STEVENS INSTITUTE OF TECHNOLOGY

Preventing Ferry Fatalities: Providing a Safer Ferry for Developing Nations
Final Design Review
Carl Nagle and Harlysson Maia
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Abstract:

The purpose of this document is to serve as an overview the work completed toward a ferry safety project during the course of the 2012-2013 academic year. The scope of work encompasses defining design needs, hull form comparison, vessel arrangements, stability analysis, structural considerations, resistance estimations, propeller design, and machinery selection. In addition to these key components, auxiliary system recommendations are provided. These auxiliary systems include electrical planning, life saving measures, and communications aiding devices.

Problem Situation:

In developed nations, ferry accidents are an uncommon occurrence and fatalities resulting from ferry operations are almost unheard of. In developing nations, ferry accidents are frequent events and fatalities from ferry operations result over 1000 deaths each year (Weisbrod). One cause of this striking difference is the substandard condition of ferry fleets in developing nations. In many cases vessels used are bought second hand and illegally modified for passenger transport. These older vessels, many being over 30 years old at the time of purchase, are not stable after modifications and are prone to capsize.

Design Needs:

The first step in the design process was to define the user requirements and purpose of the vessel's use. User requirements consist primarily of passenger/cargo capacity along a set waterway length. The vessel's purpose was to operate on a particular river system. Bangladesh was chosen as a target region for the ferry design. Bangladesh is a highly riverine nation where a large portion of the population lives in coastal zone and uses the ferry service on a routine basis to move about the country to work or travel. Bangladesh is also notorious for its ferry disasters.

An inquiry into the desired user requirements resulted in multiple route targets from Bangladesh. Three target cities were provided with all passages departing from the capital Dhaka. The particulars of each route are listed below in table 1. Based on the three given routes an optimal route was developed to best satisfy all three requirements with the goal of providing a design that was as universal as possible.

Route	Approx Distance	Passengers	Cabin Berths	Minimum Depth
Dhaka-Chandpur	150 km	Unspecified	Unspecified	2m
Dhaka-Madaripur	180 km	350-500	50	2m
Dhaka-Barisal	250 km	200-1500	150	2.5m
Optimal	282 km	750	75	2m

Table 1: Specified Routes

Nose in passenger berthing has been requested, meaning passengers would board the vessels from the bow end. The primary purpose of this vessel will be for passenger transport. Some locations in Bangladesh employ ferry vessels to transport trucks and busses across rivers however these particular routes are not tasked with vehicle transport.

In addition to requirements requested by Bangladesh, the design will need to maximize stability and limit free space in the design. Vessels are routinely overloaded by greedy owners and determined passengers. With no fixed seating, passengers and cargo are squeezed into every available space to make the journey (Huq). The open space on each deck creates a greater opportunity for dynamic loads to shift, reducing the overall stability of the ferries. The design incorporated fixed seating to limit passenger motion aboard ship along with setting a more fixed cap on the total amount of passengers that could be transported on each trip.

Another factor which must be considered is the fact that Bangladesh is the most disaster prone region in the world. On average Bangladesh experiences 6 natural per year. Monsoon rains and cyclones are frequent in the region, making it prone to flooding conditions. The impacts of Mother Nature only exacerbate the need for a vessel with a high level initial stability to ensure survivability in inclement weather.

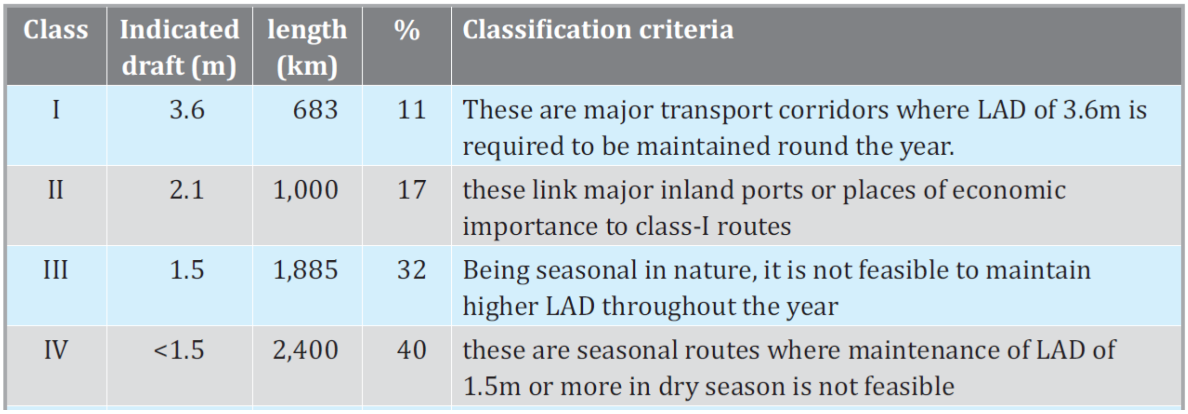
In addition to the ferries operation requirements, a tandem use was developed for the ferries to serve as a local transport vehicle for Humanitarian Aid Disaster Relief (HADR) kits. The HADR design team working at Stevens Institute of Technology, in a joint effort with students from the University of Alabama, chose Bangladesh as a target region to model the impacts such a kit could have on a disaster torn country. The kits provide basic necessities such as water-purification and remote power sources to effected regions. The ferry design was asked to design ferries so that they would be transport these kits locally as a means to reduce the overall commit level from developed nations in the event a disaster strikes the region.

The kits are to be stored in US Army JMIC containers for transport. The total package of each kit weighs in at approximately 500 pounds. After simulation the HADR team calculated at minimum 130 kits would be needed to provide sufficient relief to Bangladesh in the event of a natural disaster. A requirement for the using the ferries as transport would be ease of loading and unloading said kits. To facilitate this process, a bow ramp was designed onto the ferries so that kits could be rolled on and rolled off (RO-RO) the vessels by means of truck or forklift. This RO-RO capability additionally benefits the ferry design by providing only one means of getting on or off the ferry from port, increasing the ability for crowd control in preventing potential overloading of the vessels.

Design Constraints

The main constraint of the Bangladesh river system is the lowest available depth (LAD) of the rivers. The low water depth found in the majority of Bangladesh's rivers has to do with the high siltation rate of the river systems. Presently the Meghna River, a tributary which must be passed leaving Dhaka, has the highest rate of sediment discharge in the world and the third highest water discharge rate. The high levels of sedimentation lead to the development of braided river systems, where meandering flows will form sandbars throughout the river system. During the dry season (November to May), it is possible for these bars to emerge forming a series of narrow channels through the river (Reza). This bar formation is cause for the low LAD of just 2m found on the requested routes.

Based on information provided by the Bangladesh Inland Water Transportation Authority (BIWTA), routes into Dhaka and Barisal have a guaranteed LAD of 3.6m during all seasons (Husain). BIWTA employs a classification system ranging from class one to class four rivers throughout Bangladesh as a means to gauge the navigability and LAD. These routes are classified as class one routes, used to connect the inland regions with seaports found close to the Bay of Bengal such as Chittagong. These routes only account for roughly 11% of the river system in Bangladesh. A breakdown of the river classification system can be seen below in table 2.



Class	Indicated draft (m)	length (km)	%	Classification criteria
I	3.6	683	11	These are major transport corridors where LAD of 3.6m is required to be maintained round the year.
II	2.1	1,000	17	these link major inland ports or places of economic importance to class-I routes
III	1.5	1,885	32	Being seasonal in nature, it is not feasible to maintain higher LAD throughout the year
IV	<1.5	2,400	40	these are seasonal routes where maintenance of LAD of 1.5m or more in dry season is not feasible

Table 2: River Classification

The route to Madaripur is most likely a class II route. The class I standing of Dhaka and Barisal indicate there is a formal fairway available to gain access to these ports meaning the minimum depth reported is most likely a braided sandbar formation outside of these fairways. On these routes it is feasible to increase the draft past the minimum depth assuming the vessel operator can stay within the designated navigation channel. Load lines should be implemented on the final design to ensure the vessel is not overloaded depending on which class of river it will be traveling in.

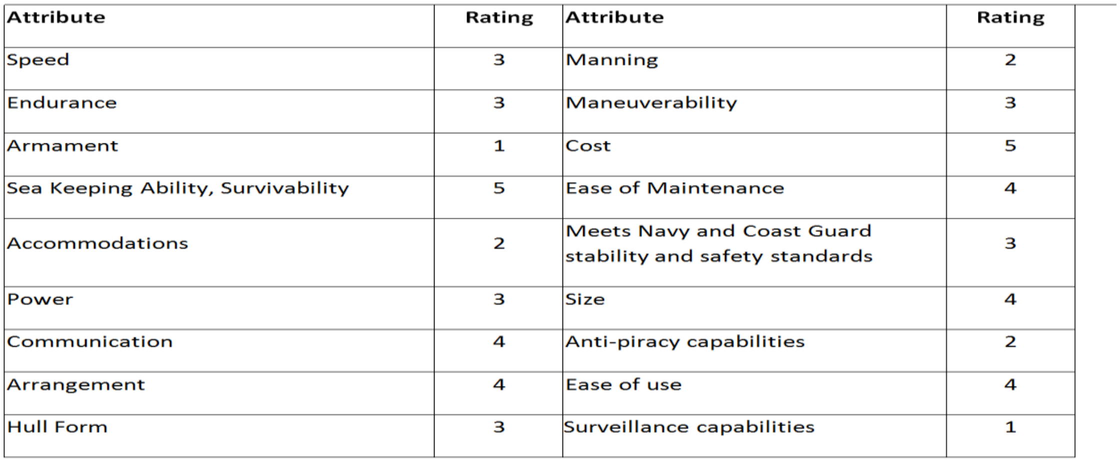
There are conflicting reports of water depth throughout the river system, as rivers are not dredged and routine recording seems unlikely. River tracking completed using ARCGIS software, a program using satellite imagery to determine water depths, indicates that middle portion of rivers from Dhaka to Chittagong is on average 20+m deep. The LAD for this section of river is reported as 5m (Reza). Using this data from what appears to be a reliable source, the consensus was it is plausible for the LAD to be greater than the reported values, especially in navigation channels. With this factor in mind the team decided upon a design draft of 2.5m, slightly greater than the originally indicated values.

The complications of this river system have resulted in limitations on ship velocity. According to the BIWTA operators must run at a safe, moderate speed of 12 knots (Huq). Due to this restriction, the target maximum speed of the design shouldn't greatly exceed this 12 knot limit in order to limit potential speeding and risk. By capping the design speed at 15 knots, it is easier to assure the vessel will be operated safely, by limiting the potential for faster operation, and still allow some reserve power in the event of rough conditions such as a storm. This factor is of particular importance because a substantial number of ferry accidents are caused by collisions, resulting from ferry operators attempting to overtake other vessels along the waterway.

Measures of Merit

Based the design criteria, a measures of merit table was established in order to determine which aspects of the vessel's design would receive the most attention during the design process. The measures of merit system works by ranking criteria on a scale of one to five to determine each criteria's relevance; with five being the highest priority items. The established measures of merit are shown in table 2.

Table 2: Measures of Merit



Attribute	Rating	Attribute	Rating
Speed	3	Manning	2
Endurance	3	Maneuverability	3
Armament	1	Cost	5
Sea Keeping Ability, Survivability	5	Ease of Maintenance	4
Accommodations	2	Meets Navy and Coast Guard stability and safety standards	3
Power	3	Size	4
Communication	4	Anti-piracy capabilities	2
Arrangement	4	Ease of use	4
Hull Form	3	Surveillance capabilities	1

The top priority aspects received 5's. These consist of *sea keeping* and *cost.* The vessels ability to complete deliveries and survive in a turbulent river system is the ultimate goal. Given the impoverished nature of the region, cost concerns will have to be paramount in order to make any design feasible.

Measures of great importance received 4's. These measures consisted of *communication, ease of use, arrangement,* and *size*. *Communication* was assigned a four because currently there is no means to communicate with pilots/operators aboard the ferries underway. This poses a serious risk as they often lack in house weather systems. One of the primary causal factors in regional fatal accidents is inclement weather. Even if the government can detect severe weather fronts, they have no way of relaying the message to operators, leaving them alone to deal with a hazardous, dynamic river system. *Ease of Use* was placed in this level to ensure things were kept as simple as possible for an often under qualified crew. *Arrangement* and *size* are allotted into this category with intentions to use these measures as a means to cut down on another main causal factor, overcrowding.

3’s were given to measures of moderate concern. *Hull form, power, speed, endurance, meeting Navy/Coast Guard standards,* and *maneuverability* were all placed in this level. The *hull form* should be kept simple as a means to ease fabrication, there isn’t much traffic so *maneuverability* isn’t a top concern, high end *power* and *speed* require often large, complex, and expensive systems, and this isn’t intended to be a warship, some of the Navy and Coast Guard’s standards may be overkill for the project. Great e*ndurance* isn’t a grave factor either because during normal operating conditions the vessel will be in port at least twice a day.

Measures ranked as 2’s include *anti-piracy, manning,* and *accommodations.* The people will use these ferries no matter how they are accommodated, ferry crews are generally small, and a small amount of time will be used to incorporate theft deterrents into the design.

1’s include *surveillance and armament,* during intended use, the ferry will have little to no use for these measures, some may be included but will be the first cut attempting to make cost.

Parametric Analysis

After defining the initial design requirements, the next step was to conduct background research into the field of ferry vessel operations. The goal of this research was to determine an approximate size of the vessel based on the target passenger capacity. To achieve this, the general parameters of 34 vessels were tabulated and compared in a parametric analysis. The sample pool consisted of 17 mono-hulled vessels and 17 multi-hulled vessels from all over the world with passenger capacities ranging from 60 to 2500 passengers.

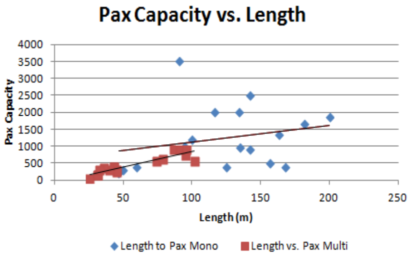
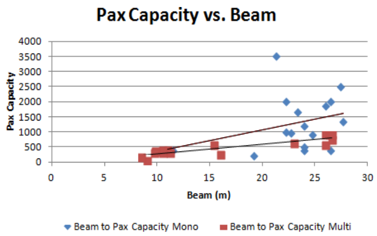


Figure 1

The first characteristic of focus was the overall length of the vessel. This was done by comparing each vessel’s passenger capacity to its corresponding overall length. Based on these findings a target length of 50m is anticipated for mono-hulled vessels, 90m for multi-hulled vessels. A plot of passenger capacity versus length can be seen in figure 1 to the left.

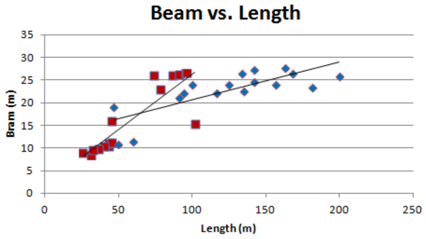
Next was the target beam of the design. Using a similar comparison resulted in target beams of 16m for mono-hulled designs and 25m for multi-hulled designs. A plot of passenger capacity versus beam can be seen in figure 2 to the right.

Figure 2



One outlier was present in the data for mono-hulled vessels. The MV John F. Kennedy, one of the Staten Island Ferries, has a passenger capacity of 3500 passengers at a length of 91m and a beam of 21.3m. This vessel fell in the middle of the length range for mono-hulled vessels and its high passenger capacity greatly altered the line of best fit for each plot of parametric data. After further examination of this outlier it was removed from the parametric analysis data. This vessel had a much higher draft than we were comfortable mimicking and required a power plant that would astronomically drive up the final cost of the vessel, making it unfeasible for developing nations to afford. Removing this outlier resulted in a better representation of the parametric data and yielded an anticipated length and beam values of 95m and 18m respectively based on a passenger target of 750 for the mono-hulled vessels.

Figure 3



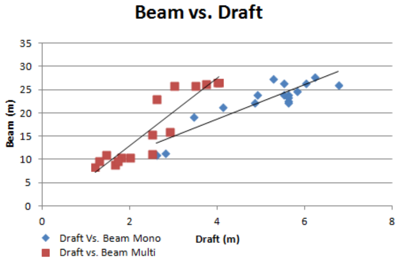
One important factor that can help to describe a vessel's shape and stability is its non-dimensional length to beam ratio, L/B ratio. The parametric plot of L/B is shown on the left in figure three. In the parametric analysis mono-hulled L/B ranged from 2.5 to 8 with an average value of 5.7. The values typically increased as the LOA increased. Multi-hulled vessels typically have a lower L/B ratio with values ranging from 2.5 to 6 with an average value of 3.93. Multi-hulls typically have to have a wider beam to equivalent length mono-hulled vessels in order to compensate for wave motion in between the hulls.

With stability being strongly linked to overall survivability, a top priority merit in the design process, it is paramount for the design to have a low L/B ratio. Using the anticipated values for a mono-hull design yields a L/B ratio of 5.27. With the goal being increased stability the beam was increased to 20m from 18m, yielding a L/B ratio of 4.7. This lower L/B value may result in a decrease in maneuverability, increase in resistance, and an increase in initial stability when compared to the typical design in this parametric survey.

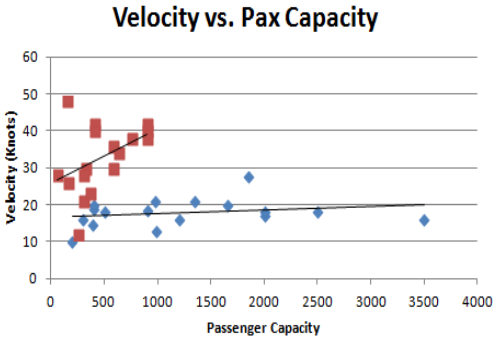
In the case of the multi-hulled vessel, anticipated values of length and beam yield a L/B of 3.6. Multi-hulled designs have a greater initial stability than their mono-hulled counterparts. Due to this fact, no beam extension was considered for the multi-hull design since mono-hulls are currently used in Bangladeshi ferry operations and the anticipated L/B value is already less than the average of the parametric multi-hull data.

The design has a target draft of 2.5m. Based on parametric data this value is significantly less the draft of ferry vessels of similar length and beam. In mono-hulled vessels draft ranged from 2.6m to 6.75m, multi-hulled vessels had drafts ranging from 1.4m to 4m. For vessels mono-hulled vessels about 20m in beam, drafts ranged from 3.5 to 4m. Multi-hulls about 25m in beam had drafts from 2.8 to 4m. A plot of vessel beam versus vessel draft can be seen in figure 4 to the right.

Figure 4



Meeting the draft requirement will be a challenge in the design, most likely resulting in an atypical hull form. Meeting the draft restriction may be assisted by the fact that most vessels in the parametric analysis were designed to carry both passengers and vehicles while underway. The design is not tasked with carrying vehicles, with the expectation of one or two vehicles to meet HADR needs, and as a result will have a lower total cargo weight and required structural weight than most vessels in this analysis.



Other factors examined in the parametric analysis were operating speed and propulsion systems of the ferry vessels. In general operating speed ranged from 15 knots to 40 knots. Multi-hulled vessels were faster, ranging from 28 knots to 40 knots. Most of these designs were aluminum fast ferries, using primarily diesel engines and water jets to operate. Mono-hulls operated from 15 to 20 knots, using systems of primarily diesel engines and fixed pitch propellers to operate. A plot of vessel velocity versus passenger capacity can be seen in figure 5 to the left.

With a target maximum speed of 15 knots, 12 knot operating speed, it is likely the powering plant for the design will be less powerful and therefore less expensive than those found in typical modern designs. The ferry vessel will require less installed horsepower and can meet the design speed with less complicated propulsion devices. The lower installed HP of the engine plant may result in fuel savings due to decreased operating consumption. The decreased complexity of the propeller system will generate initial savings and increased the designs durability.

For complete results of the parametric analysis please reference Appendix A to this document. This appendix is an excel spreadsheet of all recorded data points along with additional reference plots not reference in this review out due to incomplete data or overly redundant material.

Hull Form Comparison

Once the preliminary characteristics were determined by means of parametric analysis, a specific hull form needed to be developed. Based on the parametric analysis, there were two main options to consider, a mono-hulled vessel or a multi-hulled vessel. Each hull form has advantages and disadvantages. Vital points of comparison regarded stability, resistance, survivability, and cost/feasibility.

The first area of major comparison was in the initial stability of the two hull forms. Since safety is paramount in the design considerations, a more stable vessel is preferred. A vessel with greater stability is less prone to capsize in the event of collision, grounding, wave motion, or flooding. In terms of direct comparison, a multi-hulled vessel, more specifically catamaran designs, have greater values of initial stability (Shuttleworth). This means it will take a greater force to begin heeling motion in a catamaran. Mono-hull designs have a greater range of positive stability, meaning it can heel to a greater extent than a catamaran. A plot of the associated righting arm of the different designs at varying heel angles can be seen in figure 6 to the right.

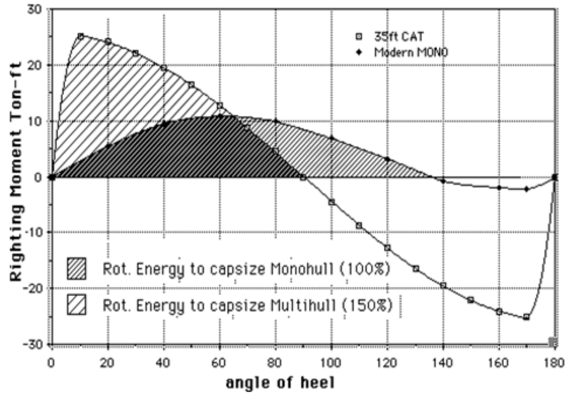


Figure 6: Stability Comparison

The righting moment shown on the plot is the force with which the hull form resists rolling motion. At low angles of heel, the catamaran's superiority is clearly seen. However as the rolling motion continues toward greater heeling motions the catamaran's righting moment decreases at a much quicker rate. The point at which a hull form will no longer resist capsize is when the righting moment crosses the x axis. For all values past this point the design is considered to have negative stability, meaning it increase the effect of rolling motions and result in capsize. Catamaran designs reach this point much quicker than mono-hulled vessels.

Since the vessel is going to be operating in a shallow river system it is unlikely it will encounter large waves. A wave that is greater than 0.6 to 0.8 times the local water depth will break due to insufficient water depth. With this fact in mind, the largest wave the vessel is likely to encounter is 1.6m to 2.8m depending on the river classification. Additionally the low fetch distance providing by the meandering river system promotes minimal wind wave generation. Waves larger than 2m are only likely to form during the monsoon season where the peak period is reported to be approximately 6 seconds. During the dry season the average wave height in the river system is less than .6m. However during cyclones waves have been recorded in excess of 5m.

The high initial positive stability of a catamaran may cause problems during passenger operations. This is due to the fact that a positively stable vessel is actively working to resist disturbing (rolling) motions. The greater the initial stability, the quicker a vessel will respond and return to a normal condition. This means that the catamaran vessel will have greater rolling accelerations than a mono-hulled vessel. Higher rolling acceleration has been proven to increase the likelihood of seasickness aboard vessels, degrading the overall usefulness of the design.

The largest waves in the system are most likely to be encountered approaching the Meghna River near Chandpur. On the prescribed routes to and from Dhaka the primary wave direction will be bow or stern seas, where a vessel is best suited to handle wave energy. With this in mind it is feasible to say the high levels of initial stability will not be needed normal operations along the river. The greater range of positive righting moment may prove more beneficial in the overall survivability of the vessel.

Survivability is paramount in the design metric. The vessel more likely to survive an accident is preferred. This aspect looks into other factors stability such as survival of grounding, flooding, and collisions. If the vessel were to ground, there is a better chance a multi-hulled vessel will experience less damage than its mono-hulled counterpart. In the event of grounding, damage is determined by the overall contact area. Since the multi-hull design has a built in gap between the two hulls, it is likely less area will be contact with the grounding surface. Additionally multi-hulls typically have a shallower draft than a mono-hull of equivalent length meaning it may be easier to accommodate the draft restrictions with a multi-hulled design. However the increased beam of a multi-hulled design increases the likelihood of grounding by increasing the probability it will encounter a shallow area. The high initial stability of a multi-hull indicates it will not be at risk of capsizing due to collision or grounding forces.

In terms of flooding and foundering, the multi-hulled design is superior to the mono-hulled design, mainly due to hull redundancy. A multi-hulled vessel will have a greater number of watertight compartments factored into the design, with equal components spread throughout the two hulls. This means in the event of a puncture from collision or grounding, water will fill a smaller total area of the hull; increasing the chance the hull form will remain operational. However due to the nature of shallow conditions in the region it is unlikely a vessel will be lost to founder without the occurrence of a collision resulting in puncture or a more severe capsize.

The primary way to increase the overall survivability of a mono-hulled design is to increase the total freeboard in the design process (Lamb). This will increase the total amount of heel the vessel will have to experience in order to immerse a deck edge, limiting the risk of capsize. Along with higher deck edges, proper loading in a mono-hulled design will lower and centralize the vertical center of gravity and result in increased stability. This increase in stability will increase the ability to endure potential collisions. In addition to these considerations a mono-hulled design has a lower probability of running aground due to its smaller overall beam. Increasing freeboard will increase the total wind draft of the vessel and additional maneuvering considerations, such as a bow thruster, will need to be worked into a mono-hulled design.

Initially the clear winner in survivability is the multi-hulled design. However when considering grounding, the multi-hulls extra beam increases the overall probability of a grounding occurrences, negating the belief that a multi-hull may withstand less damage in the event of grounding. Without the river system being exceptionally deep, the risk of total founder without a capsize event is small. This point limits the overall value of the multi-hulls survivability in the event of flooding as a deeper (greater freeboard) mono-hulled design may be just as likely to ensure that no lives are lost.

Resistance is a vital factor in hull form selection. It directly effects the power plant selection and fuel consumption values for a vessel, two major costs to consider in the overall design. Multi-hulled designs conventionally are used more frequently in high speed craft for their lower total resistance requiring less power to achieve high speeds. However at low speeds, multi-hulls have a higher total resistance than mono-hulled vessels. This is due to the fact that multi-hulled vessels have more skin friction than mono-hulled vessels and higher residuary (wave making) resistance at lower speeds than mono-hulled vessels. At high speeds the wave interference between the demi-hulls of a multi-hulled vessel is kept to a minimum as more divergent waves form, traveling along the hulls, rather than across the demi-hull spacing. At low speeds the hulls produce more transverse waves as the water is no longer pulled along the hull form with the decrease in speed. This results in the waves meeting each other underneath the hull form and results in waves from one hull acting upon the other, increasing the total wave making resistance on the hulls.

Figure 7: Mono-Hull Resistance

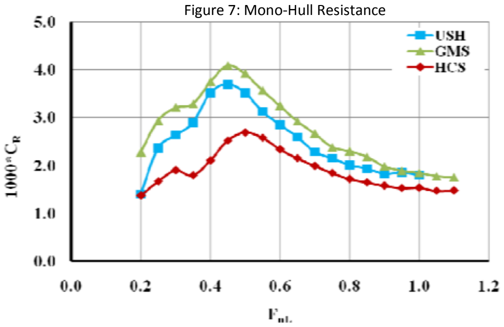
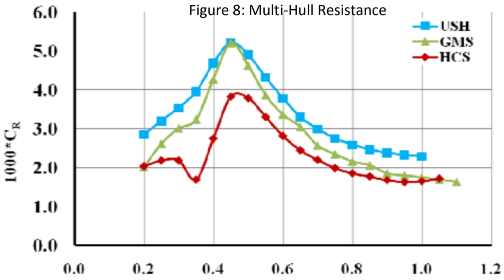


Figure 8: Multi-Hull Resistance



A 2011 study (Gelles) into the interference components of catamaran design helps prove this point with tank testing data. In the experiment three different hull forms were tested in a mono-hull configuration and in an equivalent catamaran configuration. Data on the residuary resistance was collected and is shown in figures 7 and 8 to the left. The residuary resistance of the hulls is plotted against the Froude number of the hulls. The vessels Froude number is an estimation of the vessels relative speed regarding its weight or length. Figure 7 shows the recorded resistance for three mono-hulled designs while figure 8 shows the multi-hulled equivalent in for each design. For this design, the intended design operating speed results in a Froude number of .2.

Typically ferry operations span a Froude number range of .25 to .35 (Levander). Recorded residuary resistance across this range is significantly higher for multi-hulls than the equivalent mono-hulled designs. It isn't until Froude numbers of .55 where the catamaran residuary resistance becomes less than the mono-hulled designs. These results indicate that for operation at low Froude numbers, the overall resistance will be greater in a multi-hulled design. A mono-hull design would be better suited for limiting resistance at lower speeds. Lower resistance will require a lower installed horsepower and improve the overall fuel economy of the vessel underway, aiding in both the initial and operating costs of the vessel.

The final research topic of comparison was the feasibility of both designs. Multi-hulled vessels are typically more expensive than their mono-hulled counterparts. This is due to an increase in structural requirements throughout the design and a more complicated construction process. On average it is estimated that multi-hull construction will be about 20% more expensive to construct than a mono-hulled design of an equivalent length. While multi-hulled design may be within the ability of local Bangladeshi ship builders, the added cost and maneuverability constraints placed on a multi-hull may limit the effectiveness and practicality of the design in the region.

Multi-hulled vessels have a greater beam than the equivalent mono-hulled designs, shown by the lower average L/B ratio of multi-hulls discussed in the parametric analysis portion of this document. This wider beam varies the way must be operated; many operators have commented how they are initially harder to control than a mono-hulled vessel due to a “stiffer” feel. Apart from challenging maneuvering underway, the wider beam poses problems in the crowded ports of Bangladesh. Ports are congested with traffic and ferry berths are often right on top of each other with minimal room to spare. If the beam is too wide, the ferries may not be able to fit into the constructed berths or move in and out of the congested ports efficiently.

A mono-hulled design is more maneuverable and has a narrower beam than its multi-hulled counterpart. This increases the likelihood that it will be able to fit into the system already in place for ferry operations both in maneuvering through port and fitting in established berths, limiting the number of changes required for a successful implementation into the Bangladesh ferry system. Along with increased feasibility and lower construction costs, a modern mono-hulled design is certainly within the capabilities of Bangladeshi ship builders. Bangladeshi ship building is a growing industry and has recently begun to export vessels to European countries such as Germany (Bilkis). This implies they have the ability to construct a mono-hulled design for their own government, enabling a potential increase in the overall job market of the developing nation. This implies an additional benefit of the project apart from just providing a safer form of transportation for the public.

Hull Form Selection

Based on research into the problem and potential solutions, a mono-hulled shape was selected to be further developed in the design process. A greater range of stability, improved functionality, and greater implementation feasibility were the key reasons for this choice. As mentioned in the parametric analysis, the L/B ratio was decreased from the anticipated findings of the analysis resulting in a vessel 95m in length and 20m in beam. The design has an overall depth of 7.7m, resulting in over 5m of freeboard from the designed draft to help increase survivability and limit the ability for extra passengers to board from the side of the vessel. A rendering of the preliminary design can be seen in figure 9 to the right.

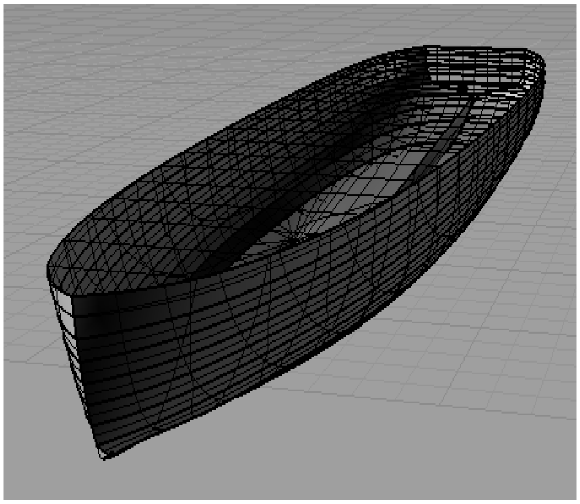
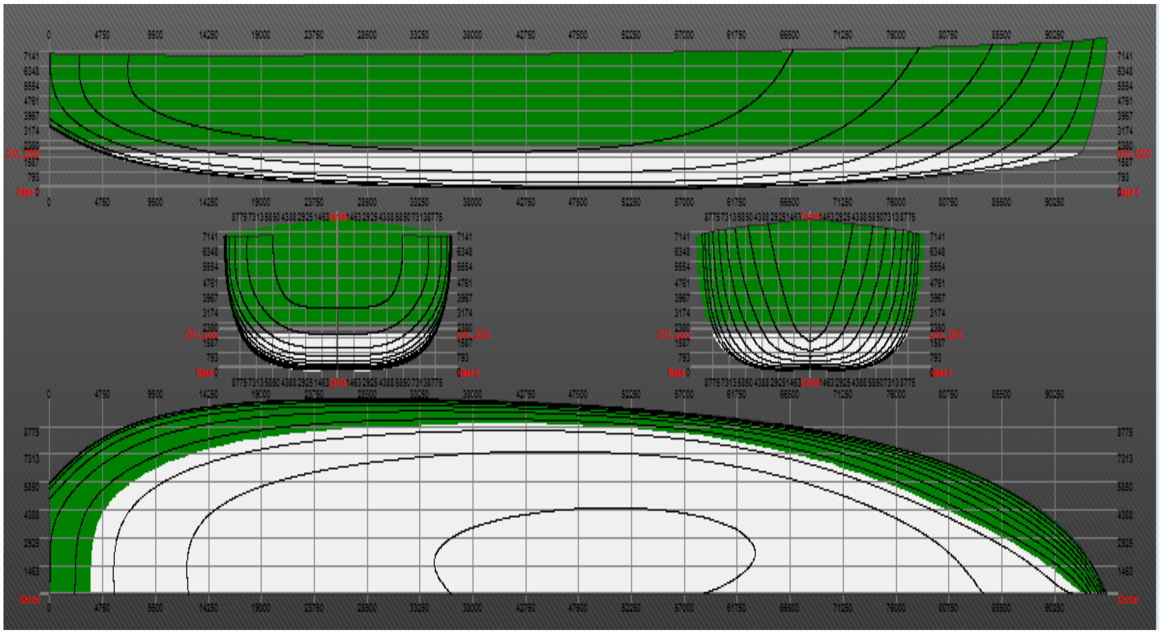


Figure 9: Preliminary Design Rendering

The design has entrance angle of 15° and quickly transitions to a relatively wide, flat bottom to compensate for the shallow conditions. Entrance angle is the angle of the hull at the bow waterline, it is determined based on required space of the hull form and finer angles reduce the resistance of the hull by creating smaller bow waves. Initial designs have yielded a vessel with a block coefficient of about .5 and prismatic coefficient of .6. These values are used to help define the hulls shape, the former indicating how "boxy" the design is underwater and latter describing how quickly it "widens out" moving aft along the design. A lines plan for the preliminary design can be seen below in figure 10. In this figure the immersed areas on the design are highlighted in white.

Figure 10: Preliminary Design Lines



In conventional ferry design the prismatic and block coefficients are kept to a minimum as a means to decrease the total resistance associated with the design. This block coefficient of this design is below the typical range for operations about the target Froude number of the design. This value may have to adjust if future arrangement plans deem there is not enough space to safely store the passengers aboard ship or further testing leads to uncertainty about stability.

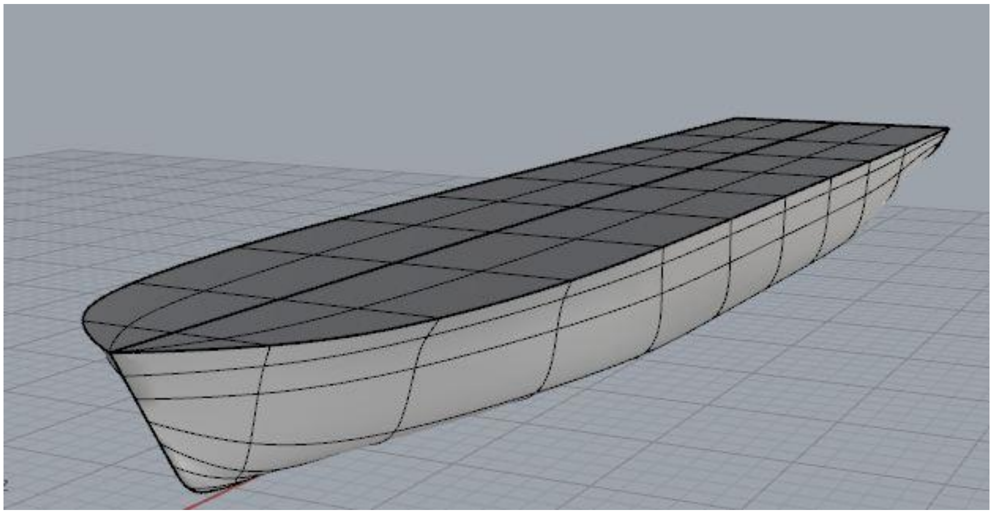
The design does not yet have arrangements for propeller or rudder placement. It is a preliminary design and details may change as the project develops. Initial stability calculations run through GHS software have yielded a high GM value of 13.4m, placing the meta-centric height of the vessel well above the hull-form. Righting arm will continue to increase in value up to 42.5° of heel, indicating a strong trend toward righting motion as the vessel heels. These values will change as the overall weight of the vessel is adjusted with complete arrangement plans, engine selection, and super structure design as variables will impact the overall vertical center of gravity and corresponding moment arm of the vessel.

Refined Hull Form Development

After completion of the preliminary design, analysis into its functionality deemed it inefficient in terms of space and corresponding fabrication costs. Fault lay in the fact that the parametric analysis comprised of many vessels intend for both passenger and vehicle transport. Since this vessel will not be carrying vehicles, there was an abundance of space and the original passenger target could have almost been tripled with a vessel of that size.

To save on both fabrication and operating costs, a smaller mono-hull form was developed. This new form took on a more conventional shape, with a smoother stern section about the waterline. Shown below in figure 11, this hull form was 70m in length, 15m in beam, and sat at a draft of 2.5m. The new design initially had 3m of freeboard.

Figure 11: Refined Hull Form

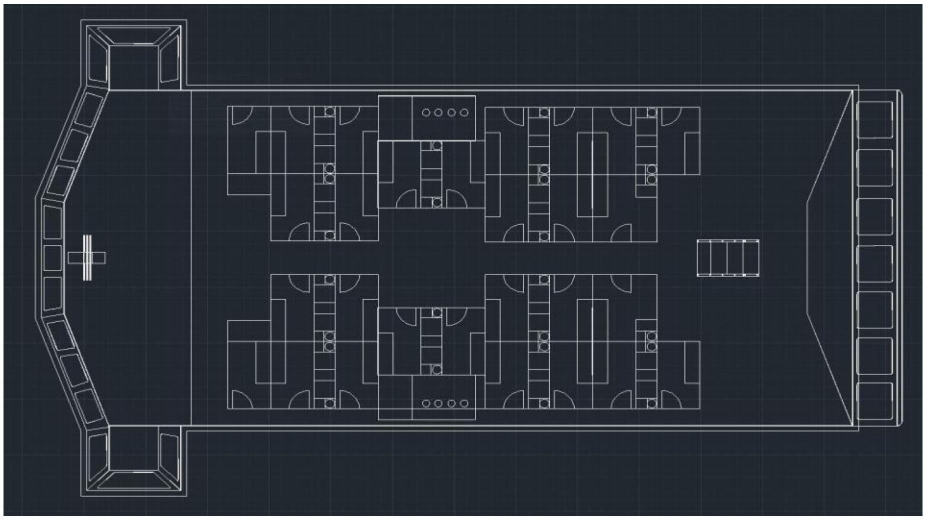


To maximize passenger capacity, enable maximize navigation visibility, and work out ramp particulars. A superstructure was added to the design. This superstructure consists of two additional decks, spanning the aft 35m of the hull from as well as a ramp that can be lowered 3m to the design waterline. Additional siding was added to the hull form, increasing the minimum freeboard about the design to 5m. A bow thruster was selected for the design with a tunnel diameter of 1m. The final design model is shown below in figure 12.

Figure 12: Refined Hull Form

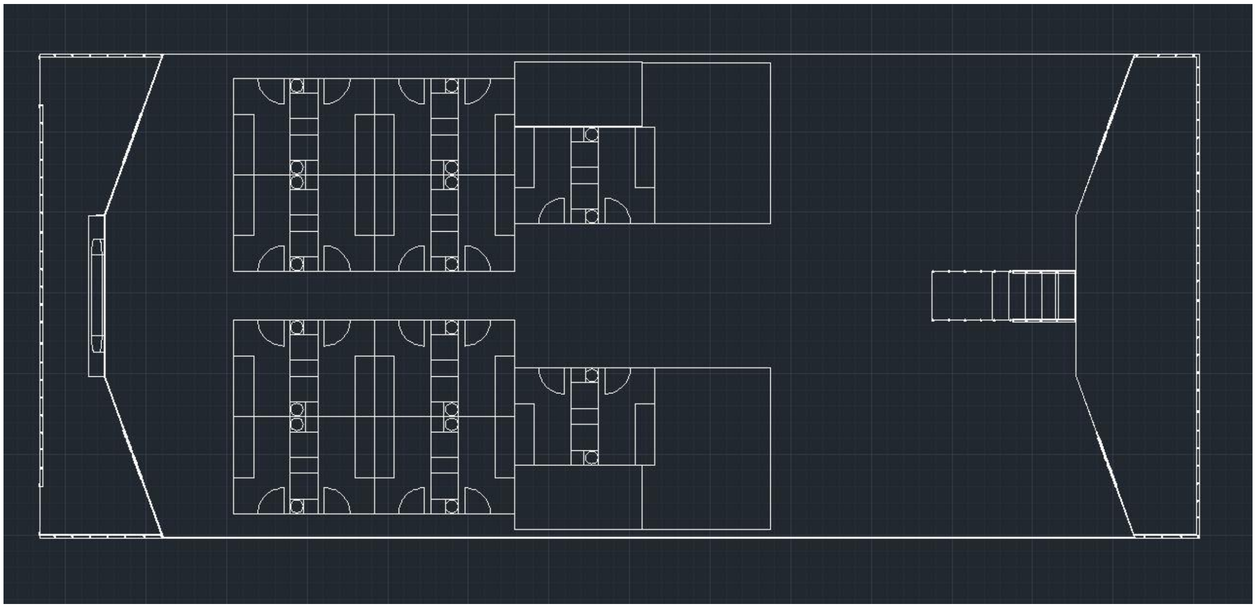
Arrangements Plan

To determine how space would be allocated throughout designed hull form, a general arrangements plan was developed. Each deck was drawn, laid out, and arranged using AutoCAD 2013 software. Sizing of cabins, seating areas, and minimum restroom criteria were designated based off the US Code of Federal Regulations, Title 46: Shipping. The plan for the top superstructure deck is shown in figure 13.



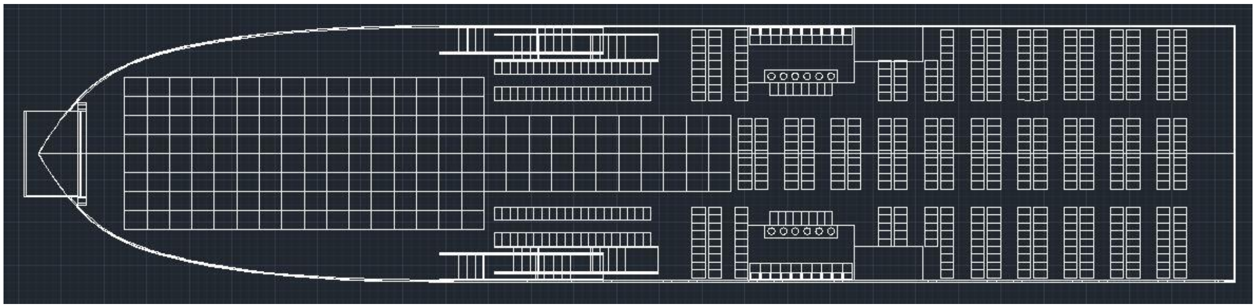
This deck consists of primarily the navigation bridge, far forward section of the plan, and first class cabins arranged throughout the deck. The preliminary plan for each first class cabin is to come with its own bathroom facilities and be sizeable to adequately fit two people. On this deck there is space for 48 first class passengers in addition to some crew berthing facilities and a general lounge/dining area in the aft section of the deck.

The second superstructure deck is shown in figure 14.



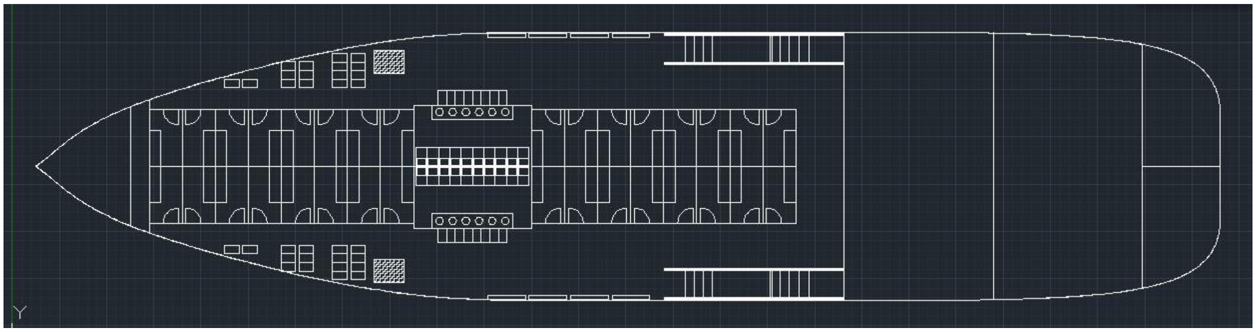
On the second superstructure deck there is space for 40 first class passengers and two small galley areas located in line with planned exhaust shafts. Area aft of the designated galley sections is intended to be used as a first class dining area, where passengers can be served food and enjoy a view of the passing environment.

The main deck is where the majority of passengers will be stowed as well as where the HADR kits will be loaded onto the ferry. The plan for the main deck is shown in figure 15.



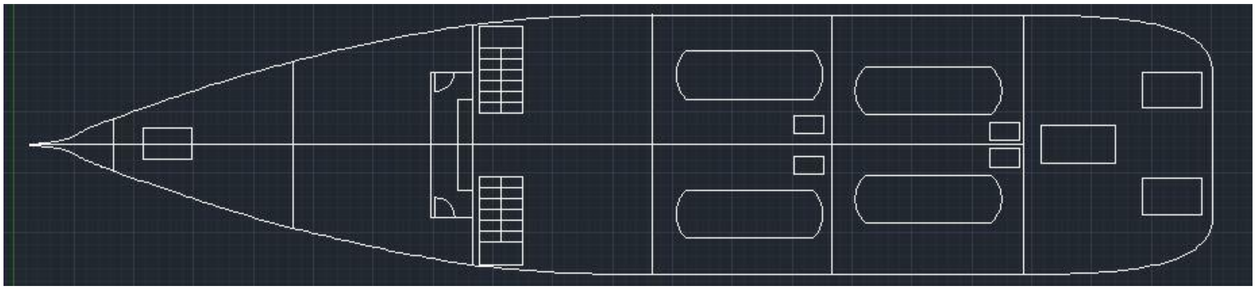
On this deck there is space for 525 seated passengers and an additional space designated to fit 172 HADR kits. When HADR kits are on the vessel this space can be used to fit vendors, cars, trucks or an additional 300 passengers based on the CFR guidelines. This deck has 20 toilets and 12 sinks placed next to planned exhaust shafts to keep major plumbing and ventilation all in one location. Additionally the main deck will serve as the vessels strength deck, the upper limit of where side shell plating shall extend to. The fixed passenger seating is arranged primarily in rows. The idea for these seats is that they shall be able to fold down onto themselves and form a flat surface approximately a meter wide with a meter in between rows to serve as a possible location for emergency bedding for trauma patients in the event of a disaster scenario, all rows of seating are underneath the superstructure and are thus protected from the elements.

The bulkhead deck is the uppermost deck to which watertight bulkheads shall extend. In the case of this vessel that is 3m from the keel, or .5m above the design water line. The arrangements plan for the vessels bulkhead deck is shown in figure 16.



This deck will house second class cabins and some additional general passenger seating. Second cabins are slightly smaller than the designed first class cabins and do not come with their own restroom facilities. Currently on this deck there is space for 64 cabin passengers and 32 additional general passengers. There are an additional 20 toilets and 12 sinks on this level as well. The space requirements for the aft portion of the deck are still being determined pending requirements for the plumbing system. The current plan is to keep passengers on this deck as forward as possible to balance out weight distribution as much as possible throughout the vessel. If additional machinery and tanks are not required for the plumbing system, this aft portion may be transformed into additional cabin space or simply left open to eliminate the potential for overloading and reduce construction costs by minimizing required material.

The final deck in the arrangements plan is the machinery deck, located approximately .9m above the keel to compensate for the planned double bottom in the vessel’s structural design, shown in figure 17.



The forward most rectangle represents the engine required to power the vessel’s bow thruster. In the partition directly aft is additional crew berthing, and stairs to access the machinery deck from the bulkhead deck. Aft of the stairs is planned space for tanks and pumps to move water and fuel to necessary locations throughout the vessel. The fat most section is dedicated to the vessel's main machinery, two medium-speed diesel engines and a generator set to provide auxiliary power. The partitions throughout this deck represent watertight bulkheads, to be explained in the upcoming segment of this report.

Presently the design can hold up to 981 passengers or 172 kits and a forklift for unloading and offloading. In total the estimated dead weight requirement of the vessel with this arrangement plan falls just short of 100 metric tons; a feasible target.

Flooding and Subdivision

With grounding and collisions being two likely scenarios the vessel may encounter during routine operations, a preliminary flooding and subdivision plan was developed to ensure the ship would survive in the event of hull failure. The plan was developed based on IMO criteria for permeability and subdivision factors and the Tons per Centimeter (TPCM) immersion of the hull form. This plan is only a preliminary solution as it does not take into account the effects of flooding on the vessels trim and may have be altered to sufficiently meet IMO standards regarding immersion.

Bulkheads shall be designed such that in the event of flooding, the ship does not sink below the margin line. The margin line is just below the bulkhead, thus ensuring the ship isn't compromised in the event of flooding. Based on IMO criteria found in regulation 6 the ship must have a collision bulkhead located at .05L, or 3.5m from the bow at the water line and watertight machinery spaces. Based on the TPCM values, it will take 338 cubic meters of water to immerse the vessel to the margin line at the longitudinal center of buoyancy. In the center of the ferry, this correlates to a compartment 7.5m long, 15m wide and 3m high. Compartments were offset from the collision bulkhead every 7.5m to a position 56m from the bow with an additional partition running longitudinally down the centerline of the ship in all compartments, with the exception of machinery spaces.

Resistance Prediction

As the dimensions of this design are relatively unique, no common series fits it perfectly for a direct estimation. The resistance for this design was firstly estimated using De Groot / NSMB Series, and then following Professor Datla's instructions, a correction factor based in series 63 was applied to the residual resistance-displacement weight ratio.

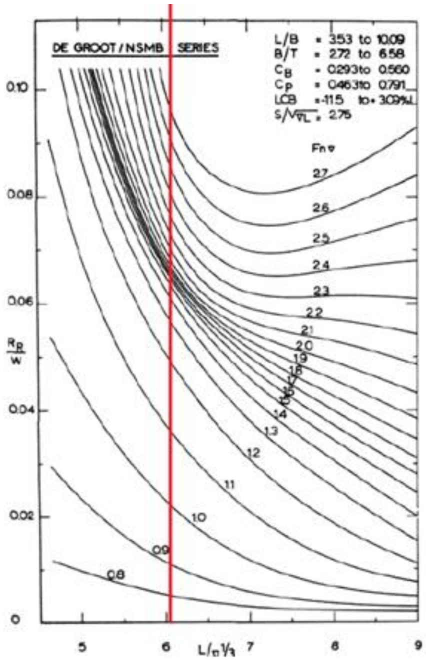
The Groot/ NSMB Series

The De Groot is a combined series of 76 models, so the parameter ranges are quite large. Comparing the design dimensions and the De Groot series' parameters ranges, it can be seen that the design fits in, but some values lies in opposite extremes, as the length-beam ratio (4.66 in series' range 3.53 to 10.09) and the beam-draft ratio (6 in series' range 2.72 to 6.58). The red line shows where the proposed design will lie in the distribution.

Length (m)	70
Beam (m)	15
VCG (m)	3,11
LCG (m)	34,3
Draft (m)	2,5
Displacement (tons, m^3)	1521
W (kN)	14.915,91
S (m^2)	900,25

Disp.^1/3 (m)	11,5003151
L/B	4,66
B/T	6
L/W^(1/3)	6,08679
Cp	0,74
Cb	0,663
LCB	49% L

Design dimensions and parameters



Residual resistance-displacement weight ratio R_r/W derived from the averaged, total resistance of 76 models compiled by De Groot (1955)

The range of velocities chosen for the estimation was from 12 to 20 knots, 12 being the cruise speed, and 15 the maximum speed. As the plot resolution was not precise to estimate the first points, it was decided to extrapolate these values from the final prediction.

V (knots)	(Rr/W)
12	
13	
14	0,0006
15	0,002

16	0,004
17	0,0065
18	0,0095
19	0,013
20	0,0175

Rr/W for each velocity

Series 63

As no single vessel in the previous series would not fit all the design parameters, it was decided to apply a correction factor based on series 63, as it has plots relating the displacement Froude number and the residual resistance-displacement weight for each length-beam ratio.

The procedure was to apply the correction based on the L/B ratio. Then, each value of Rr/W for the length-beam ratios from 4 to 6 for each velocity was taken. The values were plotted for each velocity, and then the ratio between the higher and lower ones was used as the correction factor.

V (knots)	$*(Rr/W)_1$	$*(Rr/W)_2$
12		
13		
14	0,0006	0,000625000
15	0,0020	0,002167832
16	0,0040	0,004269663
17	0,0065	0,006943182
18	0,0095	0,009686275
19	0,0130	0,012919255
20	0,0175	0,017108939

* $(Rr/W)_1$ predicted from De Groot / NSMB Series
* $(Rr/W)_2$ modified with Series 63 data

The detailed table and plots for the correction are in Appendix B to this document.

Shaft Power Estimation

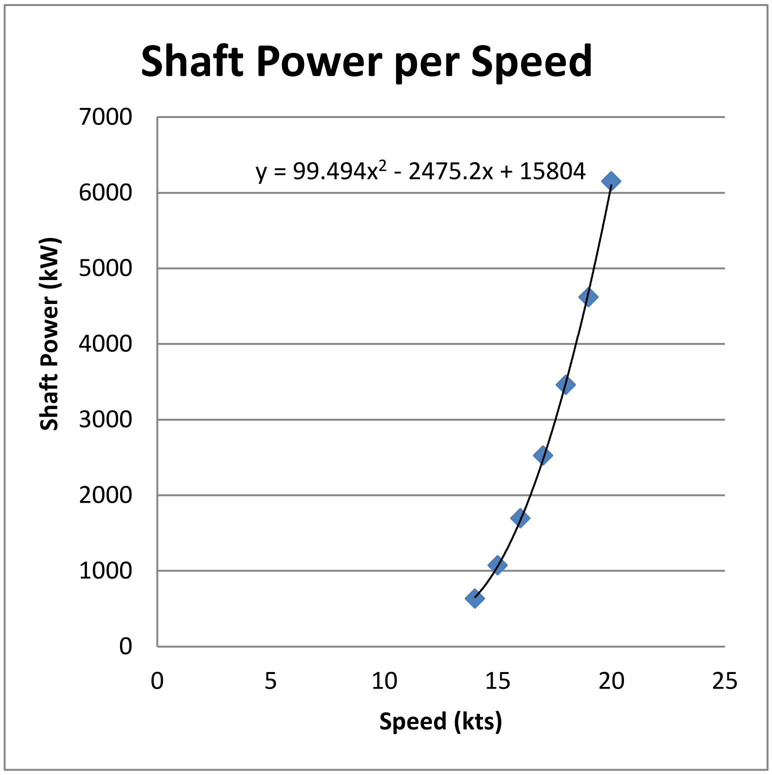
To estimate the total losses to add in the bare hull resistance, it was assumed an average of 80%. The values for 12 and 13 knots were extrapolated by using the governing equation.

Shaft Power = Bare Hull Eff. Power + App. Drag + Prop. Eff. + Design Margin

80% ~5% ~65% 10%

V (knots)	Eff. Power (kW)	Shaft Power (kW)
12		428,736
13		440,886
14	350,977355	631,7592
15	595,54653	1071,984
16	940,704103	1693,267
17	1401,45712	2522,623
18	1922,09333	3459,768
19	2565,97075	4618,747
20	3416,48209	6149,668

Final effective and shaft power per each velocity



Final shaft power per speed, and governing equation

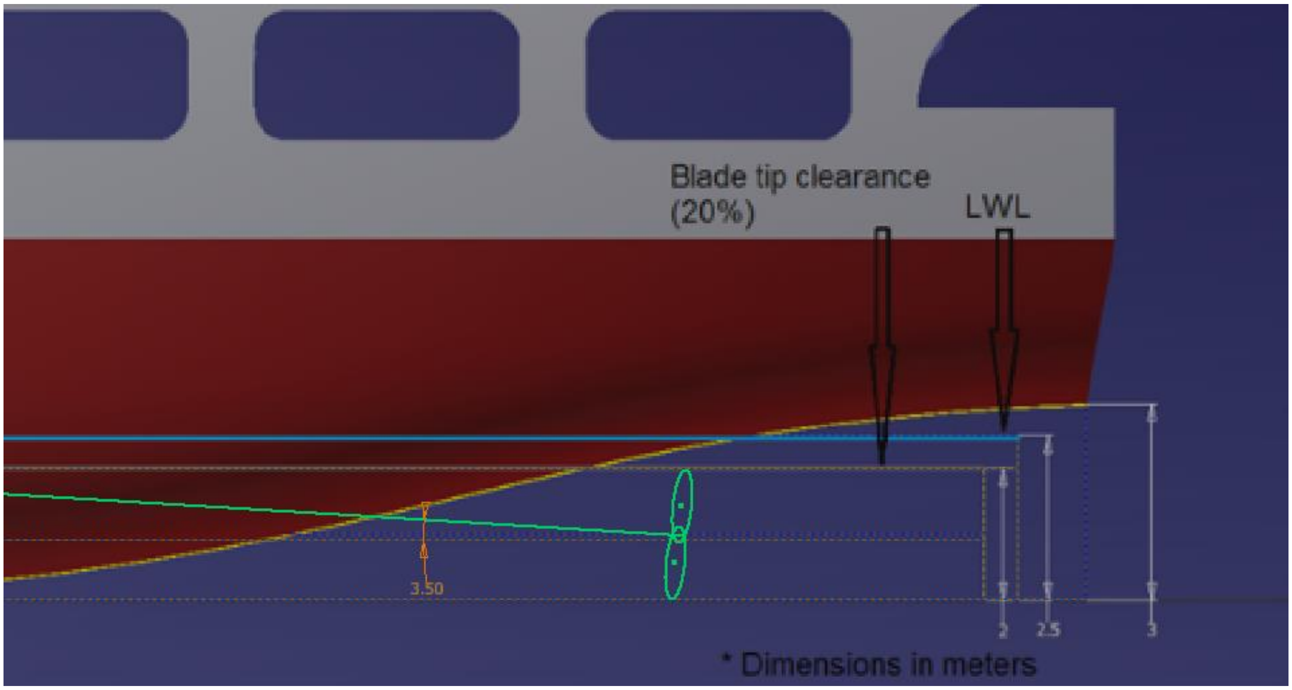
Propulsion

Crouch's Propeller Method

The method used to calculate and select the propeller was the Crouch's Propeller Method, from Dave Gerr's Handbook. This method's calculations have been verified to be with accordance with various measurements from various types of commercial vessels.

Clearance

As the vessel will use a twin-screw output, the power required per propeller will be halved. With a clearance of 20% from the LWL, and a shaft angle of, the propeller will be positioned in a secure area, with little efficiency losses, and little chance of coming out of the water. The design shaft angle is **3.5 degrees**.



Minimum/ Maximum Diameter

Setting this limitation, the propeller diameter will be **2 meters**, or **78.74 inches**. The calculated minimum diameter is **1.61 meters** (based on the waterline beam, BWL, and draft from waterline, H_d, for twin screws).

$$D_{min} = 0.8 \times 4.07 \times (BWL \times H_d)^{0.5}$$

Where:

BWL = Waterline beam, in ft

H_d = Draft from waterline, in ft

Optimum Pitch Ratios

The optimum pitch-diameter ratios were calculated for each velocity:

$$Average\ Pitch\ Ratio = 0.46 \times Kts^{0.26}$$

$$Maximum\ Pitch\ Ratio = 0.52 \times Kts^{0.28}$$

$$Minimum\ Pitch\ Ratio = 0.39 \times Kts^{0.23}$$

Optimum Pitch Ratios				
Velocities (kts) =	12	13	14	15
Average Pitch Ratio =	0,87769769	0,896155	0,9135895	0,930126
Maximum Pitch Ratio =	1,04273534	1,066369	1,0887275	1,109964
Minimum Pitch Ratio =	0,69067907	0,703512	0,7156061	0,727052

RPM

The RPM was estimated for each velocity with the DIA-HP-RPM formula:

$$D = \frac{632.7 \ \times SHP^{0.2}}{RPM^{0.6}}$$

Where

D = Propeller diameter, in inches

SHP = Shaft horsepower at the propeller

RPM = Shaft RPM at the propeller

V (Boat speed, kts) =	12	13	14	15
RPM =	180,9691	182,662	205,9219	270,8186

Minimum Shaft Diameter

With these parameters, a minimum shaft diameter of **7.67 inches** is needed.

$$D_s = \sqrt[3]{\frac{321{,}000 \ \times SHP \ \times SF}{St \ \times RPM}}$$

Where:

D_s = Shaft diameter, in inches

SHP = Shaft horsepower

SF = Safety factor (3 for yachts and light commercial craft, 5 to 8 for heavy commercial craft and racing boats)

St = Yield strength in torsional shear, in PSI (=20,000 for Tobin Bronze or Stainless Steel 304)

RPM = Revolutions per minute of propeller shaft

Propeller Weight

Assuming a four-bladed propeller, the estimated weight will be **889.742 kg**

$$Wgt = 0.00241\ \times D^{3.05}$$

Where:

Wgt = Weight of propeller, in pounds

D = Diameter of propeller, in inches

Apparent Slip and Approximate Efficiency

Assuming a common commercial value of **MWR (Mean Width Ratio) = 0.33** win result in a **DAR (Disc-Area Ratio) = 0.97** and an **Ad (Developed Area, in^2) = 3276.45**. With these values, the apparent slip and approximate efficiency for each velocity were calculated.

$$SlipA = \frac{\left(\frac{P}{12} \times RPM\right) - (Kts - 101.3)}{(\frac{P}{12} \times RPM)}$$

Where:

SlipA = Apparent slip

P = Propeller face pitch, in inches

Kts = Boat speed through water, in knots

RPM = Revolutions per minute of the propeller

Apparent Slip and Approximate Efficiency				
Velocities (kts) =	12	13	14	15
SlipA =	**0,345**	**0,33**	**0,315**	**0,3**
e (Approximate Efficiency) =	0,635	0,64	0,65	0,66

The approximate efficiency was estimated using the Chart 5-6, from page 58.

Maximum Allowable Blade Loading

For each velocity of advance, the maximum allowable blade loading at which cavitation is likely to begin is calculated. For a block coefficient of 0.663, the **wake factor = 0.7948**.

$$Wf = 1.06 - (0.4 \times Cb)$$

Where:

Wf = Wake factor (for a Twin-Screw)

Cb = Block coefficient of hull

The velocity of advance is equal to the ship's velocity times the wake factor.

And the maximum allowable blade pressure is:

$$PSI = 1.9 \times Va^{0.5} \times Ft^{0.08}$$

Where:

PSI = The pressure, in pounds per square inch, at which cavitation is likely to begin.

Va = The speed of advance, in knots

Ft = The depth of immersion of the propeller shaft centreline, during operation, in feet

Maximum Blade Loading - No Cavitation				
V (Boat speed, kts) =	12	13	14	15
Maximum Pressure (PSI) =	**6,6656**	**6,937777**	**7,199671**	**7,452368**
Maximum Pressure (N/m^2) =	**45957,7**	**47834,29**	**49639,98**	**51382,27**

Actual (Design) Blade Loading

With all the calculated data, the actual loading on the propeller is calculated for each speed, and is verified that there is no cavitation in the designed speed range.

$$PSI = \frac{326 \times SHP \times e}{Va \times Ad}$$

Where:

PSI = Blade loading in pounds per square inch

SHP = Shaft horsepower at the propeller

e = Propeller efficiency in open water

Va = Speed of water at the propeller, in knots

Ad = Developer area of propeller, in square inches

Design Blade Loading				
Design Pressure (PSI) =	**1,420062935**	**1,358588991**	**1,835955217**	**3,959136289**
Design Pressure (N/m^2) =	**9790,989277**	**9367,141354**	**12658,46562**	**27297,2838**
Cavitation?	No Cavitation	No Cavitation	No Cavitation	No Cavitation

Thrust

For each speed, the thrust delivered by the propeller is calculated:

$$T = \frac{326 \times SHP \times e}{Va}$$

Where:

T = Thrust, in pounds

SHP = Shaft horsepower at the propeller

e = Propeller efficiency

Va = Speed of advance, in knots

Thrust at Speed				
V (Boat speed, kts) =	**12**	**13**	**14**	**15**
Thrust (lb) =	**4,652.776346**	**4,451.35956**	**6,015.429876**	**12,971.94316**

For all plots and tables regarding propulsion please reference Appendix C to this document.

Machinery selection

Prime Mover

As the maximum required power is 1071.98 kW, two Wärtsilä 4L20 were selected, with a rated power of 800 kW each, and 1600 kW in total. With this configuration, there is approximately 528 kW extra, as a security margin.

The cruise speed (12 knots) is designed to be achieved at 75% of max engine RPM (750). For a shaft RPM of 181, for 12 knots, the gearbox reduction ratio must be approximately 4.15:1. For each engine, a Wärtsilä SCV62-P44 gearbox was chosen.

Prime Mover	
Cruise Speed:	12 knots
Max. Speed:	15 knots
Max. Req. Power:	1071.98 kW
Engine Selected:	2x Wärtsilä 4L20 2x 800 kW (1600 kW Total)
Gearboxes Selected:	2x Wärtsilä SCV62-P44
Reduction Ratio:	4.15:1

Prime mover main data

Wärtsilä 6L20, just for illustration

Wärtsilä SCV62-P44

Propeller

Follows the main propeller data calculated by the Crouch’s Propeller Method.

Propeller (x2)	
P/D Ratio:	1
Max. RPM:	271 RPM
Diameter:	2 meters
MWR (Mean Width Ratio):	0.33
DAR (Disc Area Ratio):	0.6732
Hub Ratio:	20% of Diameter
Max. Thrust Produced:	12,972 lbs

Main propeller data

Bow Thruster

The required thrust force is calculated as follows:

$$F = \frac{T}{D}$$

Where:

F = Required thrust force

T = Torque

D = Distance between the center of the bow thruster and the pivot point of the boat (with the transom as pivot of the boat)

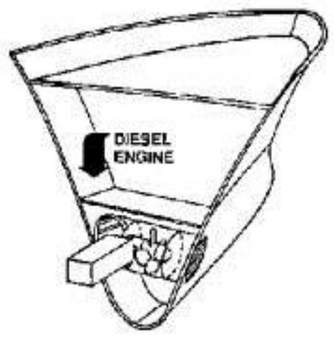
For the design parameters, a required thrust force of 410.13 kW was calculated. A Harbormaster BT-550 tunnel bow thruster was selected, with a Caterpillar 3508 diesel engine. No additional gearbox will be needed, because the engine RPM output is the same required for the bow thruster input. The engine selected delivers 599 kW to the bow thruster, letting approximately 190 kW of security margin.

Follows the main thruster and engine specifications:

Bow Thruster		Thruster Propeller	
Model Selected:	Harbormaster BT-550	Max. RPM:	474 RPM
Bow Thruster Req. Power:	410.13 kW	Diameter:	60 inches
RPM Input:	1200 RPM	# of Blades:	4
Engine Selected:	Caterpillar 3508 1200 RPM 599 kW	Min. Thrust Produced:	13500 lb

Caterpillar 3508

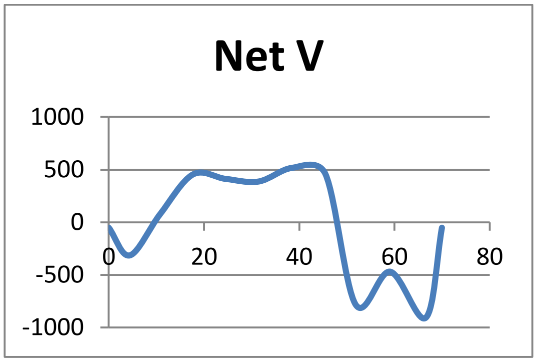
Harbormaster BT-550

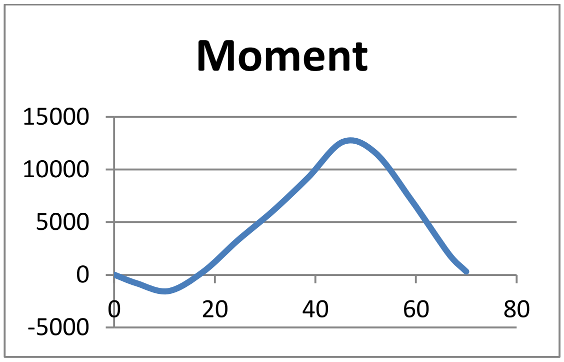


Bow thruster arrangement

Structural Design

The vessel’s structural system was design using the American Bureau of Shipping’s (ABS) steel vessel rules (SVR). The first step in developing a successful structural design is to estimate the still water shear force and bending moment on the hull girder. This was done by developing a net force curve from the buoyant forces and weight forces acting on the hull. In this analysis, the total weight of structural members is estimated to be 78% of the vessels total displacement and is distributed using the Prohaska method for weight distribution since the exact distribution of structural was unknown. A summary of this analysis is shown below graphically and in a tabular format. Sagging and hogging forces based on wave interaction were derived from equations provided in the ABS SVR section 3-1.





Still Water vs. Wave Induced			
Force	Still Water	Sagging	Hogging
Shear	659.1679114	-2490.89627	2707.496
Moment	12986.09189	-66017.77622	54048.01229

Shear forces are positive in middle portion of the hull where buoyant force is at a maximum and the weight is low. Shear force is negative in regions where machinery, large concentrated loads, is placed. The still water moment is largest just aft of the longitudinal center of buoyancy indicating that there will be some trimming force acting on the vessel, which will need to be calculated in further analysis. The full analysis can be seen in Appendix D to this document, a more detailed explanation of calculating wave induced forces will be described later in this structural. The follow segments of the structural design include key elements needed to be defined for the structural design as well as the characteristics of design features key to the preliminary structural design of the vessel.

Block Coefficient:

The block coefficient specified by the ABS rules is determined from the following equation, in which delta is the vessel's displacement, L is the scantling length (length on the summer load line), Bwl is the beam on the waterline, and d is the vessel's draft.

$$C_b \quad = \quad \Delta / 1.025 L B_{wl} d$$

Based on the vessel's design hydrostatics, this calculation results in a block coefficient of .63

Application of Materials:

Material selection for all resulting structural members shall be based off provided tables in section 3-1-2 of the ABS rules. These table provided material guidelines based on the determined thickness of members along with the function and location of said members.

Scantling Classification:

Midship scantlings are applied throughout .4L midship. End scantlings are to extend further than .1L from each end of vessel. Midship scantlings should gradually taper to meet end scantlings for all areas outside of .4L midship.

Longitudinal Strength

Still Water Bending Moment and Shear Force

The vessel's shape was represented as a simple beam with free-end supports for these calculations. The load on the hull girder will be represented by a uniformly distributed load on equivalent to the displacement of the hull form at the designed waterline of 2.5m, or 1526 metric tons. Calculation to determine exact loading on the girder is complex and cannot be easily or accurately completed without the assistance of computer programs. This analysis, although simplistic, is sufficient for developing a rough estimate of induced forces the girder will encounter.

Structural analysis calculations lead to a resulting maximum shear force of 660 kN on the hull girder. Moment calculation results in a maximum bending moment of 12987 kN. These values will be used to represent approximate still water shear force and bending moment values for the duration of structural design calculation.

Wave Loads

Wave loads associated with the design can be determined through the following calculations provided in section 3-2-1 segment 3.5.1 of the ABS Rules.

$$M_{ws} = -k_1 C_1 L^2 B (C_b + 0.7) \times 10^{-3} \qquad \text{Sagging Moment}$$

$$M_{wh} = +k_2 C_1 L^2 B C_b \times 10^{-3} \qquad \text{Hogging Moment}$$

where

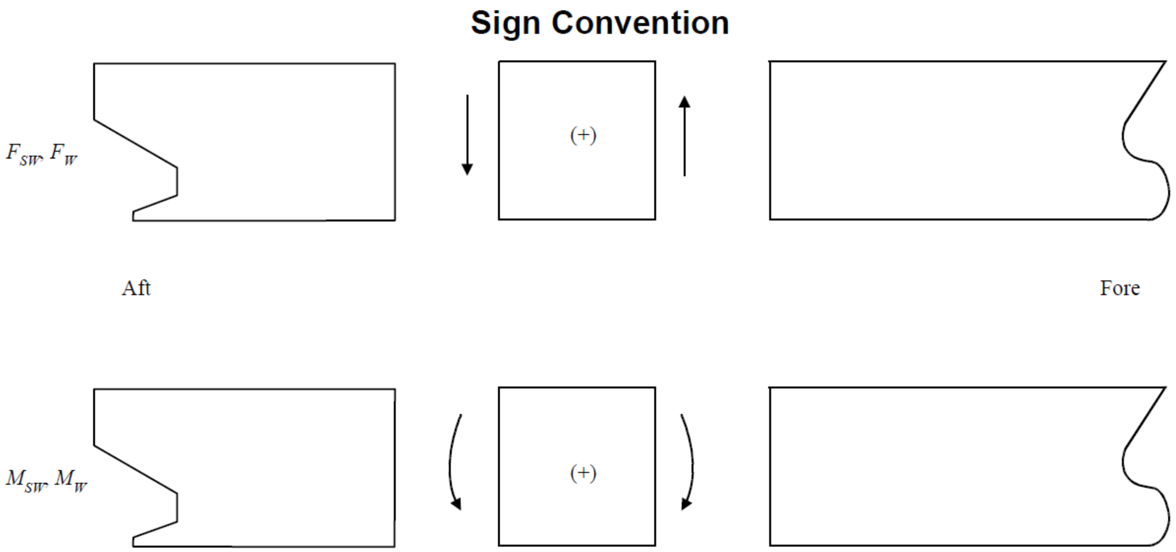
$k_1 \quad = \quad 110\ (11.22,\ 1.026)$

$k_2 \quad = \quad 190\ (19.37,\ 1.772)$

$$C_1 \quad = \quad 10.75 - \left(\frac{300 - L}{100}\right)^{1.5} \qquad 90 \leq L \leq 300 \text{ m}$$

Sagging moment results from the vessel being between two wave peaks, hogging moment will result from the alignment of midship with a wave peak. Given values from the ABS rules are in the format kN-m (tf-m, tf-ft). The rules specify not to take the block coefficient less than .6, this value was used instead of the derived block coefficient.

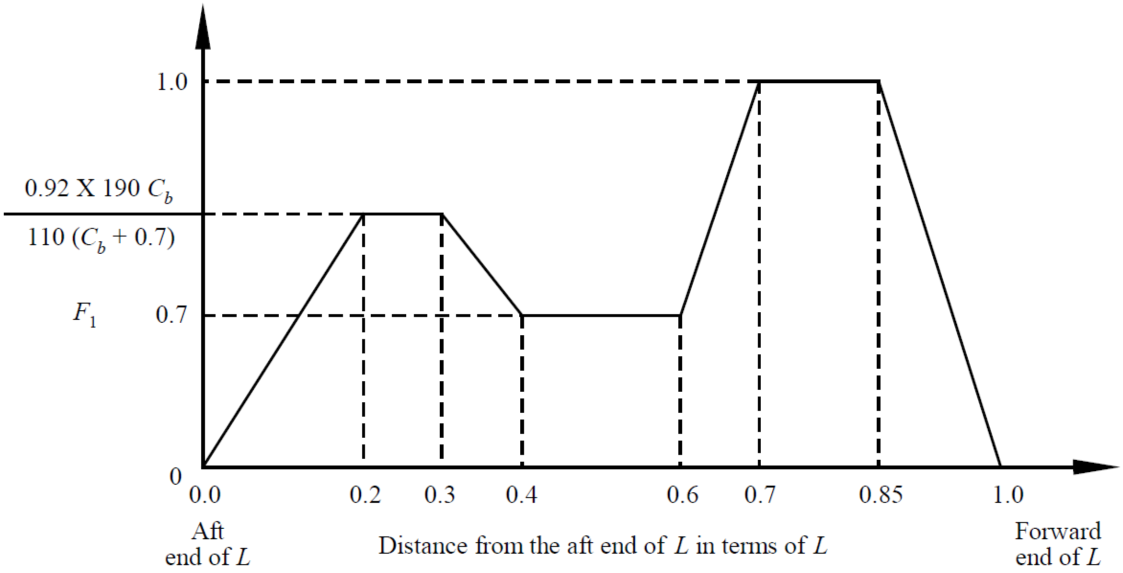
Calculation results in a wave sagging moment of -66017 kN-m. The resulting wave hogging moment is 54048 kN-m. The resulting signs (+/-) correspond to the direction of bending that will occur on the hull and are a result of the ABS sign convention for moment and shear forces, shown below. Maximum moments will occur about midship.



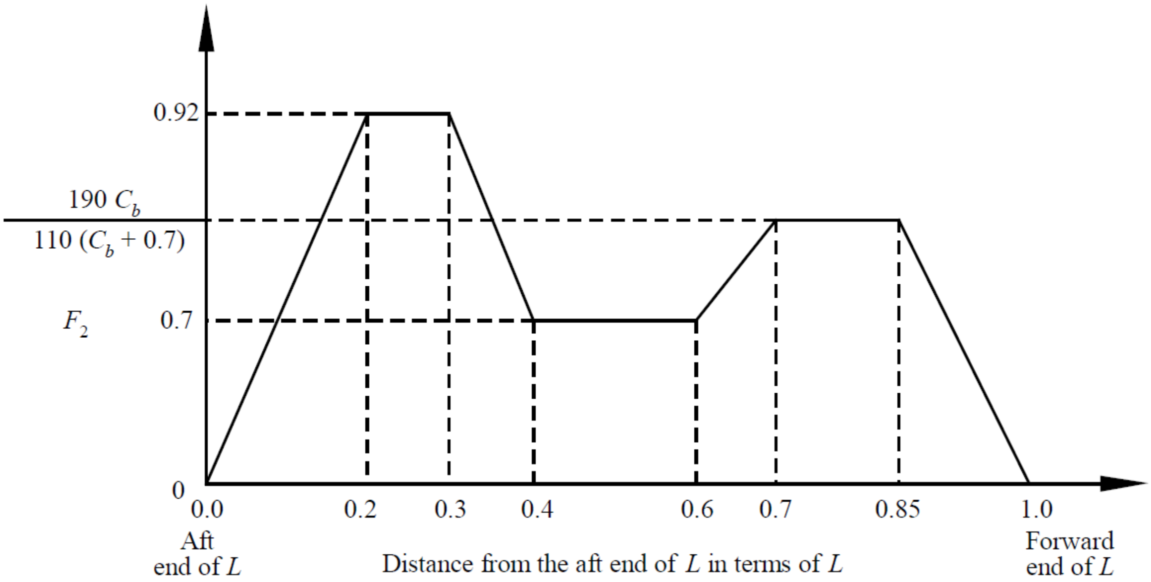
Maximum wave induced shear force can be determined through the equations below provided in 3-2-1 segment 3.5.3 of the ABS rules.

$$F_{wp} = +kF_1C_1L\,B\,(C_b + 0.7) \times 10^{-2} \qquad \text{For positive shear force}$$
$$F_{wn} = -kF_2C_1L\,B\,(C_b + 0.7) \times 10^{-2} \qquad \text{For negative shear force}$$

In these equations k=3.059 and F1 and F2 are determined based on the location along the ships length, given by the following distribution plots.



Distribution Factor F_1



Distribution Factor F_2

In uniformly distributed load, the shear force value will be zero about the midpoint. Calculation confirms this with positive and negative maximum wave induced shear forces of 2707 kN about midship.

Bending Strength Standard

The required hull section modulus about .4L midship is given by the greater value of the following equations provided in section 3-2-1 segment 3.7.1.

$$SM = M_t / f_p \quad \text{cm}^2\text{-m (in}^2\text{-ft)}$$

where

M_t = total bending moment, as obtained below

f_p = nominal permissible bending stress

= 17.5 kN/cm^2 (1.784 tf/cm^2, 11.33 Ltf/in^2)

Where the total bending moment is the sum of the maximum wave induced moment and the still water bending moment.

$$SM = C_1 C_2 L^2 B\,(C_b + 0.7) \quad \text{cm}^2\text{-m}$$

Where C2 = 0.01

Resulting calculation leads to a required hull section modulus of 30209.6 cm^2-m.The required hull moment of inertia is given by the following equation found in section 3-2-1 segment 3.7.2.

$$I = L \cdot SM/33.3 \quad \text{cm}^2\text{-m}^2$$

This equation results in a required moment of inertia of 80921.9. These values are about the neutral axis of the hull girder, or the vessel's vertical center of gravity (2.3m from the baseline). These values will have to be met once all structural members of the structure have been designed. Midship values must be maintained through .4L amidships. Hull girder strength requirements for areas outside of this region are to be checked using the distribution provided distribution factors. Effective members and their impacts are determined in the remaining segments of 3-2-1.

Shell Plating

Side Shell Plating

Minimum thickness of side shell plating is given from the following equation in section 3-2-2 segment 3.9.

$$t = (s/645)\sqrt{(L - 15.2)(d/D_s)} + 2.5 \text{ mm} \qquad \text{for } L \le 305 \text{ m}$$

In this equation s is the support spacing of the vessel's primary framing in mm. This design will use longitudinal framing space 1800mm apart. Ds in this equation shall represent the vessel's depth. For this vessel, the hull depth is 5.5m. This equation states that the value of d/Ds is not to be taken than 0.0433*(L/Ds). Computation revealed the value of d/Ds equals .46, less than the value of the latter equation, .55. As a result .55 was used rather than the actual ratio of d/Ds in the calculation of minimum side shell plating thickness. The minimum side shell plating thickness was found to be 17.8mm.

Sheer Strake Thickness

Sheer strake thickness can be found using the following equation, given in section 3-2-2 segment 3.11.

$$b = 5L + 800 \text{ mm}$$

This equation results in a sheer strake thickness of 1150mm.

Minimum Bottom Plating

The minimum bottom plating required is in reference to the associated plating from the bottom of the keel to the upper turn of the bilge. The value for minimum thickness of bottom plating in longitudinally framed vessels is determines by the following equation given in section 3-2-2 segment 3.17.2

$$t_{\min} = s(L - 18.3)/(42L + 1070) \quad \text{mm}$$

This equation results in a minimum thickness of 23.2mm for bottom plating amidships.

Shell Plating at Ends

The minimum plating thickness at the ends of a vessel is given by the following equation found in section 3-2-2 segment 5.1. The end is in reference for areas within .1L from the ends of the vessel.

$$t = 0.035\ (L + 29) + 0.009\ s \quad \text{mm}$$

This equation results in a minimum thickness of 19.6mm at the ends of the vessel. For sections of immersed bow however, the following equation is given in section 3-2-2 segment 5.3.

$$t = 0.05(L + 20) + 0.009s \quad \text{mm}$$

This equation results in a minimum plating thickness of 20.7mm for sections of immersed bow. This relates to all areas immersed .16L from the stem of the vessel. The rules indicate that the thickness of plating can be gradually tapered from .4L amidships to end plating requirements.

Bow and Stern Thruster Tunnels

Thickness of plating inside bow and stern thruster tunnels is determined by the following equation provided in section 3-2-2 segment 5.11 of the rules. This value is not to be less than the minimum required plating dictated in segments 5.1 and 5.3.

$$t = 0.008d + 3.3 \quad \text{mm}$$

Where d is the diameter of the thruster tunnel; resulting in a value of 11.3mm.

Decks

This design will incorporate three effective decks to be incorporated in the overall strength of the hull girder, meaning the decks must have the required section modulus of the hull girder defined earlier in this report. Decks will be longitudinally framed in accordance with section 3-2-7, to be discussed later in this report. The three decks consist of a strength deck, also the freeboard deck in this design, where the shell plating will extend to. This deck will consist of general passenger space and the pilot house for the vessel. The second deck will be primarily used for cabins, passenger storage, and HADR storage. The third deck's primary function will be to hold machinery space.

Reinforcement at Openings

Openings shall be required on the strength and second decks for necessary ventilation of machinery exhaust and access between decks. On the strength deck this opening is require to have a minimum corner radius of 0.125 times the width of the opening but not to exceed a radius of 600mm. In other decks the corner radius is to be .09375 times the opening width but not to exceed 450mm. Deck plating thickness is to increase 25% in way of breaks in the superstructure, this increase need not exceed 6.5mm.

Deck Plating

The minimum deck plating requirements for a vessel's decks are given in Table 1 and 2 of section 3-2-3. Table 1 lists possible associated decks for the vessel and a reference for which equation to use in Table 2 to calculate the minimum deck plating thickness.

Exposed Strength Deck within Line Openings

The vessel's strength deck is best associated with this deck type listed in Table 1 of 3-2-3 will be exposed and incorporate line openings. The following equation from Table 2 of 3-2-3 was given to calculate the minimum thickness for the strength deck.

$$t = 0.0067 s_b + 3.4 \text{ mm}$$

Where Sb is the spacing of deck beams, in this the spacing shall be 1000mm. This calculation yields a strength deck minimum thickness of 10.1mm.

Second Deck (Ds<12.8m)

This deck association from Table 1 of 3-2-3 references the above mentions equation used for the strength deck resulting in the same thickness requirement of 10.1mm for the vessel's second deck.

Third Deck (Ds<9.8m)

The deck association from Table 1 of 3-2-3 for the effective third deck of the vessel references the following equation from Table 2 of 3-2-3.

$$t = 0.0043 s_b + 4.6 \text{ mm}$$

Completing this calculation leads to a third effective deck thickness of 8.9mm.

Exposed Bridge Deck

The vessel's bridge will be exposed in this design. Table 1 of 3-2-3 references the same equation as third deck thickness, resulting in a required deck thickness of 8.9mm for the exposed bridge.

Bottom Structures

Double bottoms are to be fitted fore and aft between the peaks, as designated by the ABS rules.

Center Girders

A center girder is to extend as far fore and aft as practical. Center girder plates are to be continuous with amidships .75L. The minimum thickness and depth for a central girder is determined through the following equations from section 3-2-4, segment 3.1 of the ABS Steel Vessel Classification.

$$t = 56L \cdot 10^{-3} + 5.5 \quad \text{mm} \qquad d_{DB} = 32B + 190\sqrt{d} \quad \text{mm}$$

The resulting thickness of the central girder is 9.5mm. This value is for amidships, thickness at the ends of the vessel is to be 85% of this value, resulting from a gradual taper from midship. The resulting depth of the girder plates is found to be 780.5mm.

Side Girders

The distance from the central girder to the first side girder, the distance between girders, and the distance from the **outboard girder to the margin plate** is not to exceed 4.57m.

Solid Floors

Solid floors are to be fitted on every frame under machinery, **bulkheads stiffeners, and transverse boiler bearers.** The floors are to have stiffeners at each longitudinal and have a maximum spacing of 3.66m. Stiffeners are to be spaced no greater than 1.53m apart on every solid floor. The thickness of the solid floors is provided from equation 3-2-4/5.5.

$$t = 0.036L + 4.7 + c \quad \text{mm}$$

C in this equation is dependent on the primary framing system used, for longitudinal framing this value is equivalent to 1.5mm. The resulting solid floor thickness is 7.22mm. For frames with boilers an additional 1.5mm must be added to this value.

Open Floors

Open floors are to be installed in all areas not required to have solid floors as designated by section 3-2-4/5.1. These floors are broken up into frames between transverse supports. The section modulus for the plating associated with each frame is given by the following equation found in 3-2-4/7.3.

$$SM = 7.8chs\ell^2 \quad \text{cm}^3$$

In which c is 1 for flooring without struts, h is .66D (4.95m), s is the spacing of the frames in m (.623m), and l is the distance between connecting brackets in m (1.8m). Calculations result in a required section modulus of 78 cm^3.

Inner Bottom Plating

Inner bottom plating thickness is not to be less than the value from the following equation.

$$t = 37.0L \cdot 10^{-3} + 0.009s - c \quad \text{mm}$$

The resulting minimum thickness for this vessel is 18mm. In this equation c is 1.5mm for longitudinal framing and s represents the frame spacing (1800mm). Underneath thrust blocks and engine bed plates, the required thickness of inner bottom plating is 19mm.

Bottom and Inner Bottom Longitudinals

Longitudinal members are to be continuous or attached at their ends to develop their sectional area and resistance to bending. Bottom longitudinal members must have a minimum section modulus provided by the equation provided in 3-2-4/11.3.

$$SM = 7.8chs\ell^2 \quad \text{cm}^3$$

In which c is 1.3, h is 4.95, s is 1.8, and l is 1.83. The resulting value is 302.56 cm^3. Inner bottom longitudinal members must have a section modulus at least 85% of the section modulus of the bottom longitudinal members, or 257.2 cm^3.

Key characteristics of this preliminary structural are summarized in the follow table.

Main Component Size			
Shell Plating	23.2mm	Double Bottom	780mm
Frame Spacing	1800mm	Deck Plating	10.1mm

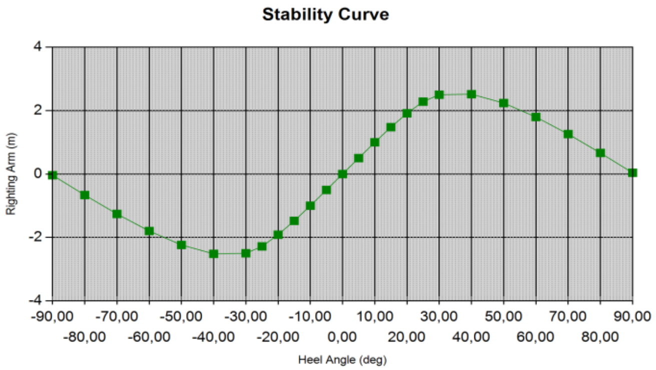
To complete the structural analysis hull members such as longitudinal frames and bulkheads must be designed to meet the minimum section modulus. Then section modulus of all components must be taken and a net value must be derived using the parallel axis theorem. This derived value must match the required hull girder section modulus; for which the calculation is shown above.

For the purposes of this design project this preliminary design was deemed sufficient based on a calculation of minimum shell plating based solely off hydrostatic forces, derived from an equation provided in section 3-2-1 of the ABS SVR. The minimum required value from this equation was 3mm.

Stability Analysis

A static stability analysis for the refined hull form was conducted using Orca 3D software, a plug-in to Rhino 3D drafting software. Results from this software found the vessel's initial vertical center of gravity (VCG) to be 3.1m from the keel and the initial GM value to be 5.77m. Readjusting for weight distribution across the vessel lowers the VCG to 2.9m and raises the GM to 5.97m. Despite the fact these values are lower than values predicted for the preliminary design, they still yield impressive results.

Figure 19: Righting Arm vs. Heel Angle



A curve for the vessel's resulting righting arms is shown in figure 19 to the left. The vessel retains positive stability through 40° of heel, meaning the vessel will attempt to return to equilibrium position until it is heeling greater than 40°. This wide range of positive stability is made even more relevant when examining the dynamic stability of the vessel.

To test the dynamic stability of the vessel, an impossible scenario was developed where 800 passengers were stationed on the deck edge (7.5m from the centerline). This scenario was a plausible test as many current capsize catastrophes occur when passengers push to one side of the vessel after a collision to see what happened. It is an impossible scenario because fixed seating aboard the vessel would not allow that many people that close to the deck edge.

Using the inclining experiment formula, a derived heeling angle of 1.5° was calculated for this scenario. When confirming with Orca3D software, a higher heel angle of 2.1° was found. The Orca value can be considered more accurate as it takes a greater variety of hull form architecture factors into account. In either case the results are impressive, indicating that capsize due to a loading shift is unlikely as the resulting heeling angle is well below the point when negative stability will occur. To see the complete Orca3D reports for initial stability please reference Appendix E. For the report regarding dynamic stability please reference Appendix F.

Additional Systems

The following segment of this report is a few additional systems that came up as potential things to incorporate into the design to bolster the overall safety of the users. The first was a communication system to focus mainly on increased communication with the 35 weather observatories scattered throughout Bangladesh (BMD). Presently only 2% of vessels operating in the region have independent forecasting equipment (Weisbrod). To install this technology would be costly and create a target for thieves, compromising the security of the vessel. A plausible solution would be to outfit weather stations and vessels with VHF transmitters and receivers. VHF waves have a maximum range of 60 nautical miles. This range would enable pilots to be within range of at least one forecasting station at all times. An additional benefit to VHF radio is that pilots would be able to communicate with one another on the water; ideally leading to a decrease in collisions.

Another possible solution to the communication problem is a text message alert system similar to those used on college campuses. Presently there are 95 million cell phones in use in Bangladesh (Danlu). Using this infrastructure, an alert system could be a powerful communication plan albeit the individual alert system would need to be designed for the task and would require operators to sign up for the alerts. Widespread text alert systems, that don't require the user to sign up, are still being developed in the US and many other countries (SIs).

In attempting to solve the issue of vessel collisions on the Bangladesh waterways, the Automated Identification System (AIS) was proposed. AIS is a navigational display that only provides the user with navigational charts corresponding to positioning, but the position and heading of all other vessels employing AIS software. However with further research this is an implausible solution. Up to date charts do not seem to be readily available for the target river system. In addition AIS requires its own infrastructure, similar to cell phone towers, which would need to be placed throughout the country (DHS). This seems unlikely to happen. The breaking point was that in order for AIS to work, every vessel needs to be operating AIS. This is even more unlikely to happen in Bangladesh where regulations are sparse and the vessels are old.

A life preserving system was also considered. Presently there is very little, if any, life preserving tools aboard ferry vessels in the developing world. The proposed plan is at minimum to have a life jacket for every passenger onboard, a sprinkler system designed in accordance to the CFR, and an onboard bilge pump capable of removing 40 cubic meters of water per hour. Ideally self-inflating life rafts shall also be stored on the vessel. The hard part with incorporating this technology into the design isn't the physical restraints on the design, but the fact that potential users are unlikely to be willing to spend the extra money on this technology.

The last major additional system still under consideration is the plumbing system. Plumbing of some degree will have to be incorporated into the design, but to what degree is still uncertain. At the minimum a plumbing system will require black and gray water tanks in addition to at least one pump to move water throughout the vessel.

Next Steps

Short term steps needed to solidify this design to the point where accurate cost estimation is possible, an electrical loading and wiring plan must be developed, structural design must be completed such that a more accurate estimation of fabrication material is possible, and the plumbing system must be designed. Ideally after that point the cost of each system should be analyzed and the design should take a quick run through the design again, attempting to cut out any unnecessary costs. If the design is deemed cost efficient enough, a model should be made to test sea keeping and maneuvering characteristics of the design. Using a wide beam and simple technology, the team feels this was a fair start in developing a safe, affordable ferry for developing nations.

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