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Preliminary Design Analysis of RoPax for Nigeria Coastal Water Pliability

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Abstract

This paper describes procedures used for preliminary design analysis of a roll-on; roll-off passenger vessel abbreviated as RoPox. As the name presupposes, RoPax ships are used for carriage of rolling type-cargoes and as well as passengers. RoPax are usually medium size ships with high performance characteristics that enhance their application for both long and short distance journeys. For instance, in Nigeria where most of her regions are surrounded by seas, this type of ship is apt. Several methods were implemented in order to obtain some preliminary results scoped in dimension, hydrostatic and hydrodynamic characteristics. The methods used correlate well with conventional values discussed in reality and in literatures.

Keywords

Preliminary Design Analysis, RoPax, Coastal Water, Transportation, Ferries, Hydrostatics, Hydrodynamics

1. Introduction

In recent times, global trading is dominated by international shipping industry to meet the requirements of the world demand. As such, the application of various types of ships especially, a type that could combine both the carriage of persons and goods is important for economic reasons. The Roll-on/Roll-off passenger (RoPax) and cargo ship is one of such ships that have received wide usage and attention recently. RoPax ship is famous among other classes of ships due to its ability and flexibility to integrate with other transport system functions such as carriage of goods, persons, rolling cargoes and rendering of services of all types. Its speed of operation has made it exceedingly famous on many shipping routes. It is defined in International Maritime Organization (IMO) as "a passenger ship with Ro-Ro cargo spaces or special category spaces" [1].

The most important role of this type of ship is to serve as a passenger/car ferry, particularly on short sea route.

Two classes of RoPax currently exist, namely; 1) night ferry and 2) day ferry. Night ferries are used for long distance journey and are designed to have accommodation spaces for passengers and crew. Since, insecurity is prevalent in the Gulf of Guinea, night ferries could not be used in this route. Day ferries are mainly used for short route [2].

They could therefore be recommended for application in maritime transport service in the coast of Nigeria.

The transportation industry in Nigeria is faced with challenges ranging from high cost of transportation to poor road infrastructures. However, it is believed that, the introduction of RoPax vessel will offset these problems within the southern part of the country enriched with natural and human resources. RoPax are also used for a short route within coastal regions of developed nations for economic and sustainable development [3].

In developed countries like European countries, a feasibility study carried out indicates that the use of RoPax has contributed drastically to the economy of countries [4]. This work is intended to add; to the development of the maritime industry especially that of Nigeria by first, proposing a preliminary engineering model of a typical vessel that can ply the coastal waterways of Nigeria as part of economic diversifications and emancipation.

Designing a ROPAX ferry to meet both international and national standard implies the application of modern design concepts of specified constraints of the vessel, environment, cost and cargo. Employment of holistic design approach as elucidated in [5], may be useful to enhance from conceptual design to other reference design stages. This is assumed to enhance the optimality of the design as compared with the conventional, traditional, pedagogical design concept.

The focus of this work will be on the determination of basic design parameters that could be used by indigenous shipbuilding industries and researchers for further analysis, development and perhaps subsequent construction of RoPax in Nigeria. This paper also aims at the determination of hydrostatic design and hydrodynamic parameters for the preliminary design for a Roll-on/Roll-off Passenger (RoPax) vessel for application in Nigeria coastal waterway and in extension it's applicability to inland waterways. To realize this goal, the following objectives are considered. These are to:

- Perform a feasibility study of RoPax for the specified route;
- Determine principal dimensions of the proposed ROPAX;
- Determine hydrostatic and hydrodynamic parameters of the vessel.

2. Literature Review

2.1. State of the Art Literature Review of RoPax

Determination of Dimension of RoPax

The determination of the dimensions of a new ship design requires design data from experiments carried out in a towing tank, where appropriate scaling laws can be applied to obtain the particulars of the proposed ship. Most of the data of fast displacement hulls for design purpose is based on systematic experiments carried out years ago in model tanks ([6] [7] [8] [9] [10]). Numerous methods of extrapolation and manipulation of model data to actual ships have been investigated and a summary of few of the methods for preliminary estimates of dimension can be found in [11]. Design data of similar RoPax ships in service have also been tabulated and approximations formulated to still enhance the determination of principal dimensions [12].

Investigations into the determination of wetted surface area of round bilge hull forms have been carried with the use of results from model test experiments ([13] [14] [15]). Reference [11] presented two approximation methods for the determination of principal particulars of new ship. The methods used include, displacement carrier method and volume carrier method. The displacement carrier method is used for ships such as tanker and bulk carrier. The volume carrier method is basically used when the ship involved does not carry much weight but occupy large volume of deadweight. A flow chart by [16] is also given in this book by [11] to enhance preliminary estimate of the dimensions of volume carrier and displacement carrier ships.

To overcome the problem of excluding the ship's speed from the determination of the preliminary dimensions of a proposed ship, an introduction of performance data into the initial estimation of dimensions becomes imperative [11]. There are various methods (such as ITTC-78, Froude method, ITTC method, Hollenbach method, Compton method and so on) to calculate the resistance of a ship which will lead to the prediction of effective power characteristic of the ship. This power can then be integrated into the flowchart, and iteration process is run with changes in some variables of the systematic series chosen for the proposed new design.

Resistance Analysis of RoPax Ships

It is frequently necessary to estimate calm water resistance characteristics of various hull forms before model tests are run. This can produce a decision that will enhance selection of optimal hull form characteristics for a proposed design. It was observed in [17] that due to constraint in speed range of the methodological for high speed crafts, new method of obtaining resistance data for a new ship is pertinent.

The resistance of a ship is composed of viscous and non-viscous component. The viscous component is due to the friction of the water body on the ship hull. This resistance component is generally called the frictional resistance, and depends on the Reynolds number. The non-viscous part is contributed by the waves in water and Eddy effects. It is usually referred to as residuary resistance, and it is dependent on the Froude number.

Several regression methods have been investigated by researchers for determination of resistance of ships. Reference [8] carried out an investigation of resistance prediction of SKLAD series and concluded that all the independent terms in the equation for residuary resistance-displacement coefficient should exceed ten. A similar analysis was consequently investigated in [18] for S-NPL systematic series with negligible concession.

Reference [19] proposed a regression method for the determination of the residuary resistance-displacement weight. Four coefficients were included in the resistance equation as independent variables. Reference [20] presented a statistical approach to predict resistance and power of ships. The formulation presented in the work was backed with theoretical expression for the residuary resistance as well as a method of extrapolating data for Froude number beyond the limit specific in the analysis. Reference [21] reviewed the various systematic series available with methods of data extrapolation for design purpose. The researcher also assesses the multifarious regression equations and recommended care should be taken in their application due to constraints on speed limit expressed in terms of Froude number. In addition, reference [21] carried out the analysis of resistance of a 60 m high-speed displacement hull. In 1959, [22] proposed a graphical method of determination of power of round bottom high-speed ships. This method expresses the power in term of the length and the speed of the ship.

The resistance of a ship can also be estimated by application of computational fluid dynamics (CFD) during the early stage of design. There are several works carried out in the application of CFD tool for ship hull optimization as described by [23] and [24]. Furthermore, ship resistance is not only related to the shape of the hull, but also depends on dynamic effects like sinkage and trim developed during navigation [25]. A possible basic CFD setup to study the problem is explained by [26]. Whereas [27] went further to implement a self-propelled model free to sink and trim. Similar investigations have been done by [28] on a container ship and by [29] on the Wigley hull, and they have been the references for the work presented here.

Most of the methods mentioned can only be used in the early stage of ship design. Verifications can then be conducted through model tests. There are basically three types of test required for complete examination of the actual design analysis of ship. These include the resistance test, open water propeller test and self-propulsion test. The explanation of the various processes in each of the test outlined can be found in [30].

2.2. Design Challenges of Current RoPax Ships

Despite the many economic impacts of RoPax vessels, there are many problems associated with this type of vessels; which are expressed in International Maritime Organization [1] as

- Lack of internal bulkheads;
- Water Ingress into Openings for car access;
- Low freeboards;
- Car stowage and securing issues;
- Increase in the size and number of lifesaving equipment;
- Highly technical crew engagement;
- Stability issues.

Lack of internal bulkheads

This is attributed to the fact that this type of ships carries Roll-on/roll-on cargo and requires an open internal hull for the cargo to roll in and off easily.

Water Ingress into Openings for car access

The ramps at the bow and stern of the ship pose a potential risk of water leakage because they are large openings in the hull, close to the water line. The possibility of a deliberate or accidentally leaving of the ramp unsecured may cause danger of water getting to the cargo space. The second potential danger is the result of dynamic loading and unloading of vehicles that eventually causes distortion and fatigue of ramps.

The location of the cargo access doors is at a height a bit above the waterline, which, in the case of an unplanned trim or heel of the ship due to the displacement of the load, both during navigation and while being located in a port during loading and unloading of cargo, can lead to sudden leakage of large amounts of water into the cargo accommodating area [3].

For the time past, many accidents had occurred due to water ingress into the RoPax. In case of flooding, large undivided garage spaces allow for a sudden inrush of contact. This phenomenon is water and the generation of free surfaces that can threaten the stability of the ship and can cause the rapid listing and possible capsizing of the ship. The main problem and the uniqueness of RO-RO ships is the potential loss of the positive stability due to water ingress into the vehicle garage, caused by an accident such as collision

RoPax ships, contrarily to other types of ships, may encounter difficulties to meet the survival time requirements because of the capsize mode related to the likely flooding of the large vehicle space, which is commonly located above the subdivision or car deck [31]. As the damaged openings may extend vertically above the car deck, the vehicle space may also get flooded due to the action of waves, and the ship may even capsize if the accumulated floodwater mass exceeds some critical quantity. The major accidents and challenges so far reported are summarized below.

Some of the major examples of incidents caused by instability are summarized as follows; a RoPax named "Herald of Free Enterprise" capsized and foundered just outside Zeebrugge Harbor in Belgium in the year 1987. Over hundred lives were lost [32]. This vessel had been designed to the standard of 1960 SOLAS convention. The accident therefore demonstrated that the existing stability criteria were still unsatisfactory and therefore, emphasis on the necessity for more realistic rules to improve the safety of RoPax ships was made.

New amendments made to argument the existing approach by introducing the following three changes;

- A value of 150 mm for a minimum range of positive residual righting arm;
- A value of 0.015 m-rad. for the area under the righting lever curve of the ship in the final damaged condition;
- A minimum GZ value of 0.1 m.

Subsequent modifications to the above amendments were made in 1990 with the introduction of residual stability standards concerning righting levers, the area under the GZ curve and limiting angles of inclination for both cargo and passenger ships. This came into force at the beginning of 1992 ([33] [34] [35]).

A RoPax ferry named "Estonia" also sank in 1994 with over 850 lives lost as a result of large amounts of accumulated water on the cargo decks. This water collection reduced the stability of the ferry. Following this incident, a panel of experts met in December 1994 to identify ways of augmenting the maritime safety of Ro-Ro passenger ships. The conference agreed that all existing Ro-Ro passenger ships must deal with the damage stability requirements of SOLAS'90 [33]. The tragic accidents of the Herald of Free Enterprise and Estonia stressed the magnitude of the problem presented when water enters the deck of ships with large undivided spaces (such as Ro-Ro vessels).

Reference [36] reported that a committee called "Joint Northwest European project" established to address the development and also for validation of numerical tools for assessing the damage survivability of passenger/Ro-Ro vessels. The research resulted in the development of the static equivalent method (SEM) for Ro-Ro ships [36]. This method statically analyzed the volume of water that will diminish the damage GZ curve to exactly zero [37]. From this neutral stability position, it follows that any lesser amounts of water will imply survivability of the ship and further additions of water will cause ship capsizing.

The "Regional Agreements Concerning Specific Stability Requirements for Ro-Ro Passenger Ships" otherwise known as the Stockholm Agreement [38] is considered to provide an alternative to the deterministic approach of stability analysis. This model test method requires that at least five experiments for each peak period should be carried out and be documented by means of a written report and a video recording of the experiments.

The ship model should exhibit the same outer and internal configuration as the original ship, and it should be placed in beam seas with the damage hole facing the oncoming waves. More details can be found in [1].

The development of new regulations and the revision of SOLAS still continues. In recent years much works are being undertaken within the umbrella of the Harder Project [39] [40] and [41]. The aim of the "Harmonization of Rules and Design Rationale (HARDER)" project is to harmonize the stability demands on passenger and cargo ships greater than 80 m in length. The final outcome of the HARDER project can be found in [38]. The NEREUS project commenced in 2000 has the aim of developing design tools and methodologies to improve Ro-Ro damage resistance against capsize. Some of the validation work carried out within NEREUS can be found in [42].

Stability

In this section, some approaches to stability calculations are reviewed. These approaches are deterministic and probabilistic methods to ship stability analysis. The deterministic approach to ship stability is mandatory, whereas the probabilistic method is accepted as an alternative approach when the deterministic method is found to be unsatisfactory. Each approach reviewed in turn in the next sections.

Deterministic approach to ship stability analysis

The deterministic approach gives the possibility to account for the floodable length and for the disposition of transverse watertight bulkheads. The floodable length changes with longitudinal position of the ship. It is the maximum length of a compartment, which if it is flooded, would permit the vessel to float at a waterline that is below or touches the "Margin Line". The "Margin Line" is a fair curve drawn 76 mm below the bulkhead deck, which is the uppermost deck to which watertight bulkheads extend. Ships are subdivided according to their "Criterion of Service" and their "Factor of Subdivision (or Subdivision Standard)". The "Criterion of Service" is a numeral that expresses the degree to which a ship is a passenger carrying ship. For example, a numeral of 23 corresponds to a ship primarily engaged in carrying cargo with a small number of passengers, whereas a numeral of 123 applies to a ship engaged, mainly, in the carriage of passengers as discussed in [43].

This assignment of the numeral depends on the ship length, the number of passengers, the total volume of the ship below the margin line, the volume of the machinery space and the volume of the accommodation spaces below the margin line. The lower the value of the numeral assigned the further apart the watertight bulkheads may be spaced. The "Factor of Subdivision", designated F, depends on ship length and the designated criterion of service.

The "Factor of Subdivision" states the permissible length between watertight bulkheads. It is expressed as a percentage varying from 30 to 100 percent. A factor of "F = 0.3" means the bulkheads may be spaced a separation distance only equal to 30 percent of the floodable length. If the factor of subdivision is greater than 0.5, the ship must satisfy the "one compartment standard (any one compartment can be flooded without the ship sinking)", if F is between 0.33 and 0.5 then the vessel should satisfy the "two compartment standard" and finally if F is smaller than 0.33 the floating structure should meet the "three compartment standard".

So, when the floodable length at each location along the ship length is calculated (Lewis, 1988); the permissible compartment length at each point is obtained from the multiplication of the floodable length and the factor of subdivision. In this way, a permissible length curve along the ship is derived. However, when a ship is damaged and some compartments become open to sea, the seawater cannot fill such volumes totally as some space are already occupied by internal ship arrangements e.g., bulkheads, main engines, auxiliaries, pumps, cargo et cetera. So, before the floodable length can be calculated, definite values of the permeability of the spaces involved must be determined. That is, the fraction of floodable volume in a compartment. Thus, the floodable length curve should be determined for different levels of permeability. An indication of the influence of permeability levels on the floodable length is discussed in [32]. At the moment the floodable length curves have been found the level of stability at the appropriate level of impermeability can be interrogated. Acceptability is achieved for a peculiar level of stability for the chosen level of permeability when the triangle apex lies below the corresponding floodable length curve. Invariably, the locations of transverse watertight bulkheads are determined by ensuing each constructed triangle meets the requirement indicated.

Probabilistic approach to ship stability analysis

The probabilistic approach to stability analysis was developed in 1973 to estimate the probabilities of different damage stability related events and available accident records were used. It is the known occurrence of such damage stability related events that govern the concept of stability in this procedure. In the probabilistic approach, the survival probability of a damaged ship is defined through the "attained survival probability index, A".

3. Material and Methods

3.1. Focus Area

The area of operation of the proposed RoPax is between to two extremes, namely: Lagos and Cross River States which border the Nigeria Coast to the west and south respectively. The coastal zone of Nigeria lies across a total of nine states, out of the 36 states of the Federation. These states include, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Lagos, Ogun, Ondo and Rivers. The coastline of Nigeria traverses a length of about 853 km facing the Atlantic Ocean. The projected population of Nigeria is about 206 million people with the coastal states accounting for 25% of the national population (*i.e.*, about 51.5 million people). The Nigerian coast and marine areas are under the influence of moderate oceanographic dynamics consisting of semi-diurnal tides with tidal ranges varying from one metre in the west to three metres in the east. The vegetation of the Nigerian coastal area is characterized by mangrove forests, brackish swamp forests and rain forests [44]. The present study considers all the nine along Nigeria's coastal area. Unaccounted number of jetties or harbors exists within these states with major seaports in Lagos, Rivers and Cross River States.

3.2. Materials

The following materials were used in the work;

Map

The distance between Lagos and the Cross Rivers States was measured from the Map in **Figure 1**. The horizontal distance on the map is one meter per 100 kilometers on the water surface which is equivalent to 61 miles or 53 nautical miles.

Interview Form

Interview form was developed to enhance collection of data which was used in the determination of a feasible RoPax for Nigeria Coastal Water and Inland Water ways. The interview focused on the determination of the number of passengers and cars plying the operational region of the proposed RoPax vessel by land and the cost variation per head. The time taken between the two extreme operational areas was interrogated to enhance the design of the proposed RoPax in terms of comparative analysis with land transportation. Investors' willingness to diversify into RoPax proposal was also sought. Hundred interview forms were distributed within Uyo Metropolis in Akwa Ibom State and Calabar in Cross Rivers State. Fifty forms were distributed in the two states to the various transport works in both private and public companies. Three sets of workers were interviewed. They include managers, office works and the drivers. Similar questions directed to each of the three sets of people. It is worthy to note that the sample size was determined based on purposive sample technique.

Basis RoPax Hull Form

A typical hull form from [37] is shown in **Figure 2**. The basic characteristics of this RoPax were also obtained to enhance comparison with the proposed design from [37].

Software

The following software was used in the design analysis:

SolidWorks: This software was mainly used for two purposes; to proportion the basis hull form to the dimension that will be obtained based on the feasible result, and to generate the half-breadths using spline tool to trace from the basis hull body plan and employing smart dimension tool in measuring the half-breadths at predefined heights on each station from the centerline of the body plan.

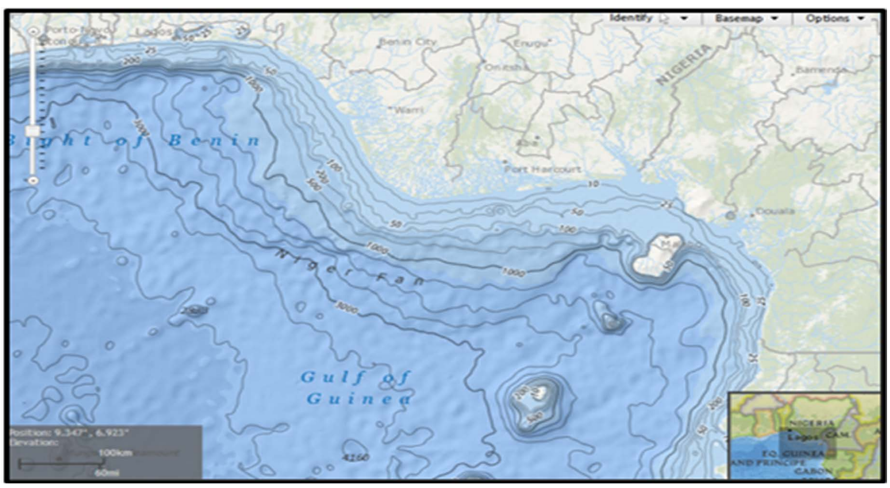

Figure 1. Map showing some Bathymetric data on Nigeria Coast [33].

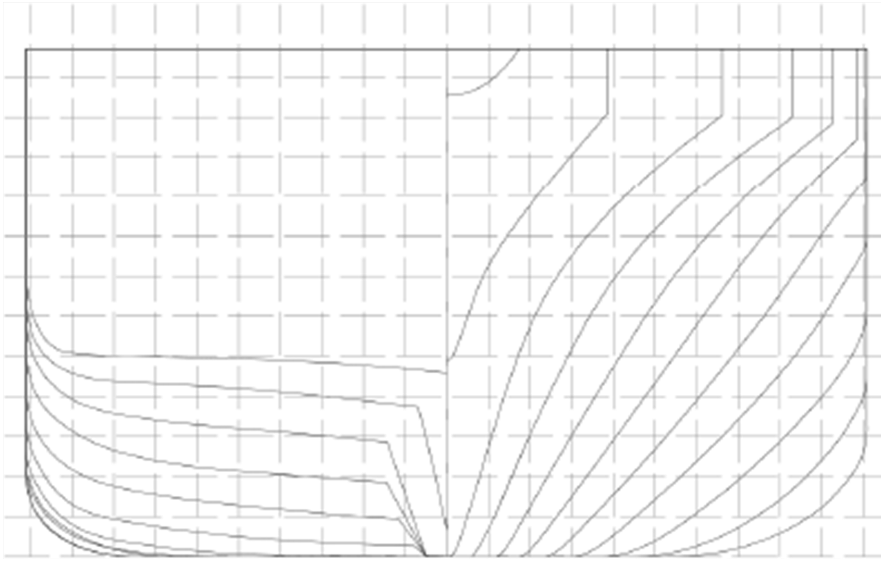

Figure 2. Basis Hull form [37].

Inventor: The half-breadths obtained in SolidWorks software were used as inputs in inventor software to obtain the 3D representation of the RoPax which enhances the determination of some hydrostatics results.

Maxsurf: This software was used in carrying out the hydrodynamic analyses by importing the 3D hull modeled in Inventor into its hull fitting module and thereby performing the resistance and power calculations using the resistance module of Maxsurf.

3.3. Methods

The following methods were used to achieve the objectives of this work.

Purposive Sampling Method

The data collected from interview were sampled based on the intuition of the researchers in order to meet the aim of the work.

Kristensen Method

This is one of the empirical methods employed in the determination of principal dimensions of a new ship. In this method, databases of RoPax which contain some basis dimensions, number of passengers and lane meters of RoPax are used in the formulation of equations which are expressed in Equations (1) to (15) [12].

Length, Beam, Draughts and Depth:

$$L_{PP} = 22.5 \times N_P^{0.255} \tag{1}$$

$$L_{OA} = 1.078 \times L_{PP} + 1.93 \tag{2}$$

$$B = 0.116 \times L_{PP} + 7.5 \tag{3}$$

$$T_{\min} = 0.028 \times L_{PP} + 0.95 \tag{4}$$

$$T_{\max} = 0.028 \times L_{PP} + 2.45 \tag{5}$$

where, L_{PP}, L_{OA}, B, N_p and T are the length between perpendiculars, length overall, beam, number of passengers and drafts respectively.

Depth to Uppermost Continuous Deck (Weather Deck)

The height of the uppermost continuous deck (weather deck) above the keel, H, is also an important main dimension since it will enhance the determination of the ship's freeboard. It is given by Equation (6).

$$H = 0.05 \times L_{PP} + 6.94 \tag{6}$$

Lightweight

The lightship weight is basically the weight of the steel material of the hull, outfitting and propulsion machinery. It is proportional with the three main dimensions, L_{pp}, B and D. The lightship data was plotted as function of L_{pp}, B and D in [12] from which the following empirical equation for the lightship weight W_L has been derived:

$$W_L = 0.176 \times L_{PP} \times B \times T_{\min} + 6 \tag{7}$$

Lane Meter

The number of lane meters is determined as a function of the number of passengers for each cargo category as follows;

$$L_M = 1.015 \times \text{passengers} + 105 \tag{8}$$

The ratio of deadweight per lane meter is given in Equation (9) as;

$$\text{Deadweight}/L_M = 12.4 \times L_M^{-0.185} \tag{9}$$

The deadweight is the function of lane meter as stated in Equation (9). This implies that the deadweight for the cars can be calculated with this formula. Also, the weight of the passengers is added to the cars' deadweight. The weight of a passenger is taken as 100 kg approximately plus luggage's weight. The assumption of the passengers' weight is based on European Committee for Standardization (CEN) 16,258 [12].

Design Draft (T_D)

The design draught of the ship can be calculated using the empirical formula given in Equation (10) as;

$$T_D = T_{\max} + 0.0015 \times L_{PP} - 0.55 \tag{10}$$

Gross Tonnage

Equation (11) calculates the gross tonnage of the ship as a linear function of displacement.

$$GT/\Delta = 0.0000352 \times \Delta + 1.14 \tag{11}$$

Service Speed (Vss)

Vss is given in Equation (12)

$$Vss = 0.085 \times L_{PP} + 8.98 \tag{12}$$

Block Coefficient (C_B)

This can be derived numerical by using Equation (13)

$$C_B = a - bVs/L \tag{13}$$

where Vs, is the velocity in knot in Equation (13) and in m/s in Equations (14) and (15); values of "*a*" and "*b*" may be taken as 1.23 and 0.935 respectively. Using the last formula, the design average block coefficient of the ship is estimated as 0.5.

Froude number

$$Frs = Vs/\sqrt{gL} \tag{14}$$

Reynolds number

$$Rns = Vs/v \tag{15}$$

Volume Carrier Method

Volume carrier method is also an empirical approach initial investigated by [45]. This method has been refined and used by many other researchers and designers [11]. The method is applied to obtain other parameters such as areas of the passenger deck and area of the car deck. This can be achieved by using the equations below and given the initial numbers of passengers and cars as 300 and 85 respectively. A flowchart for this methodology is shown in **Figure 3**. This

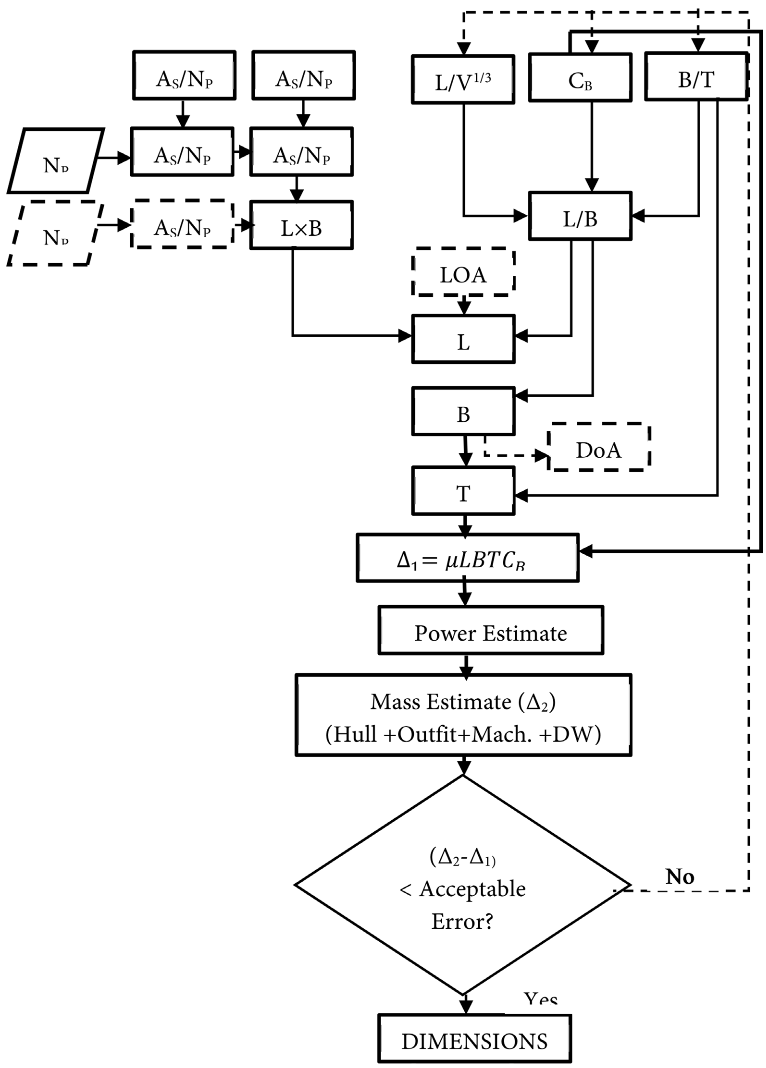

Figure 3. Flow chart of molland's dimension estimate method [11].

flow chart is implemented in this work.

The following Equations [(16) to (25)] were used for implementations of this method.

$$L \times B = 121 + 0.27A_P + 0.6A_V \tag{16}$$

$$A_V = 156 + 10.2N_V \tag{17}$$

$$D_{oA} = 4 + 0.6B \tag{18}$$

$$L/B = \left[\left(L/\nabla^{1/3}\right)^3 \times C_B \times T/B\right]^{1/2} \tag{19}$$

$$L = \left[\left(L \times B\right) \times L/B\right]^{1/2} \tag{20}$$

where: A_P, is the total passenger area;

A_s, is the seating area;

A_V, is the vehicle area;

N_P, is the number of passengers;

N_V, is the number of vehicles;

D_{OA} is the overall Depth;

ρ is the density of seawater taken as 1025.3 kg/m^3;

DW is the Deadweight;

∇ is the volume displacement.

Table 1 shows the range of values used in this method. The range of values in the table is based on the size of the RoPax with the intending number of passengers and car.

4. Results and Discussion

4.1. Feasibility Study

The data collected from field survey (Table 2(a) and Table 2(b)) show that the distances covered by land are approximately, 1800 km and 1440 km between Lagos-Calabar and Lagos-Akwa Ibom respectively using the calculated sample mean with the means of the time taken for the two states. Also, the map on Figure 1 was used for the determination of distance on water between Lagos and Calabar which indicates the maximum distance this vessel will cover in 12 hours. The findings as per duration on water and on land indicate that transportation

Table 1. Range of values for volume carrier approach [11].

Item	Value
A_S/N_P, m^2	0.85 - 1.25
A_P/A_S	1.15 - 1.45
$L/\nabla^{1/3}$	6.0 - 9
B/T	3.5 - 7.5
C_B	0.35 - 0.85
L_O/L	1.13 - 1.15

Table 2. (a) Range of values of speed extracted from interview conducted; (b) range of values of time extracted from interview conducted.

(a)

Cal-Lagos		Uyo-Lagos	
Speed Range (km/hr)	**F**	**Speed Range (km/hr)**	**F**
170 - 165	5	170 - 165	4
160 - 155	20	160 - 155	15
150 - 145	25	150 - 145	16
140 - 135	30	140 - 135	35
130 - 125	15	130 - 125	20
120 - 115	3	120 - 115	6
110 - 105	1	110 - 105	2
100 - 95	1	100 - 95	2

(b)

Cal-Lagos		Uyo-Lagos	
Speed Range (km/hr)	**F**	**Speed Range (km/hr)**	**F**
18 - 17	1	18 - 17	1
17. - 16	10	17 - 16	11
16 - 15	10	16 - 15	15
14 - 13	30	14 - 13	35
12 - 11	32	12 - 11	35
10 - 9	17	10 - 9	3

by water would take short distance and time compared to land transportation. The distance on water is about 800 km. Worthy of note is that for a viable RoPax, the number of passengers should not be below 300 and the number of cars estimated for this route is 85.

4.2. Proposed RoPax Principal Dimensions

The preliminary design carried out demonstrates that for a viable design of RoPax, an overall length of 92.5 m, which is the average of the two methods considered in this work is required and the length between perpendiculars is 85 m. Table 3 shows the summary of the ship dimensions using two forms of empirical approaches developed by [12] and [44]. The column for average is the considered principal particulars of the ship. A scale factor of 30 was chosen for the model. Also, from Table 3, the basic dimension of the model is shown in the last column. This is in accordance with the laws of similitude [45]. For experimental investigation of the resistance and other hydrodynamic characteristics it would be important to consider the dimensions of the model shown in Table 3.

4.3. Lines Plans

The lines plans include the body plan, the sheer or profile plan and the half-breadth or water-plane plan are given using half-breadths. A modified body plan of the proposed RoPax is shown in **Figure 4**.

4.4. Hydrostatics

The hydrostatic coefficients of the proposed design are indicated in **Figure 5**. At the design draft of 4.037 m, the block, prismatic, midship area and waterplane area coefficients are found to be approximately, 0.62, 0.67, 0.92 and 0.87 respectively.

Some hydrostatic signatures can also be read from **Figure 6**, which indicates

Table 3. Preliminary Particulars of Proposed ROPAX using formulae by [12] and [45].

	Kristensen Method	Karayannis Method	Avg	Model Particular
L_{OA}, m	100	85.2	92.6	3.08
L_{PP}, m	90	80	85	
LWL	-	88.6	88.6	
B, m	21	19.1	20.5	0.68
$T_{\max}$,	5	3.47	4.24	
$T_{\min}$, m	3.5	-	3.5	
T_D	4.6	3.47	4.04	0.14
∇, m^3	4528	3395	3961.5	0.15
Δt	4641.2	3483.3	4062.2	0.15
D_{OA}, m	11.5	10.64	11.07	0.37
LM, lm	360	-	360	

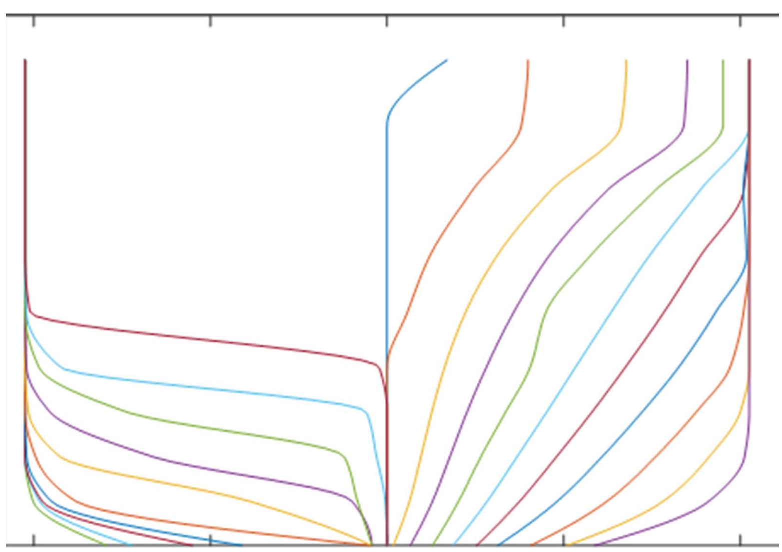

Figure 4. Body plan of the RoPax.

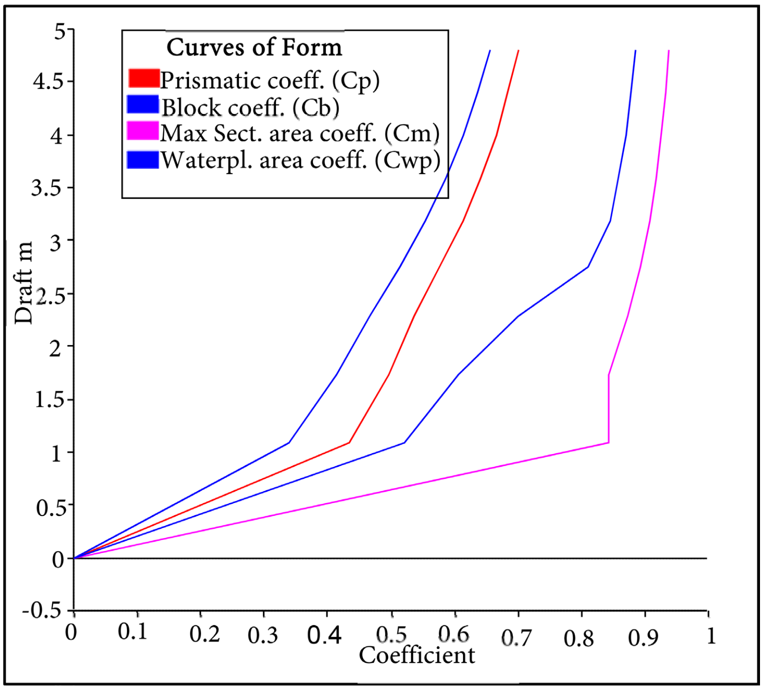

Figure 5. Hydrostatic coefficients obtained from inventor.

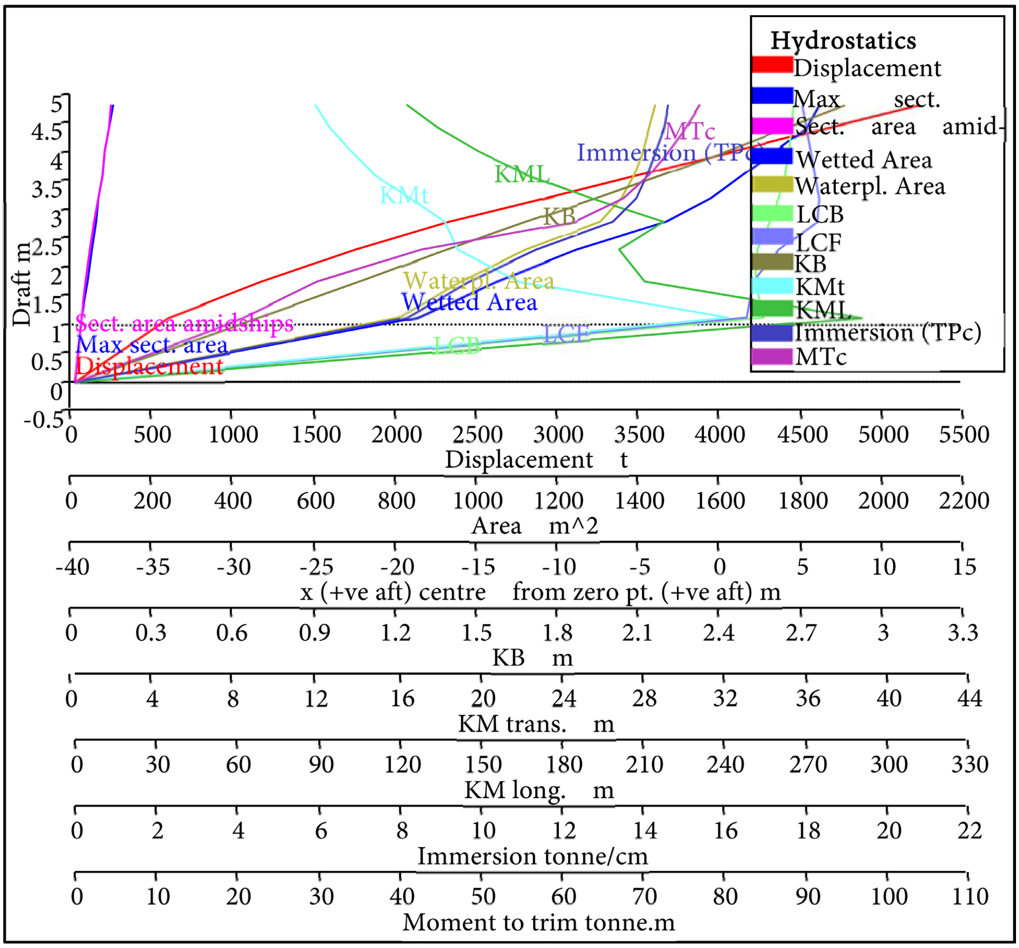

Figure 6. Hydrostatic characteristics of the RoPax.

that at a design draft of 4.037 m, the displacement mass, water plane area, moment to trim ton meter.

4.5. Hydrodynamics

The resistance and powering characteristics of the proposed ship at the preliminary are given in Figure 7 and Figure 8. Figure 7 shows the resistance at each given speed. This was obtained in Maxsurf by using Holtrop and Menn method.

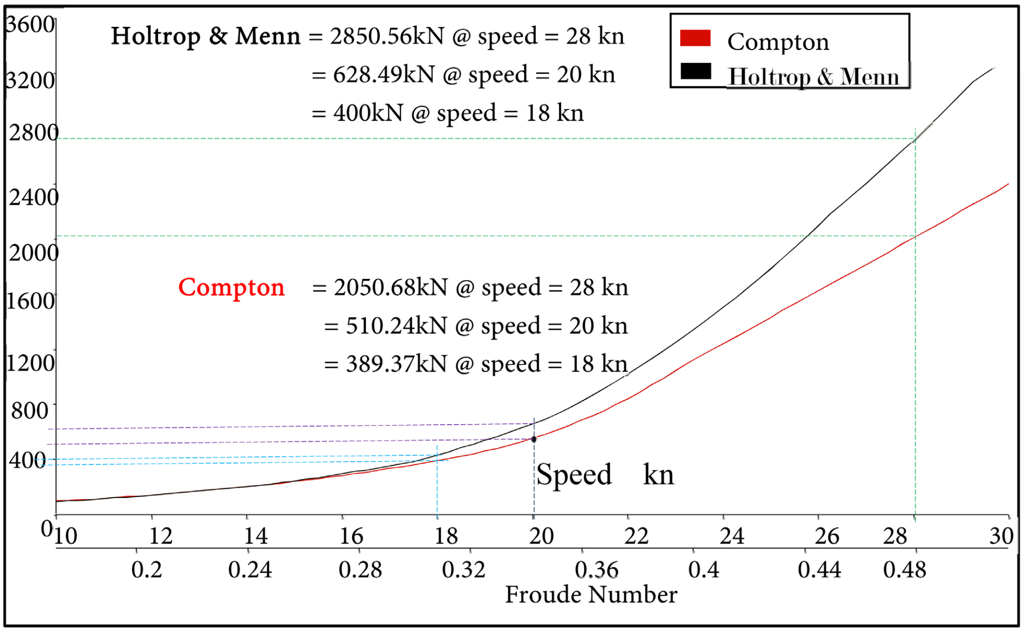

Figure 7. Bare hull resistance against speed.

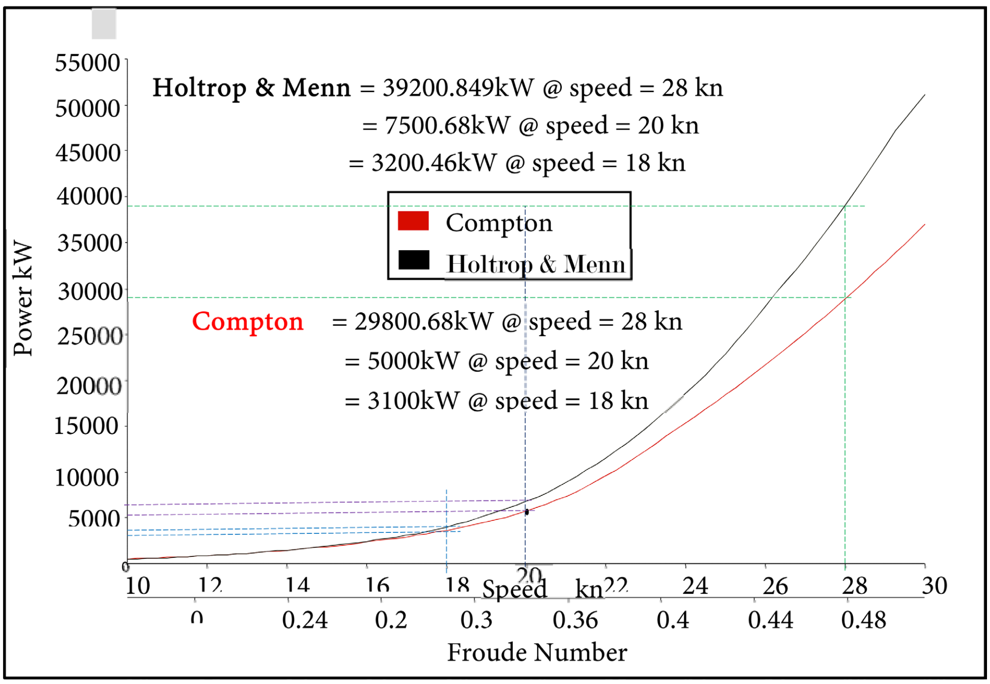

Figure 8. Effective power against speed.

Also, the powering characteristic obtained using the same method is shown in Figure 8. A work carried out in [46] agrees in trend and in values to this present despite the fact that different empirical methods were used. [46] made use of Savisky and Central-Aero Hydrodynamic Institute Methods while the present method compares Holtrop and Menn method [47] with Compton method [48].

Figure 7 and Figure 8 also compare the two empirical methods of determining resistance and power of a ship. At the speed of 18 knots, the total bare hull power of 3200 KW and 3100 KW for Holtrop and Menn and Compton Methods respectively was obtained. These values are validated with a work carried out by [31] at the same speed. It is noted that, beyond the speed of 20 knots, the values of both the resistance and power become overestimated as expected since in Holtrop and Menn the empirical formular can only be valid within the speed range of zero to twenty knots.

5. Conclusions

An application of technical design methodologies has been elucidated in this work for determination of preliminary dimensions and other relevant characteristics of RoPax ship which could navigate safely, economically and satisfactorily within the coast of Nigeria. At the end of this work, the objectives have been achieved through an iterative process illustrated in the conventional ship design spiral and marred by the use of computational algorithms that are based on recent and conventional methods. The use of various tools to optimize the hull form was stressed.

Microsoft excel inbuilt curve fitting tool (Trendline), MatLab inbuilt tools for curve fitting and as well as a flow chart to implement the method of Regression Splines with a developed flowchart.

Some codes developed were used to verify some of the design tools used in the work. Agreement noticed implies that the methods used are valid within some speed limits. The hull form hydrodynamic optimization was noted to give rise to the selection of the best hull for the proposed ship to ensure minimal energy lost in service. The determination of the other properties of the ship using empirical formulas was carried out also, and comparison was made with other existing or novel empirical relationships. This work also introduces computational algorithms into the design space which enhances rapid changes of any parameters of the design. The selection of the main and auxiliary systems could therefore be carried out considering values obtained at this stage of design. The results obtained in this work agreed very well with those obtained from software.

In the determination of coefficients of form and hydrostatic signatures of the vessel at some selected drafts the range of values indicates that the ship has fine hull form and full hull form as the draft changes. This is indicated by the C_B and C_P values generated. At the design draft of 4.037 m, the block coefficient obtained is 0.82 with a corresponding prismatic coefficient of 0.09. The high values obtained at this point show that the RoPax has a full hull form. This is in accordance with existing range of values for any oceangoing ship with values spreading from 0.5 to 0.90 at the design draft.

The hydrodynamic resistance results shown in **Figure 7** and **Figure 8** agree both in trend and values with minimal deviations. This is in agreement with the general resistance graph. A comparison of these graphs with other published materials could show this. It can be seen also that using Maxsurf software for resistance analysis of this type of ship is viable and recommended. However, there are needs to include computational fluid dynamics methods as a way of validation in the resistance analysis aspect of the design.

6. Further Work

With the preliminary results obtained, it would be possible to have a clue on the actual design of the RoPax that would ensure its application in the Nigeria coast considering basically the performance that would give an insight into cost estimate and profitability analysis. Hence, it is recommended that, the actual design be done in order to compare results with that obtained in this work for future application.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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