

4.2.6 Effect of EEDI on L/B ratio of the ship types considered for the analysis

When L/B increases between 12 and 24 knots of speed, the difference between EEDIref and EEDIattained grows; when L/B increases between 18 and 24 knots of speed, however, the disparity reduces. Similar trends may be seen in the EEDIattained and Effective Power

(Pe)/Displacement lines. It is simple to determine that a big L/B is preferable at low speeds and vice versa.

4.2.7 Effect of EEDI on the rate of Change in B/T ratio of the ship types considered for the analysis

The difference between $EEDI_{ref}$ and $EEDI_{attained}$ increases with the increase of B/T at 12 knot speed, but decreases with the increase of B/T ratio at higher speed (18 and 24 knots). $EEDI_{attained}$ and Effective Power (Pe)/Displacement line has similar trend. It can be decided easily that at low speed, it is better to have large B/T and vice versa.

4.2.8 Effect of EEDI on the rate of Change in Prismatic coefficient, C_P of vessels

As may be seen from figures 4.19, 4.20, and 4.21, plotted graphs demonstrate that a low prismatic coefficient will not increase a vessel's EEDI regardless of speed. As the prismatic coefficient and rises from 0.73 to 0.78, the disparity between EEDIref and EEDIattained reduces. The Effective Power (Pe)/Displacement line and EEDIattained show different patterns.

4.2.9 Validation between the Present EEDI reference line and the EEDI attained in terms of CO2/Tonne-mile emission and in terms of Allowable Power

For various types of vessels, the maximum permissible power at the moment is shown in Figures 4.22 and 4.23 together with the EEDI reference line. It's quite intriguing to watch how closely the achieved lines for each of the ship types adhere to the reference line. The inclusion of highly specialized tonnage under the classification of Ropax ships is the cause of the significant dispersion and poor correlation of the reference line values.

The Ropax and Reefers are permitted to have increased engine power or faster speed, as shown in Figure 4.23. The data shows that historically, Tugboats are not permitted to have higher engine power and speed than Ropax and Reefers. Therefore, a ship owner is not permitted to increase the pace of his tugboat (particularly in short shipment). In that situation, there is a chance of fraud since the ship owner may register the boat as general cargo rather than a tugboat. The decision of whether to base the reference line on historical data or only hydrostatic calculations arises at this stage.

CHAPTER FIVE

CONCLSUION AND RECOMMENDATIONS

5.1 Conclusion

This dissertation examined how ship design and hydrostatics for boats operating in the Gulf of Guinea are affected by the energy efficiency design index. The International Maritime Organization (IMO) passed the EEDI as a required regulation of ship CO_2 emissions in order to benchmark energy use and regulate pollution. It was used to conduct a case study of three vessels, the Ropax, Tugboat, and Reefer.

In the study of EEDI, the perspective of ship engine-propeller design and matching receives little attention; however, since the ship propulsion system is where the majority of CO_2 emissions originate, this study used the Hughes-Prohaska method to extrapolate the results to large scale vessels in order to determine the actual resistance and effective power of such ships. The particulars were taken from several already-existing ships, but assumptions were established based on the displacements of the vessels so that the analysis of their EEDIs could be statically determine. From the investigations carried out, it can be concluded that;

i. According to the authorized reference power plots, the model resistance and effective power test performed at the towing tank demonstrated some excellent agreement with actual power. The benchmark data proved this method's accuracy, which was greater than 95% and suitable for use.

ii. For a traditional marine propulsion system without emission abatement techniques, EEDI is a great way to regulate pollution from ships. For these ships, the relatively low EEDI limiting CO_2 emissions means a trend of high propulsive efficiency and eliminates the low energy efficiency ships.

iii. From the perspective of Hughes-Prohaska, the key methods of reducing EEDI were to reduce the ship speed, optimizing the ship hull and maintain the lower block or pragmatic coefficient. In this case, the 13% sacrifice of ship speed at design stage would result in the 14% reduction of EEDI. This made the ship speed reduction an easy method to meet the EEDI requirements.

iv. The data of the relevant design parameters to meet the EEDI at different phases were calculated, however, these data were subject to change due to the sudden nature of improvement in energy saving technologies and toughing of regulations on emission index to include Nitrogen Oxide (NOx) and Particulate Matter (PM).

The highest quantity of goods that may be transported with the least amount of fuel usage is considered by the EEDI as a measure of transport efficiency. Although reducing CO_2 emissions from the shipping industry is the main goal of adopting EEDI, it also forces the industry to build more and more energy-efficient ships because CO_2 emissions are almost proportional to fuel consumption, which is a reflection of total hull resistance. So an increase in a ship's EEDI also indicates an increase in the resistance of the ship's hull.

It might be argued that the fact that tiny vessels are permitted to have greater EEDI levels is unfair, and this is what causes confusion when comparing the EEDI of small and big vessels. It might be claimed that current EEDI allows tiny boats to have greater EEDI and vice versa if the current reference line is the only one used. It implies that smaller vessels are permitted to go at a faster rate than huge vessels. The present reference line allows for a greater EEDI for tiny boats, according to the EEDI computation, however this does not imply that small vessels can achieve low EEDI.

The tables demonstrate that the reached EEDI for tiny vessels is likewise quite high since all of the physical characteristics of the ship have been taken into account. Therefore, it may be said that the reference line permits smaller boats to have higher EEDI since at that range, the achieved EEDI is likewise quite high. However, it is true that, no matter how we alter or enhance the hull design, it will not be sufficient to create a ship that would travel at the same speed while reducing EEDI by 30% (Phase 3 of CO_2 reduction).

Most of the time, the existing efficient hulls are sufficient to meet phase 0 criteria. With minor hull parameter changes and improved hull design, phase 1 requirements can be satisfied without slowing down, but subsequent phases are not feasible. Therefore, based on the situation as it is now, it will gradually reduce both the need for electricity and ship speed. The power and speed cuts will undoubtedly have an impact on the shipping industry. Since it will save ship owners money on fuel and there is no doubt that the price of bunkers will rise daily, the effects of EEDI on ship design should be addressed permanently. To save fuel, the ship's owners and operators must lower the ship's operational speed. The sister vessel conundrum is a significant element that is absent from the present EEDI standards. The sister vessel notion is destroyed by current EEDI restrictions. Let's imagine that for several sister boats, one sister vessel's keel lay is in phase 0 and another is in phase 1. Therefore, the second vessel must be altered in some way in order to satisfy the EEDI standards of Phase 1, and as a result, they can no longer be sisters. Whether or if this law will actually cut CO_2 emissions is something that truly matters. All types of vessels are not covered by the current IMO standards.

They intend to complete the present EEDI regulations and establish suitable reference lines for the boats that weren't taken into account in the regulations as of now. Again, if we assume a 25-year vessel life, the vessels constructed up until phase 0 (no decrease is necessary) will be in use until 2038 while emitting at the same rate. more, it may take ten years or more to see the true effect. EEDI will only have an impact on international shipping "as and when older, less efficient tonnage is replaced by new, more efficient tonnage." Even though EEDI is currently not a reliable emission indicator, having an emission control instrument at the design stage is beneficial in every way. The study comes to the conclusion that slowing down a ship is still the best way to comply with EEDI regulations.

5.2 Recommendations

i. Further research could look at how the formulation could be modified through adopting new coefficients or present coefficient values to make the EEDI more meaningful and efficient.

ii. Further research should consider using more ship models should be tested in the towing tank in order to ascertain the true total ship resistance of the main vessels as this would help in address some marginal errors between the reference EEDI and the attained EEDI of vessels. An import investigation can be made by analyzing two existing vessels of same type where one vessel is above the reference line and another one is below. This practical investigation will help to describe what makes a vessel more efficient in terms of EEDI.

iii. The model resistance test conducted should be repeated severally to ascertain the values of the results generated therefrom, in order to ensure calibrated data matches the actual values with less marginal errors.

iv. In this dissertation, only three types of vessels were investigated. Other types of vessel should also be analyzed to understand the impact of EEDI on Ship design and hydrostatics. It would be interesting to see and compare the hydrostatically optimized results and EEDI optimized design. It was investigated here in this study by comparing the Effective power/Displacement and EEDI attatined curves but, more hydrostatic impacts can be analyzed. EEDI can be used only as a design parameter at present, not an accurate CO_2 emission indicator as the formulation considers the installed main engine's maximum continues rating. But a vessel has different loading conditions, (in terms of capacity, power and electric power consumption), which the present formulation does not cover. A vessel having an EEDI of 5 gm/tonne-mile does not mean that she always emits at the same rate. It would be a good future work to analyze EEDI at different loading condition, to investigate the maximum achievable speed at different cargo loading cases. The Energy Efficiency Operational Index is the actual indicator of CO_2 emission as it does not consider the installed power and maximum cargo capacity; rather it is based on operational data. It would be a nice to establish a relationship between EEDI and EEOI in a sense that, EEOI is always less than EEDI. As both the EEDI and EEOI have the same unit (gramCO2/Tonne.mile) this relationship would be good to describe the actual CO_2 emission.

5.3 Contribution to knowledge

Several researchers made use of Holtrop and Mennen resistance and power estimation theory to carry out their own analyses. In as much as this method is valid, it can be very unrealiable and prone to interferences. Therefore, this present study contributed to knowledge by following the tedious process of the Hughes-Prohaska method which entails conducting resistance and power prediction experiments at a towing tank and extrapolating the result therefrom to determine the resistance and power demand of the large ships. After doing all these, the researcher then carried out analysis on the effects of energy efficiency design index for selected ships for pliability in the Gulf of Guinea region. This resulted in developing a new model which is the first of its kind world over. This template can now be deployed as an emission control instrument at the design stage of ships with proofs that are beneficial to regulate ship energy consumption, diminish pollution and optimize running costs.

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APPENDICES

APPENDIX A: Results of Analysis of Ship Hydrostatics Parameters, EEDI and Effective Power

Table 4.6: Effect of speed on EEDI for Ropax vessel

Effect of EEDI on speed of Ropax at 12knots

Ship speed (knots)	EEDI_attained	EEDI_ref	Effective Power, Pe	Displacement	Pe/Disp
12	16.6	17	5880	5000	1.176
13.5	10	12	10966.66	15000	0.731111
17	9	10.5	18906.66	25000	0.756266
19	8	10	23933.33	35000	0.683809
21	8	9	30466.66	45000	0.677037
24	7.9	8.5	37320	55000	0.678545

Table 4.7: Effect of speed on EEDI for Tugboat

Effect of EEDI on speed of Tugboat at 12knots

Ship speed (knots)	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
12	12	14	2538.66	5000	0.507732
13	8	9	6060	15000	0.404
14	6	6.5	7380	25000	0.2952
15	5	6	9581.33	35000	0.273752
16	4	5	12222.66	45000	0.271615
18	4	4	13982.66	55000	0.25423

Table 4.8: Effect of speed on EEDI for Reefer vessel

Effect of EEDI on speed of a Reefer at 12knts

Ship speed(knots)	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
12	29.1	35	5717.33	5000	1.143466
13.5	19	25	7421.33	15000	0.494755
17	17	22	12190.66	25000	0.487626
19	16	20	18573.33	35000	0.530667
21	14	18	22640	45000	0.503111
24	13.1	16	27520	55000	0.500364

Table 4.9: Effect of length on EEDI for Ropax vessel at 12knots speed

Effect of Length on EEDI of a Ropax at 12knots					
LWL in metre	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
94.5	16.6	17	5880	5000	1.176
120	10	12	10966.66	15000	0.7311107
140	9	10.5	18906.66	25000	0.7562664
160	8	10	23933.33	35000	0.6838094
180	8	9	30466.66	45000	0.6770369
200	7.9	8.5	37320	55000	0.6785455

Table 4.10: Effect of length on EEDI for Tugboat vessel at 12knots speed

Effect of EEDI on Length of Tugboat at 12knots					
LWL in metre	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
32.7	20	20	2538.66	5000	0.507732
34	8	9	6060	15000	0.404
35	6	6.5	7380	25000	0.2952
36	5	6	9581.33	35000	0.273752
38	4	5	12222.66	45000	0.271615
40	4	4	13982.66	55000	0.25423

Table 4.11: Effect of length on EEDI for Reefer vessel at 12knots speed

Effect of EEDI on Length of Reefer vessels at 12knots					
LwL in metre	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
135	29.1	35	5717.33	5000	1.143466
143	19	25	7421.33	15000	0.494755
155	17	22	12190.66	25000	0.487626
170	16	20	18573.33	35000	0.530667
185	14	18	22640	45000	0.503111
200	13.1	16	27520	55000	0.500364

Table 4.12: Effect of beam on EEDI for Ropax at 12knots speed

Effect of EEDI on beam of Ropax at 12knots

Beam	EEDI_attained	EEDI_ref	Effective power, Pe	Displacement (T)	Pe/Disp
16	16	17	5880	5000	1.176
19	10	12	10966.66	15000	0.731111
21	9	10.5	18906.66	25000	0.756266
24	8	10	23933.33	35000	0.683809
27	8	9	30466.66	45000	0.677037
30.64	7.9	8.5	37320	55000	0.678545

Table 4.13: Effect of EEDI on beam of Tugboat vessel at 12knots speed

Effect of EEDI on beam of Tugboat 12knots

Beam	EEDI_attained	EEDI_ref	Effective Power, Pe	Displacement (T)	Pe/Disp
12.82	12	14	2538.66	5000	0.507732
13	8	9	6060	15000	0.404
13.3	6	6.5	7380	25000	0.2952
13.6	5	6	9581.33	35000	0.273752
13.8	4	5	12222.66	45000	0.271615
14	4	4	13982.66	55000	0.25423

Table 4.14: Effect of EEDI on beam of Reefer carrier at 12knots speed

Effect of EEDI on beam of Reefer at 12knots

Beam	EEDI_attained	EEDI_ref	Effective Power, Pe	Displacement (T)	Pe/Disp
20.6	29.1	35	5717.33	5000	1.143466
22	19	25	7421.33	15000	0.494755
24	17	22	12190.66	25000	0.487626
26	16	20	18573.33	35000	0.530667
28	14	18	22640	45000	0.503111
30.64	13.1	16	27520	55000	0.500364

Table 4.15: Effect of EEDI on draft of Ropax vessel at 12knots speed

Effect of EEDI on draft of Ropax

Draft	EEDI_att	EEDI_ref	Pe	Disp (T)	Pe/Disp
4.67	16	17	5880	5000	1.176
4.9	10	12	10966.66	15000	0.731111
5.92	9	10.5	18906.66	25000	0.756266
5.94	8	10	23933.33	35000	0.683809
6	8	9	30466.66	45000	0.677037
6.1	7.9	8.5	37320	55000	0.678545

Table 4.16: Effect of EEDI on draft of Tugboat vessel at 12knots speed

Effect of EEDI on Draft of Tugboat at 12knots

Draft	EEDI_att	ref_EEDI	Pe	Disp	Pe/Disp
5.9	12	14	2538.66	5000	0.507732
5.92	8	9	6060	15000	0.404
5.94	6	6.5	7380	25000	0.2952
5.96	5	6	9581.33	35000	0.273752
6.1	4	5	12222.66	45000	0.271615
6.2	4	4	13982.66	55000	0.25423

Table 4.17: Effect of EEDI on draft of Reefer vessel at 12knots speed

Effect of EEDI on Draft of Reefer at 12knots

Draft	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
5.22	29.1	35	5717.33	5000	1.143466
5.3	19	25	7421.33	15000	0.494755
5.4	17	22	12190.66	25000	0.487626
5.6	16	20	18573.33	35000	0.530667
5.8	14	18	22640	45000	0.503111
6.1	13.1	16	27520	55000	0.500364

Table 4.18: Effect of EEDI on L/B of Ropax carrier at 12knots speed

Effect of EEDI on L/B of Ropax at 2knots

L/B	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
5.9	16	17	5880	5000	1.176
6	10	12	10966.66	15000	0.731111
6.2	9	10.5	18906.66	25000	0.756266
6.3	8	10	23933.33	35000	0.683809
6.4	8	9	30466.66	45000	0.677037
6.5	7.9	8.5	37320	55000	0.678545

Table 4.19: Effect of EEDI on L/B of Tugboat vessel at 12knots speed

Effect of EEDI on L/B of Tugboat at 12knots

L/B	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
2.6	12	14	2538.66	5000	0.507732
2.65	8	9	6060	15000	0.404
2.7	6	6.5	7380	25000	0.2952
2.75	5	6	9581.33	35000	0.273752
2.8	4	5	12222.66	45000	0.271615
2.9	4	4	13982.66	55000	0.25423

Table 4.20: Effect of EEDI on L/B of Reefer vessel at 12knots speed

Effect of EEDI on L/B of Reefer vessel at 12knots

L/B	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
5.9	29.1	35	5717.33	5000	1.143466
6.1	19	25	7421.33	15000	0.494755
6.2	17	22	12190.66	25000	0.487626
6.3	16	20	18573.33	35000	0.530667
6.4	14	18	22640	45000	0.503111
6.5	13.1	16	27520	55000	0.500364

Table 4.21: Effect of EEDI on B/T of Ropax at 12knots speed

Effect of EEDI on B/T of Ropax vesseel

B/T	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
3.4	16	17	5880	5000	1.176
3.8	10	12	10966.66	15000	0.731111
4.3	9	10.5	18906.66	25000	0.756266
4.6	8	10	23933.33	35000	0.683809
4.8	8	9	30466.66	45000	0.677037
5.01	7.9	8.5	37320	55000	0.678545

Table 4.22: Effect of EEDI on B/T of Tugboat at 12knots speed

Effect of EEDI on B/T ofTugboat at 12knts

B/T	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
2.2	12	14	2538.66	5000	0.507732
2.21	8	9	6060	15000	0.404
2.22	6	6.5	7380	25000	0.2952
2.23	5	6	9581.33	35000	0.273752
2.24	4	5	12222.66	45000	0.271615
2.25	4	4	13982.66	55000	0.25423

Table 4.23: Effect of EEDI on B/T of Reefer at 12knots speed

Effect of EEDI on B/T of Reefer at 12knots

B/T	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
3.94	29.1	35	5717.33	5000	1.143466
4.1	19	25	7421.33	15000	0.494755
4.3	17	22	12190.66	25000	0.487626
4.6	16	20	18573.33	35000	0.530667
4.8	14	18	22640	45000	0.503111
5.01	13.1	16	27520	55000	0.500364

Table 4.24: Effect of EEDI on Prismatic coefficient for Ropax vessel at 12knots

Effect of EEDI on Cp of Ropax at 12knots

Prismatic Coefficient, Cp	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
0.73	16	17	5880	5000	1.176
0.74	10	12	10966.66	15000	0.731110667
0.75	9	10.5	18906.66	25000	0.7562664
0.76	8	10	23933.33	35000	0.683809429
0.77	8	9	30466.66	45000	0.677036889
0.78	7.9	8.5	37320	55000	0.678545455

Table 4.25: Effect of EEDI on Prismatic coefficient of Tugboat at 12knots

Effect of EEDI on Cp of Tugboat at 12knots

Prismatic Coefficient, Cp	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
0.6	12	14	2539	5000	0.5078
0.61	8	9	6060	15000	0.404
0.62	6	6.5	7380	25000	0.2952
0.63	5	6	9581.3	35000	0.273751
0.64	4	5	12222.66	45000	0.271615
0.65	4	4	13982.66	55000	0.25423

Table 4.26: Effect of EEDI on Prismatic coefficient for Reefer vessel at 12knots

Effect of EEDI on Cp of Reefer at 12knots

Prismatic Coefficient, Cp	EEDI_attained	EEDI_ref	Pe	Disp	Pe/Disp
0.83	29	35	5717.33	5000	1.143466
0.84	19	25	7421.33	15000	0.494755
0.85	17	22	12190.66	25000	0.487626
0.86	16	20	18573.33	35000	0.530667
0.87	14	18	22640	45000	0.503111
0.88	13	16	27520	55000	0.500364

Table 4.27: EEDI reference Line and EEDI attained for all vessel types

Dead Weight (Dwt)	Ropax_ EEDI_ref	Ropax_ EEDI_Att	Tugboat_ EEDI_ref	Tugboat_ EEDI_Att	Reefer_ EEDI_ref	Reefer_ EEDI_Att
5000	17	16.6	14	12	35	29.1
15000	12	10	9	8	25	19
25000	10.5	9	6.5	6	22	17
35000	10	8	6	5	20	16
45000	9	8	5	4	18	14
55000	8.5	7.9	4	4	16	13.1

Table 4. 28: Effective Power (Pe) and allowable Power (P_{MCR}) for all vessel types

Dead Weight (Dwt)	Pe (Ropax)	Ropax_All-Power_ref	Ropax_All-Power_Att	Pe (Tugboat)	Tugboat_All-Power_ref	Tugboat_All-Power_Att	Pe (Reefer)	Reefer_All-Powe_ref	Reefer_All-Power_Att
5000	5880	4500	4410	2538.667	2000	1904	5717.3333	4200	4288
15000	10966.67	8600	8225	6060	5000	4545	7421.3333	7000	5566
25000	18906.67	14500	14180	7380	6000	5535	12190.667	11000	9143
35000	23933.33	19000	17950	9581.333	8000	7186	18573.333	15000	13930
45000	30466.67	23800	22850	12222.67	10000	9167	22640	18000	16980
55000	37320	28970	27990	13982.67	11000	10487	27520	21000	20640

APPENDIX B: COMPUTED MODEL TOWING TANKS TEST RESULTS FOR THE DETERMINATION OF RESISTANCE AND EFFECTIVE POWER FOR SHIPS USING THE HUGHES-PROHASKA METHODS

Results of the Model Resistance test conducted by the Towing tank of the Centre of Excellence in Marine and Offshore Engineering, Rivers State University. The extracted Excel file used for the analysis is further attached.

COMPUTED MODEL TOWING TANKS TEST RESULTS FOR THE DETERMINATION OF RESISTANCE AND EFFECTIVE POWER FOR SHIPS USING THE HUGHES-PROHASKA METHODS					
MODEL Particulars	**Computed Formulae**	**Units**	**Ropax**	**Tugboat**	**Reefers**
Froude Number	**Fr**		0.14	0.13	0.12
Length of Ship	L	m	94.5	32.7	135
Beam of the Ship, B	B	m	16	14	20.6
Ship Speed, Vs	Vs	knots	12	12	12
Draft of the Ship, T	T	m	4.67	5.9	5.22
Ship Kinematic Viscosity at 15 degrees (1025kg/m2)_Seawater	υ	m2/s	0.00000119	0.00000119	0.00000119
Scale between model and ship	λ		1: 25	1: 25	1:25
Density of freshwater	ρ_{fw}	kg/m3	1000	1000	1000
Density of Seawater	ρ_{sw}	kg/m3	1025	1025	1025
Model Block Coefficient (C_B)	Same for Model & Ship		0.72	0.6	0.7
Model Kinematic Viscosity at 10 degrees (1025kg/m2)_Fresh water	υ	m2/s	0.00000135	0.00000135	0.00000135
Length of the Model, L_M (m)	$L_M = \frac{L}{\lambda}$	m	3.78	1.308	1.69

Model Beam, BM	$B_M = \frac{B}{\lambda}$	m	0.64	0.56	0.824
Model Draft, T_M (m)	$T_M = \frac{T}{\lambda}$	m	0.1868	0.236	0.2088
Model Speed, V_M	$V_M = F_r\sqrt{g.L_M}$	m/s	0.852527583	0.501494774	0.570040735
Model Wetted Surface area, S_M	$SM = 1.7LT + CB * L * B$	m2	2.9422008	0.9642576	1.5746744
Ship Wetted Surface area, Ss	$S_s = S_M\lambda^2$	m2	1838.8755	602.661	984.1715
Model Reynold's number, ReM	$R_{eM} = \frac{V_M L_M}{\upsilon}$		2387077.233	485892.714	713606.5502
			4.377866471	3.686540387	3.853458828
Model Frictional Coefficient, Cfom	$C_{Fom} = \frac{0.067}{(Log\ ReM - 2)^2}$		0.003495826	0.004929885	0.004512044
Ship Speed, Vs	$V_s = F_r\sqrt{g.L_S}$	m/s	4.262637916	2.328368592	4.36699439
Ship Reynold's Number, Res	$R_{es} = \frac{V_S L_S}{\upsilon}$		952941176.5	329747899.2	1361344538
			6.979066093	6.518182037	7.133968053
Ship Frictional Coefficient, CFos	$C_{Fos} = \frac{0.067}{(LogRes\ - 2)^2}$		0.001375562	0.001576964	0.001316475

Model Resistance, RM	RM	N	30	3.6	6.3
			0.72680328	0.251497008	0.32494644
Model Resistance Coefficient, CTM	$C_{TM} = \frac{R_M}{0.5\rho V_M^2 S_M}$		0.028058346	0.029689754	0.024624533
Form factor, (1+K)	(1+K)		1.12	1.16	1.13
Correlation Coefficient	CA		0.0004	0.0004	0.0004
Total Resistance Coefficient for the Ship, CTS	$C_{TS} = C_{TM} - (1+K)(C_{Fom} - C_{Fos}) + C_A$		0.00002295	0.00002624	0.00003165
Total Resistance for the Ship, RTS	$R_{TS} = \frac{1}{2}\rho V_S^2 S_s C_{TS}$	KN	3110.1	1165.2975	2293.33050
Effective Power, PE	$P_E = R_{TS} * V_S$	kW	37320	13,982.66	27520
Efficiency factor for power utilization – Max. Continous Rating (MCR)	η_x		0.75	0.75	0.75
Allowable Power, P(MCR)	$P_{(MCR)} = \eta_x * Pe$	kW	27,990	10487	20640

Vessel speed range

Ropax	Tugboat	Reefer
2.3	2.3	2.3
4.269	4.269	4.37
6	6	5
12	12	12
24	18	24

APPENDIX C: Procedures for Conducting Model Resistance Test at the Centre of Execellence

The procedure for conducting Model resistance test at the towing tank of the Centre of Excellence of the Rivers State University, Port Harcourt is extracted from the manual and attached as APPENDIX C.

Operation Overview

The HMI allows the user to input a series of parameters that will allow a particular test to be carried out automatically, and to have within its real time control a set of limitations beyond which the test will be slowed down, and or stopped. The Personal Computer is provided to allow the data logged during a test to be displayed and analysed once the PLC has gathered the data. The data is transferred between the PLC and the Computer wirelessly once the test has been completed by pressing the 'Get Data' button on the spreadsheet screen.

Operating the Carriage

The desk mounted console has an Isolator, Emergency Stop and Reset buttons and a Touch screen HMI. The Isolator should be turned 'On' and assuming all the Emergency Stop buttons are in their normal operating positions, then the reset button can be pressed and the light will go out and power will be applied to the catenary and the carriage. Turn the isolator on the Carriage 'On' and press the Reset button on the panel of the C The buttons along the bottom of the page select other screens which are used to log data and move the carriage manually.Once all the systems are reset the HMI will show the following Screenarriage. The system is now ready for operation.

Setting Carriage Parameters

The first column allows setting of the Acceleration, Deceleration, Distance and Test Velocity of the carriage. Touching each of the white boxes pops up a keyboard window which allows the user to enter values within the allowed limits of the carriage system. Once a value is entered the software will calculate the distance the carriage will travel to achieve that parameter. Once all the parameters have been entered the total distance must be less than or equal to the useable length of the tank. If it exceeds the maximum distance available, then ERROR will be displayed and the test will not be allowed to continue until one or more of the parameters are adjusted to within the maximum range.

Setting the Carriage in Motion

The second column on the screen allows for running the carriage. The top display shows the carriages actual position along the tank. The test should only be started from the HOME position when the display indicates 0.000m, as this will give maximum available tank run. Pressing the Home button will always cause the carriage to be returned to its starting datum position. In this mode the carriage will return to the Home end of the tank at a slow speed and when it nears its datum point will slow to a creep speed so that it can stop at exactly the same position each time it reaches the Home limit switch.

Operating Powered Dynamometers

The third column allows for the operation of either the H75E or the R31 when fitted (refer also to the manual for the relevant product regarding its operation). Maximum speed is set by Cussons dependant on the model of motor supplied. Touching the top display allows the required test speed to be entered, this is a positive or negative number dependant on the direction of rotation required. Pressing the Start or Stop causes the motor to start or Stop and run at the entered speed.

Logging operation

The system allows a maximum of 12 channels to be logged simultaneously. Carriage speed and Distance Travelled are always logged for every test. After this a further 10 channels can be selected by the user to also be logged. Pressing the white box next to the channel name selects that channel and a cross will be put in the box. Pressing a second time will deselect the channel. If more than 10 channels are selected, only the first 10 will be logged in order of left to right top to bottom. (e.g. If the first 3 columns of channels were all selected, only the first 2 columns would be logged, the 3rd column would be ignored). Logging start position determines where the logging starts in relation to the position of the carriage. Setting this value to zero will cause logging to start immediately the carriage starts moving. Logging stop position determines when the logging stops relative to tank position. These values can be set according to the calculated values from the main menu if you only require logging once the carriage is 'at speed'. If not leave Start at 0.00 and Stop at maximum.

The data logger can sample 10,000 samples per channel, the minimum Sampling Interval is 20ms (i.e. 50 samples /second) therefore the minimum sampling time will be 200seconds. If for some reason you need to sample for longer than this i.e. with a stationary model in waves, then you will have to increase the sampling interval.

The Start Logging buttons starts the logger immediately it is pressed and should mainly be used when calibrating the transducers or setting the system up for a run, as the same limitations above apply to this mode. Pressing the DATUM button goes to the following screen.

Dynamometer Calibration & Amplifier Card Set-up

R35E-01 Resistance dynamometer Card No - 5

Full scale 200N = 10V Calibration stand has 2:1 load ratio Applied load = 10kg = 10 x 9.8065 = 98.065N Allowing for 2:1 ratio, applied load to dynamometer = 2 x 98.065 = 196.13N 7.4.6.1

Amplifier set-up Output for 10kg (196.13N) = 9.80V Output for 0kg (0N) = 0.00V Scale output = 196.13N/9.80V = 20N/V

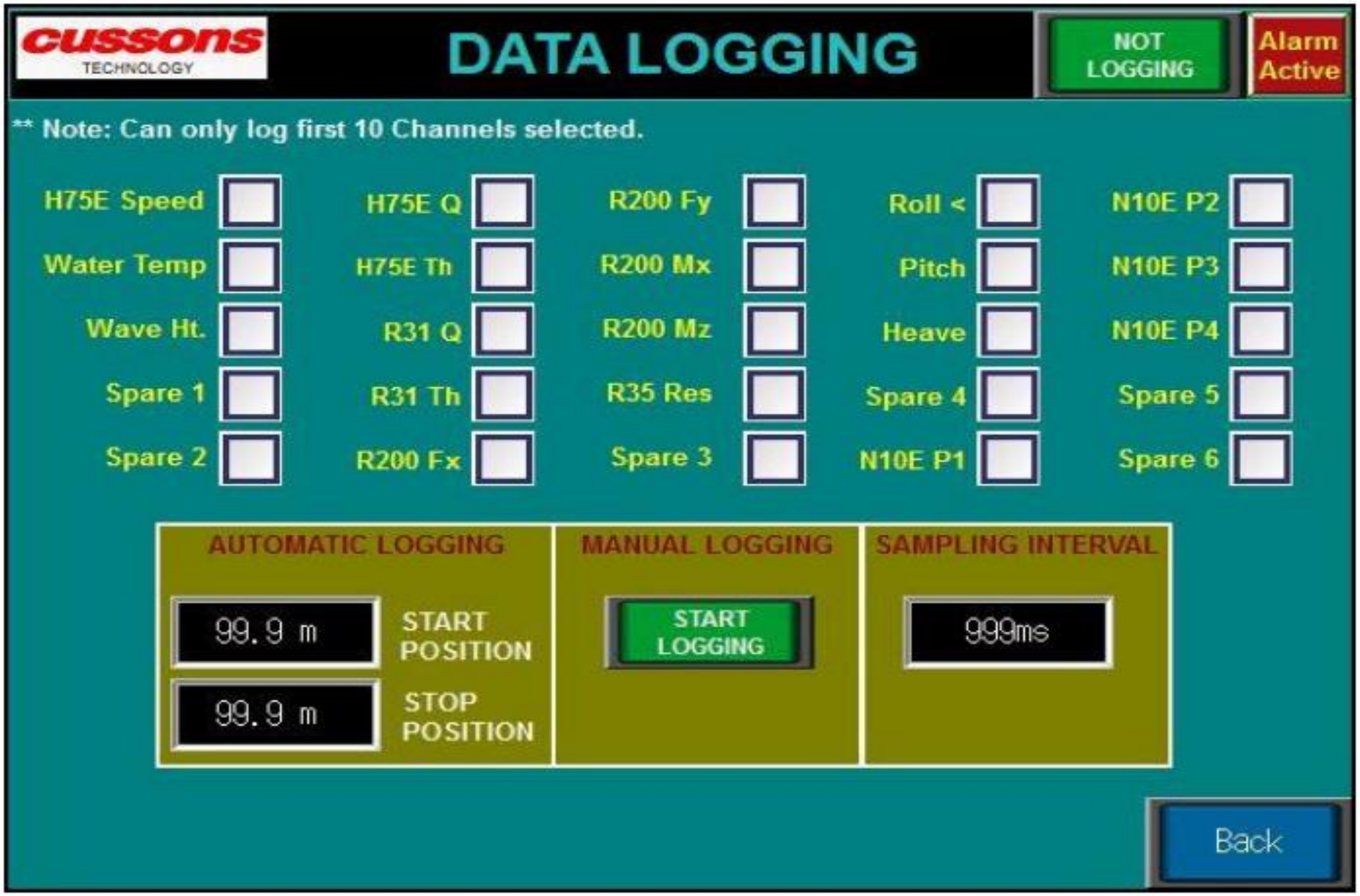
Measured output (Pull) = 9.80V Error (Pull) = 0.00V 0 % (full scale)

Measured output (Push) = -9.82V Error (Push) = 0.02V (20N/V) x (0.02V) = 0.4N (0.4/200) x100 = 0.2 % (full scale)

Data logging set-up

Input channel - 0 to 10V = 0 to 20000 Amplifier output 0 -10V = 0 to 200N Gradient (M) = 200N/20000 = 0.01 Offset (C) = 0

Equation entered in spread sheet Y = MX + C Y = 0.01X + 0


cussons
TECHNOLOGY
DATA LOGGING
NOT LOGGING
Alarm Active
** Note: Can only log first 10 Channels selected.
H75E Speed
Water Temp
Wave Ht.
Spare 1
Spare 2
H75E Q
H75E Th
R31 Q
R31 Th
R200 Fx
R200 Fy
R200 Mx
R200 Mz
R35 Res
Spare 3
Roll <
Pitch
Heave
Spare 4
N10E P1
N10E P2
N10E P3
N10E P4
Spare 5
Spare 6
AUTOMATIC LOGGING
99.9 m
START POSITION
99.9 m
STOP POSITION
MANUAL LOGGING
START LOGGING
SAMPLING INTERVAL
999ms
Back


cussons
TECHNOLOGY
C40E Carriage Control
Alarm Active
11:06:22 AM
Carriage Setup
Carriage
Dyno
Wake Rake
ACCELERATION
DISTANCES
POSITION
SETPOINT
ANGLE
9.9 m/s/s
99.999 m
-999.999 m
-9999 RPM
999°
DECELERATION
MAX SPEED
9.9 m/s/s
99.999 m
HOME
9999 RPM
HOME
DISTANCE
99.9 m
99.999 m
START
START
STEP
VELOCITY
9.999 m/s
99.999 m
STOP
STOP
ENABLE
ERROR
= TOTAL DISTANCE
Jog
Logging
System
Datum
Alarms
Info


CUSSONS