CONCEPT DESIGN OF A CLINIC SHIP FOR THE HEALTH CARE SYSTEM IN THE PERUVIAN AMAZON BASIN

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ABSTRACT

In the Peruvian Amazon basin rivers are the only link among the small communities, scattered on a wide territory. With that in mind and according to the needs of local communities, a health care network system based on mobile clinic units onboard small crafts has been conceived, within a cooperation programme between the Universidad Católica Santo Toribio de Mogrovejo (Perú) and the University of Trieste (Italy). This way, patients along the inland waterways can be reached. Ships to be operated in this service, must be especially designed to sail in different environmental conditions: in shallow water during dry season, against high currents during wet season and eventually in rivers showing both phenomena. Moreover, manoeuvrability and landing are subjects of major interest in ships designed for these regions. Within this frame, a study has been carried out to define main characteristics for a small clinic ship. General arrangement plans including medical equipment and clinic lay-out have been drawn. Then, according to clinic platform needs, the major engineering aspects of the ship have been studied to a concept design level: main dimensions have been defined and hull geometry has been optimized for waterway navigation; scantling of all the ship's structures has been completed, based on the most recent rules issued by classification societies and according to EC guidelines for inland navigation; propellers and propulsion plant have been studied on the whole, considering shallow water effects on resistance; intact and damaged stability and buoyancy criteria have been met according to IMO regulations.

Keywords: clinic ship; concept design; inland navigation; amazon basin; health care network; shallow water effect.

RESUMEN

En la cuenca peruana del Amazonas los ríos son el único vínculo entre pequeñas comunidades, esparcidas en un amplio territorio. Considerando esto, y las necesidades de poblaciones locales, se ha concebido una red sanitaria basada en unidades clínicas móviles a bordo de barcos, en un programa de cooperación entre la Universidad Católica Santo Toribio de Mogrovejo de Chiclayo (Perú) y la Universidad de Trieste (Italia). De este modo, los pacientes en la red fluvial pueden ser alcanzados. Los barcos a operar en este tipo de servicio, deben ser especialmente diseñados para navegar en diferentes condiciones: en aguas poco profundas durante la estación seca, contra fuertes corrientes durante la estación lluviosa y eventualmente en ríos presentando ambos fenómenos. Además, la maniobrabilidad y el atraque son de gran interés en barcos diseñados para estas regiones. Dentro de este marco, se ha realizado un estudio para definir las características principales de un buque hospital. Los planos generales, que contienen los equipos médicos y la distribución de espacios, se han diseñado. Luego, según las necesidades de la plataforma clínica, los principales aspectos ingenieríticos del barco se han diseñado hasta un nivel de diseño conceptual: se han definido las dimensiones principales y la geometría del casco se ha diseñado específicamente para navegación interna; el escantillonado de todas las estructuras se ha completado, usando los más recientes reglamentos dados por entes de clasificación y de acuerdo a normativas CE para navegación interna; las hélices y el sistema propulsivo se han estudiado por completo, teniendo en cuenta efectos de baja profundidad sobre la resistencia al avance; la estabilidad en caso íntegro y de falla y los criterios de flotación se han comprobado de acuerdo a regulaciones OMI.

Palabras clave: buque hospital; diseño conceptual; navegación interna; cuenca amazónica; red sanitaria; efecto de baja profundidad.

INTRODUCTION

The "Clinic Ship Project" takes its origin from the intention of the two cooperating Universities of giving to the first students of the Peruvian University graduating in Naval Architecture and Marine Engineering the opportunity, when developing their graduation thesis, of dealing with a topic subject. Among the various selected subjects, those combining both technical improvements and social effects were being mostly privileged.

Special attention is being now paid to projects intended to give new social and economical opportunities to people living in the Peruvian Amazon basin. Knowledge of the actual level of social organization of people living there, and consciousness of difficulties met by state actions aimed to sustain poor people; all that led to the decision of promoting a study focused on the improvement of a health care system specially aimed to the lower social classes of that region. This has been the reason for which the "Clinic Ship Project" has been launched and why the project is being developed by the two Universities, within a cooperation programme in which graduation thesis are being elaborated by Peruvian and Italian students working together.

WHY RESORT TO SMALL HOSPITAL SHIPS

The needs of local people

The ship being designed within this cooperation project is specially studied for health care needs of people living in the small villages scattered along many of the rivers of the northern Peruvian Amazon basin. People, to whom attention is mostly being paid to, are those living along the main rivers, out of the two main cities of Iquitos and Yurimaguas, which are the biggest harbours and main cities of the region.

Community hospitals located in the main cities are not supported by a health care system able to bring from afar people in need of care. Public means of transportation are arranged in scheduled service by regional authorities, but just on the main routes and with regular landing to the biggest villages. So, for people in need of care, the only way to come in touch with state assistance is to move with small and unsafe boats not specifically intended for fast cruise and for special needs.

The boat-based health care system

People living in the Amazon rainforest, specifically in the Loreto region in Peru, depending on their location, have to travel long distances in order to have access to a certain level of health care. A hypothesis has been made, based on the DIRESA health care network population estimate of 2012 [1] and using maps provided by Google Earth, of a person in need of medical services, in San Antonio, a small village along the Tigre River. Depending on the complexity of the medical needs, and the availability of qualified nurses and doctors, the voyage that a person must undertake varies from a 120 km round-trip to Paiche Playa's health centre for the simplest attention, that is to say, without the need of a physician, such as a vaccination, to a 840 km round-trip if the specialties of paediatrics or obstetrics are needed, or even to a 1882 km round-trip to Iquitos (the distance to Yurimaguas is even greater, and it is upstream on the Marañón and the Huallaga rivers) if other more specific specialties are needed.

These difficulties, met by people when moving from their living place to the health care centres, led regional government to arrange some small boats as mobile units specifically designed for health care. Small boats are operated by the Peruvian Navy, which every year draws up different expedition plans (i.e., the sailing routes to be undertaken during the dry season): a fleet of three dispensary boats (see Figure 1) and one clinic boat (see Figure 2). Different activities are planned

for every dispensary boat, a ship with healthcare facility for outpatient care (in Spanish "buque tópico"), and for the clinic boat (in Spanish "buque hospital"). Health care campaigns are also arranged in cooperation with border countries of the great Amazon region, like Brazil, Colombia and Ecuador.

Figure 1: One of the three river clinic ships of the Peruvian Navy sailing on the Amazon River near Iquitos in the Amazon region of Loreto, Peru.

Figure 2: The river hospital ship "BAP Morona" (ABH 302) of the Peruvian Navy berthed at the naval base of Iquitos in the Amazon region of Loreto, Peru.

River hospital crafts are also operated by foreign Non-Governmental Organizations, which may count on refurnished boats moved from abroad to the Amazon area – and so not specifically intended for inland navigation.

Despite all these efforts, the needs of local people may not be satisfied by the actual health care system because of the lack of resources and organization. In effect, despite the great increment recently occurred in the social security cover, about 30 % of people living on rural areas may not benefit from an adequate health care service [2], and percentage is higher in the Amazon region,

where infant mortality reaches 49.2/1000, compared to 18.5/1000 in the rest of the country [3] [4]. Such a critical situation may be overcome by the development of a more comprehensive health care system, based on mobile units which should be increased in number and specialized in duties for whichever planned campaigns or possible emergency.

The area of action of the "Clinic Ship Project"

The Peruvian Amazon jungle included in the territory of Peru is the second largest jungle after the Brazilian Amazon, and it is classified into two distinct eco-regions: the lowland jungle (in Spanish "Selva Baja"), also known as Amazon basin, standing between 80 and 500 metres above sea level, and the highland jungle (in Spanish "Selva Alta") extending into the eastern foothills of the Andes, between 500 to 3500 metres above the sea level. The Peruvian Amazon basin is divided in two hydrographical basins, the northern and the southern one, linked in the Brazilian Amazon.

Territory is covered by dense Amazon forests and, according to 2007 census [5], only 13 % of Peruvians live in this area, over a total of about 28,5 million inhabitants, with a theoretical population density of about 2,4 inhabitants per square kilometre. Most of them live in the metropolitan area of the main cities, so in the uttermost provinces of the Loreto region it may be estimated a lower density of up to 0,93 inhabitants per square kilometre. The Loreto region (i.e., the region in the red circle of Figure 3) is the area of action of the "Clinic Ship Project", its capital city Iquitos counts a population of about 440.000 over a total of about 1 million people in the region, and it is by far the biggest city in the region, followed by Yurimaguas (pop. 69.000), Nauta (pop. 30.000) and other four cities with a population ranging from 25.000 to 20.000.

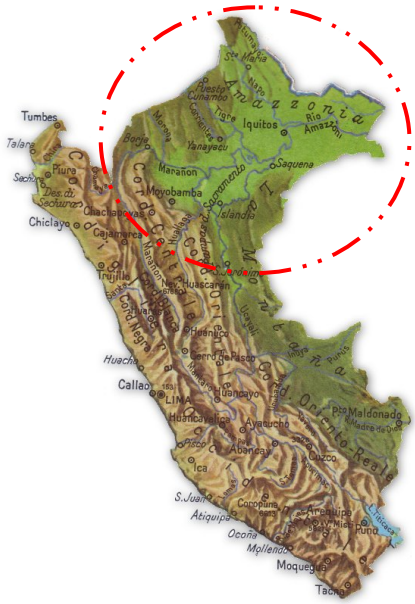

Figure 3: Physical map of Perú and, in the red circle, the northern Amazon region of Loreto, Peru.

While the rest of the Peruvian Amazon is accessible by roads from the coast, almost the entire Loreto region is not linked to the coast and access to it is only by boat from Yurimaguas or Pucallpa, or by flight from Lima or Panama City. Yurimaguas is the main city link, close to the east border of the region (accessible by main Peruvian road system), to Iquitos, sited in the centre of the region. Pucallpa is in the centre of the Peruvian Amazon region, and is also linked to the main Peruvian road system. Boat travel from Yurimaguas or Pucallpa to Iquitos lasts from 3 to 5 days depending on the river current and ship speed. Iquitos is the only international port in the northern Amazon region.

The northern Peruvian Amazon basin contains long and powerful rivers which are all contributors of the Amazon, such as the Napo, Tigre, Pastaza, Morona and Marañón on the north side, and the Ucayali and Yavarí on the south side. Transport network in Peruvian Amazon counts on 14.000 kilometres of main river, out of which, 6.000 kilometres are navigable to vessels with a 4-foot draught all year round [6][7]. Transport by waterway network accounts for more than 90 % of the movement of goods and passengers in the region [8]. The Ucayali River is the main north-south axis and the Marañón River the main east-west axis for freight traffic and access of people to Peruvian coast, while the Amazon River connects the region to Brazil and the Atlantic Ocean.

Road network has been poorly developed along rivers, apart from the stretch of road (a rough track) along the Amazon River near Iquitos. Single stretches of unpaved roads like trails have been opened in the jungle for connecting rivers whose course is parallel, just as a complement to the inland waterway network.

THE AMAZON RIVER NAVIGATION

Type of boats for general cargo and passengers

Most of the movement of freight and people inside the Loreto region go by boats: in Figure 4 popular small crafts are shown. The small powerboats in the foreground are launches for freight and passenger transportation on short-range routes, called “peque-peque” from the typical noise of their outboard engine.

Figure 4: Different types of boats for inland navigation, at the Iquitos harbour in the Amazon region of Loreto, Perú.

“Peque-peque” boats can take aboard up to about 20 people and load freight in small quantities; their main dimensions reach about 10 metres in length and 1,5 metres in breadth, and speed is limited to a few knots. They may be open or covered, usually by a light sunshield of reed or wood panels.

The bigger boats in the background of the same figure are medium-size ferry boats (on the left) and small-size ferry boats (in the centre) for freight and passengers on medium-range routes. Both motorboats have inboard engines, a small navigation bridge and an upper deck for freight transportation. Ferry boats range from a few metres in length up to about 40 metres and a maximum of about 6 metres in breadth. The smallest are made of wood and have a deck arrangement like that

of launches (just one passenger deck), while the medium to large size ferries have hull and superstructures made of steel and have usually two decks (for passenger accommodation) in addition to the main deck (for loading cargo) – and a very few number of ferries have three superstructure levels for passenger accommodation. A typical large-size ferry can load about 200 people usually lodged on the two upper decks, which may have a few cabins, but mostly hammocks, in case of more-days sailing, while freight is loaded in holds and on the main deck.

In any case, depth of all larger boats usually does not exceed the value of 4 feet for reducing odds of hitting the river bed, whose depth is not yet exactly known by pilots ever in sailing on main rivers. By the way, most pilots are usually sailing by sight (also in night time) and don't resort to any kind of navigational equipment like radars, echo sounders, speed logs and GPS devices. The navigation bridge, when existing as a separate space, is a small housing for the rudder wheel and engine order telegraph and the back side is equipped with two berths when long navigation requires taking turns.

Typical ferry boats are shown in Figure 5 while landed at a private port in Iquitos. They have the hull shape typical of a barge, that is flat-bottomed with a flat rising bow and nearly vertical sides, while waterplane area and main deck are nearly rectangular. Ships have usually superstructures extended on two levels (first and second accommodation deck) from the central part to the aft end of hull. The open space on the main deck at bow is fit for loading cumbersome and heavy cargoes. Cargo is also stowed indoors both on the main deck and in a small hold made out amidships of the hull, while passengers are lodged on the two accommodation decks. Astern, the main deck ends at the engine room, which usually extends from bottom to the first deck. At the bow end of the upper deck a small housing is located, which serves both as navigation bridge and captain's cabin.

Figure 5: Typical ferry boats for inland navigation landed at the Iquitos harbour, Loreto Region, Perú.

These kind of ships do not have specific requirements for maximum speed, and usually they may reach a continuous sailing speed of a few knots (from about 5 to a maximum of 10 knots), which is maintained during navigation depending on river current.

Berthing is obtained by beaching the ship's bow on the sloping river banks; mooring and loading of ship is made manually by crew, generally with no use of mechanical devices.

Environmental conditions and river navigation

River navigation in the Amazon region is subject to climate. According to tropical climate, during the rain season, river discharge increases greatly, and current velocity and water depth are at upmost. Along over the year a high fluctuation in current velocity and in water depth (up to 10 metres or more on the Amazon River [9] [10]) is usual. Nevertheless, the Amazon River and most of its tributaries show sufficient water depth for large boats and a ship's draught of 3-4 feet, is usually accepted as a grounding-free condition valid throughout the year. As already said, mostly pilots don't use any kind of nautical charts, so they are used to sailing by sight, maintaining ship's routes away from dead water areas of river bed.

This becomes a problem for navigation in two and sometimes even three cases. The first case is when the river presents the high level of water depth, in the wet season. During this period, the problem is the augment of river discharge, and consequently the increase of river current velocity. This means that the ship must have greater power to reach the desired design speed. The second case is during the dry season, when rivers present their lowest depth. In this time of the year, navigation is restricted in some areas, for ships with draughts of 1.20 metres or more. Nonetheless, smaller craft and especially designed ships do navigate regularly in these areas, where shallow water effects cause ships resistance to suffer considerable increases. The third case is when both effects combine. This condition presents in certain rivers when, even during the wet season, the river shows its higher depth and there is still a shallow water effect on ships, even if on a milder scale. Being the worst case, this last condition is the one chosen for design

Performances of the ship are referred to the high part of the Putumayo River where even during the wet season, when the river is at its highest level, there is a significant shallow water effect on the ship. River depth in these cases varies slightly around 6 metres.

A critical fact for boats navigating on the Amazon River and its tributaries is the risk of impact with floating trunks and vegetation. Trees growing along the river banks are forced to fall into water by current erosion, especially on the outer side of any river bend, where current (and also depth of river bed) is higher, making bank line ever changing. Trunks may also dig in the river bed: when ships pass over, the trunk may be released and hit the hull or, at worst, the propeller and/or rudder. In order to avoid some kind of troubles, special types of propeller protection devices are used.

A very interesting solution has been developed by the engineers of the SIMA Shipyard of Iquitos, the major shipyard of the Peruvian Amazon region. In some cases (see Figure 6) no further devices are used for protection of rudders, which are intrinsically preserved from trunks impacts by propeller shield. In Figure 7 a more typical way for protection of propeller and rudder is shown. According to that system, each propeller is placed in a deep tunnel and is protected by a skeg and a sound heel. Insertion of the shaft lines in deep tunnels between longitudinal stern protrusions (Figure 6 & Figure 7) has the double advantage of propulsion system protection and use of higher diameter propellers.

Figure 6: Special protection devices used at the SIMA-Iquitos Shipyard for the river boats sailing in the Amazon region.

Figure 7: Closed propeller wells arranged within tunnels for propeller and rudder protection, SIMA Shipyard, Iquitos.

Inland navigation in the Amazon basin is made more difficult by the river bed soil composition; soils are very heterogeneous but almost all have river origins, and sand is ever present. River current causes sand to be dragged and mixed, so coming to be in suspension in water and, due to a low clearance between ship's bottom and river depth, to come in contact with the ship's hull. A water rich of sand is a very technical matter for the outer gaskets of propeller and rudder axes, other than for the seals of the thru-hull valves. Sand may very rapidly wear away gaskets, enter in and erode bearings, implying the engine to be switched off. Repair of such failure needs to be made in dry dock, so becoming a very serious damage for shipowners. In order to avoid this kind of troubles, special types of stave bearings are used, placed outboard of the stern gland or stuffing box, which have a rubber sleeve (in place of Lignum Vitae) lubricated by a water flow passing along grooves, leading outboard.

Specific environmental conditions also affect on board comfort design. In work spaces and crew and passengers accommodation decks, very basic comfort levels are usually accepted. Clearly, high temperature and humidity all over the year suggest to close those spaces with outer bulkheads and to install air conditioning systems.

River boats for Amazon region have barge-like hulls designed to have basic performances regarding both speed and manoeuvrability. Flat-bottomed hulls allow to increase ships' displacement at lower draughts, while flat rising bows facilitate beaching on sloping banks (see Figure 5), in a region where, due to high seasonal fluctuation in water height, river banks are a cheap alternative to floating docks. Clearly, hull plates of bow bottom are reinforced to sustain concentrated grounding forces and to reduce wearing effects of friction on the river banks.

In conclusion, river boats are especially designed to be a sound means of transportation while sailing in extreme environmental conditions.

PROPOSAL FOR A NEW CLINIC SHIP

Mission profile

The new clinic ship (see Figure 8) has been thought as to complement the fleet of the health care system based on three small infirmary ships and one small hospital ship operated by the Peruvian government through the Peruvian Navy.

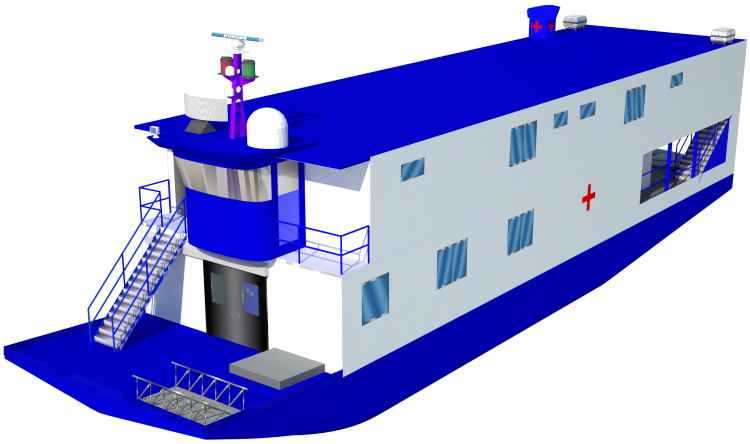

Figure 8: Pictorial view of the clinic ship.

Mission profile has been determined basing on the assumption that clinic ship service has to be fulfilled in different scenarios: for a routine health care service, for specific campaigns (e.g., against typical tropical diseases, like the cataract pathology known as "river blindness"), or again for humanitarian or emergency assistance.

Routes have been defined according to standard practice of performing long-range campaigns from the regional capital city of Iquitos, the main port of the northern Amazon basin, to the outmost villages along the country borders – while villages in the far west are reached by roads from the Andean region. In accordance with that expected range, fixed on 2700 nautical miles, equivalent to about 5000 kilometres, proper fuel oil tanks capacity has been provided.

As a reference performance for design speed, continuous speed v_S of 10 knots has been regarded as appropriate in calm shallow water (of 6m of depth). In defining propulsion power, a proper allowance has been considered for taking into account the extreme environmental conditions, by

referring to upriver navigation in a river current up to about 2.5 metres per second (nearly 5 knots), and a minimum speed of about 5 knots has been assured for safety reasons.

As for the navigation limit due to river depth, it has been judged appropriate for the clinic ship to sail with a maximum draught TD equal to 4 feet that is, a navigation restricted on main rivers. Villages on minor river branches may be reached too, by the use of a tender based on the ship.

Long-range navigation may be performed with the maximum displacement corresponding to the limit mean draught TS of about 4 feet. That sailing condition is reached when the ship is loaded at the upmost, with full load of provisions, stores and cargo (crew and passengers with their personal effects), and it is also the reference condition for ship's structure design (the so called scantling draught).

A maximum continuous service period of one month has been considered in defining needs of provisions and medical equipment. A proper amount of fuel oil has also been considered for the on board power units, which have to supply ship's equipment (e.g., water purifier and sewage treatment unit) and all services to accommodation areas and clinic premises (including the air conditioning units). Air conditioning would enlarge energy consumption significantly, that is why solar panels have been thought as an extra source of power. This would be placed on top of the 2nd deck, taking advantage of the 140 square meters of free area that would provide with approximately 22 kW.

As in the standard practice, landing of the ship may be obtained by bow beaching on sloping river banks and/or by spring lines from on board bollards. As health care service will be carried out when ship is at rest, in order to assure the ship stays upright, ship is equipped with a ballast system for trimming, while heeling is obtained by athwartships moving of the liquids in tanks. During sailing, the maximum trim is fixed in about 1 degree, in line with the more strict comfort requirements for living on board.

General arrangement

The design of the new unit has been developed under the more strict and updated safety regulations, making reference to international rules which, while being accepted as a sound standard in Europe, are not considered as mandatory by Peruvian flag administration.

As for the technical choices regarding materials and parts for structures, propulsion plants, systems, equipments and fittings, reference has been made to the local availability and standard practice, providing that standards offer acceptable quality levels according to technological, environmental and safety criteria.

The comfort proposed on board to crew and passengers is based on the better accommodation standards to which local people are accustomed. So, the ship has not been supplied with integrated air conditioning system – just single units are provided in the clinic premises. According to that criterion, no noise and vibration insulations in the cabins have been accounted as necessary, and indoor set up as covering on steel structures and piping has been disregarded in accommodation and working areas, while in clinic areas, for sanitary reasons, inside covering of hull structures is required.

The clinic ship has main dimensions in line with the standard size of the ships usually operated in the northern Amazon region of Peru. So, it has to be expected that pilots and crew may work at best. Ship's main dimensions are the following: overall length LOA equal to 26,60 metres, moulding breadth B equal to 6,36 metres, depth D (at the main deck) equal to 1,70 metres, design draught TD

of 1,10 metres (which corresponds to a design mean draught of 1,00 metre and a displacement ΔD of 121,22 metric tons) and a maximum permissible mean draught TS of 1,20 metres. The betweendeck height of main and upper deck is equal to 2,40 metres, while maximum gross height above the bottom is of about 1,70 metres. Superstructure deck develops from bow to stern, leaving uncovered just a small area of the weather deck at bow end, where a hatch opening of the first hold and gangway devices is located. Main dimensions of ship have been established basing on the space needed for accommodation and clinic areas.

The ship's arrangement is very simple and is shown in Figure 9. In the main hull all the technical areas are confined (the engine room serving also as auxiliary room for ship's general service equipment), along with the fuel oil, drinking water, sewage and ballast water tanks (fore peak and aft peak), and the two holds, one forward and one amidships. Holds are fitted for loading small-size general cargoes and are especially suitable to load stores and equipment for humanitarian assistance, of an overall weight of 2 metric tons. The two holds and the engine room are accessible by hatch openings at the main deck level.

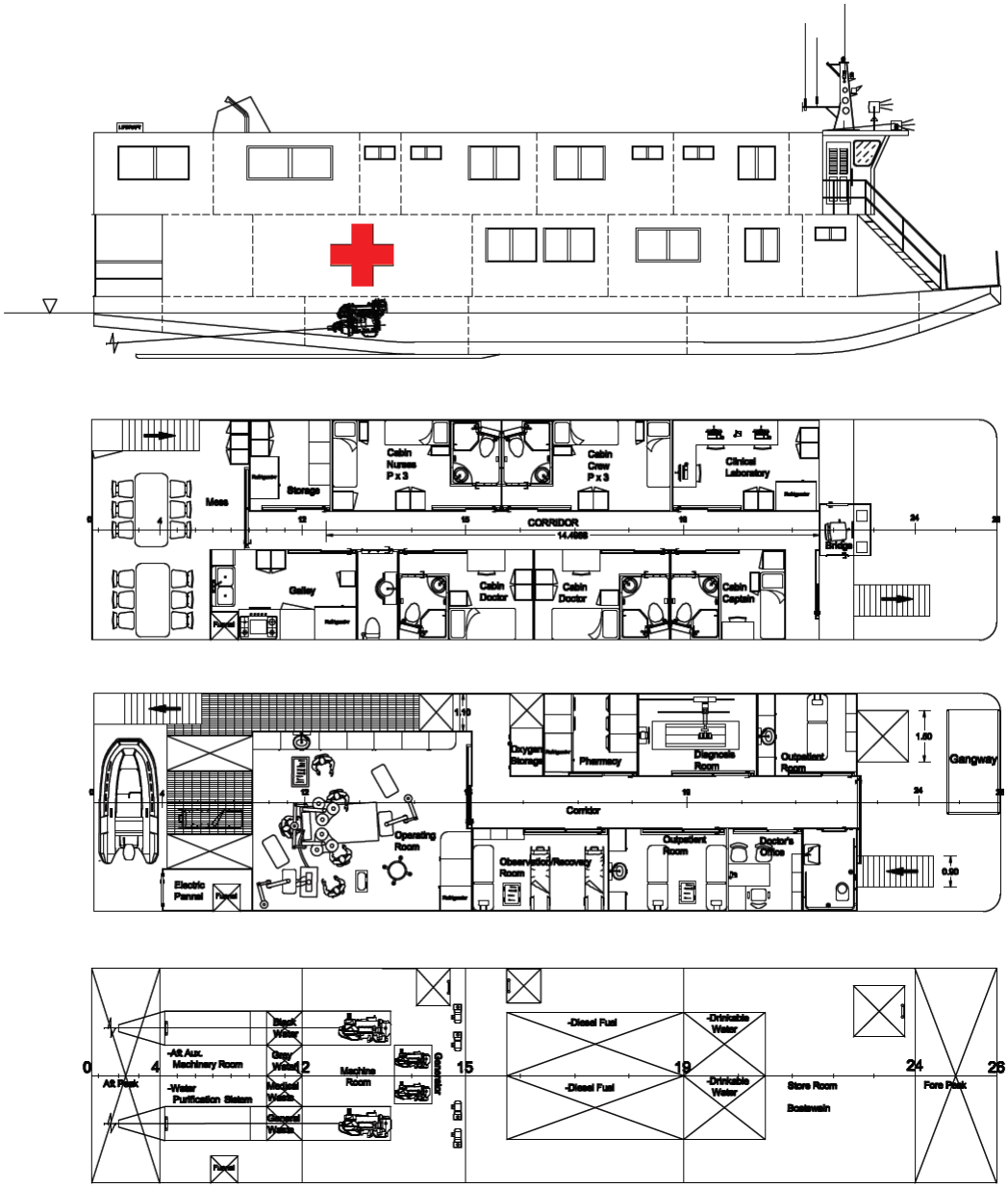

Figure 9: General arrangement plan. From the top: Longitudinal view, upper deck, main deck and lowerdeck layout.

Accommodation and clinic areas have been separated: hospital premises are located on the main deck, while accommodation areas for passengers and crew are all located on the upper deck. Clinic spaces are directly accessible from both the bow gangway and the tender station. Segregation between accommodation and clinic spaces guarantees more safety and security during sailing or staying in port: access to the two different areas may be independently closed for security reasons, while outdoor staircases give direct access from upper deck to life rafts and lifeboat, so allowing people to leave the ship in the event of an emergency.

On the main deck, clinic premises present, from bow to stern, a dentistry room, a diagnosis room equipped with digital X-Ray and ultrasound scanning, a doctors' office, a toilet, one consulting rooms, a pharmacy, an observation/recovery room, a technical space for oxygen storage and an operating room for minor operations and obstetrics and gynaecology. All rooms are aligned on both sides of a long passageway beginning at the bow end bulkhead and ending at the right side of the ship. The two passageway's ends, which are the only access to clinic spaces, act as escape routes and are closed by sound waterproof doors for safety and security reasons. Operating room fills up the main afterward part of main deck. Beyond the operating room, a technical space for the electric panels and for the funnel ducts has been made.

At stern end of the weather deck the devices for a tender are installed, while at bow end a gangway and a davit are fitted; other small deck equipments like bollards, basket for spring lines and minor safety devices are fitted along the ship's length. From the main deck, three hatch openings lead to two holds and engine room (even accessible by a large casing).

The upper deck arrangement is similar to that of the main deck, with all rooms overlooking the inside passage. Moving from bow to stern one may find a small navigation bridge, a clinical laboratory, a series of cabins with private bath for crew (one cabin with three bunks) and captain (one cabin with two bunks) and for clinic staff (two single rooms for doctors and one cabin for three medical assistants), one toilet and, at stern end, the dining and meeting hall preceded by a storeroom and a galley. The meeting room, overlooking bow and sides, gives direct access to a staircase. Another staircase is placed at the front end of the passageway, giving direct access from below to the bridge wings. As for the main deck, the two passageway's ends are the only access to deck and act as escape routes (fitted which doors that may be closed for security reasons).

BASICS ON THE CLINIC SHIP DESIGN

In general, ship's design is an iterative process based on a few main stages. As for the clinic ship, the main stages have been set up, concerning hull geometry design, structural design, stability and buoyancy criteria checking, and propeller and propulsion plant design. Being the project in a first phase, just few loops of the cyclic design process have been set up, so conclusions here presented are susceptible to improvement.

Design process of the clinic ship begun with the definition of a suitable general arrangement plan for the clinic and accommodation spaces, reserving the large lower deck (i.e., the main hull volume) to the technical spaces. Basing on that plan, and according to the basic idea of shaping the hull like that of a barge, the hull geometry has been defined. Then, on the basis of the hull geometry and arrangement of decks, design and scantling of structures have been developed. A tentative propulsion power has been defined, basing on a first estimate of the ship's resistance in shallow water.

A rough prediction of weight of structures, plants, fitting, equipment and furniture, along with weight of stores and liquid in tanks, allowed to a first estimate of the ship's displacement and

position of ship's centre of gravity. Finally, stability and buoyancy criteria have been checked and, according to that, some modifications have been made on compartments' layout.

Safety criteria for hull scantling and for ship's stability and buoyancy have been applied, making reference to the Bureau Veritas classification society requirements [11], an updated body of rules enforcing the Directive of the European Community laying down technical requirements for inland waterway vessels [12]. Such new regulations cover all the issues related to safety of ships for inland navigation and are the most up-to-date rules for their design.

Hull geometry design

The hull geometry of the clinic ship has been outlined on the typical hull of main ships sailing in the Amazon region, the barge-like hull (see Figure 10). Solutions aimed to resolve the specific issues of the river navigation have been envisaged.

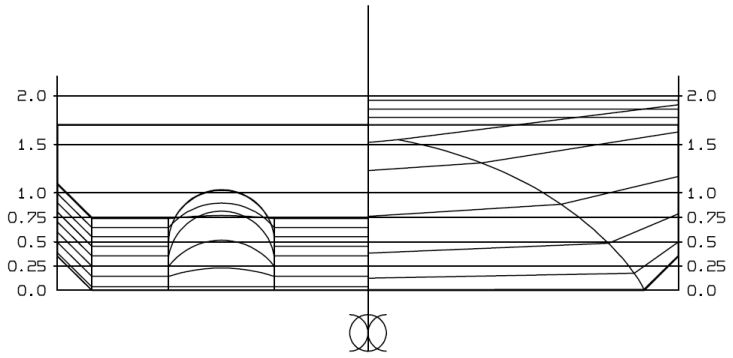

Figure 10: Body plan of the main hull

In an earlier approach [13], a single tunnel was chosen, for both the propellers and the stern bulbs housing the propeller shafts and engines (see Figure 11). Shaping the afterbody with propeller tunnels is of common practice when the required diameter of the propeller is larger than the minimum draught. This solution, currently used in several types of ships in the Amazon basin, such as oil and gas carriers that need to reach the extraction stations, proved to have certain problems in our particular case. Buoyancy in the aft section was not sufficient to maintain the trim horizontal enough to guarantee a low immersion and keep the draught at the AP below 1.27 metres in a full load condition with a trim of 0.39 metres, or below 1.18 metres in lightship condition with a trim of 0.94 metres. A first hand solution was to move the engine room to the next forward compartment. Results where that with a lightship condition, draught at the AP was 1.15 metres and trim by the stern was 0.85 metres; with a full load condition draught at the AP was of 1.23 metres and trim by the stern was 0.32. This turned out to be sufficient but not completely satisfactory; nevertheless, no further changes were adopted at the time.

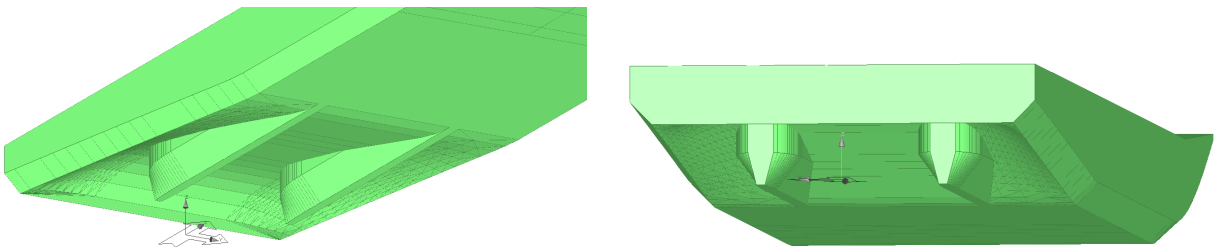

Figure 11: Earlier approach with two stern bulbs and one tunnel.

Following further investigation, after body hull shapes were chosen and re-designed. The selection was done following the guidelines in the work done by Heiner [14]. Each propeller was put into a separate tunnel, as shown in Figure 12. Parameters followed by Heiner's guidelines for designing the propellers' tunnels take into account, that the tunnel must be shaped to avoid propeller cavitation, provide a uniform and undisturbed flow to the propeller when going ahead, ensure the possibility of filling the tunnel volume with water by suction of the propeller, when starting and enabling a perfect reverse manoeuvre by filling the volume behind the propeller, only by suction of the reversed unit. This last characteristic is of particular importance in our case because, as explained in the previous work, vessels operating in Peruvian Amazon basin must ground when arriving to destination in most cases, especially for our vessel, that has to visit small villages, where harbour infrastructure is mostly non present, or in very precarious conditions, this of course, always due to the impossibility of building movable structures that follow the dynamic of the rivers and river beds. In these scenarios, when departing, the ship must overcome a greater resistance, and consequently the propeller must give a higher thrust backwards.

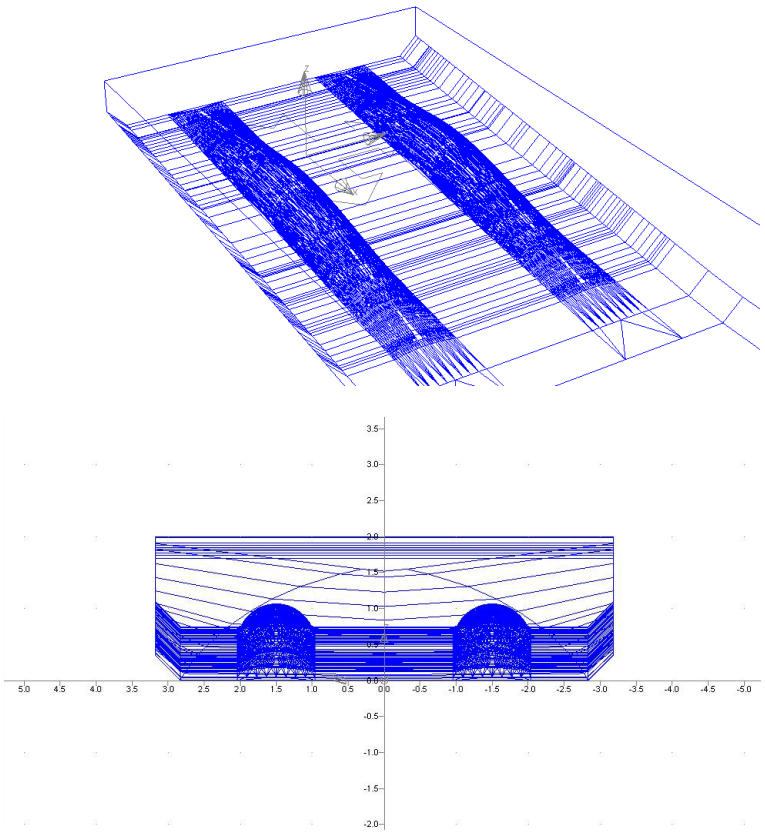

Figure 12: Different views of the propellers' tunnels'.

Calculations made to shape the afterbody depended mostly on the propeller diameter, but also on the inclination of the top of the tunnel towards the stern which, in case of being slightly larger than recommended can lead to the reduction of the effective forward thrust provided by the propeller.

Now propeller shafts are housed in skegs (see Figure 13) that extend vertically, from the hull to the bottom line. They could have been extended just until the propeller shaft, to improve the flow into the propeller, but rudder design came into the context, and demanded the skegs to be designed as they presently are. The use of suspended spade rudders is highly discouraged because of the

presence of suspended and floating debris on the river. These debris can sometimes reach the propulsion and government arrangements and cause serious damage. Therefore, it is a common practice to use a solepiece to protect rudders.

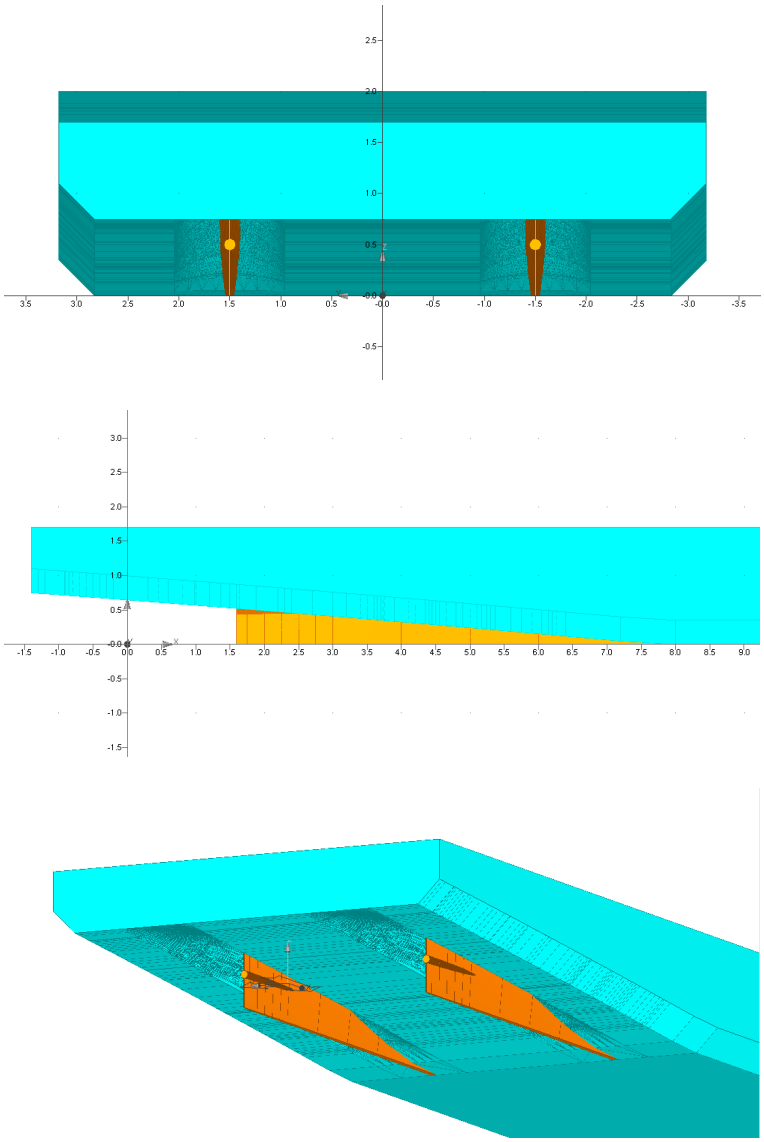

Figure 13: Different views of the skegs fitted in the propeller tunnels.

At this stage propulsive improvements are only qualitative, towing tank experiments, or CFD calculations are required to quantify the improvement and achieve more accurate results and solutions, and because this project is currently in a concept design stage, by a small team, it requires more time for further developments. However, the increase of buoyancy in the aft section has been quite successful (See Figure 14). We have gained 60.23 kN of buoyancy which led to a reduction of immersion at the AP from 1.27 metres to 1.15 metres, in the full load condition.

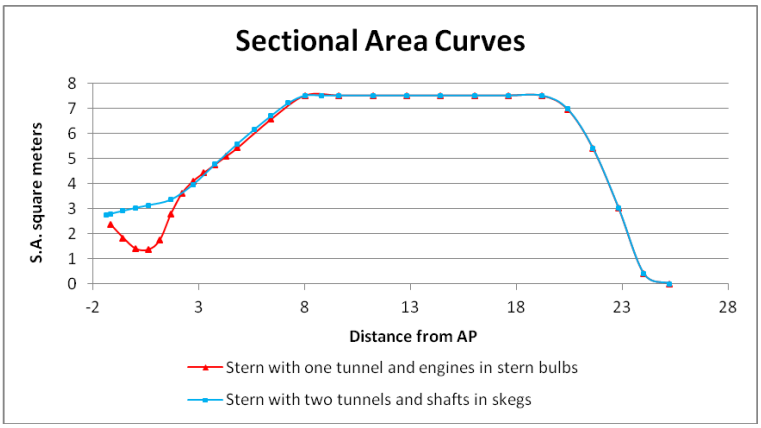

Figure 14: Increase of volume in the stern of the ship.

The hull has been improved in the bow part by giving to the hull a slight bow flare offering the ship a better route stability. The main part of the hull is a cylindrical body having flat bottom and sides connected by a flat bilge. Cylindrical body, characterized by a constant profile, extends over a wide range of the ship's length.

Structural design

Scantling of main hull and superstructures has been completed, basing on the Bureau Veritas rules for inland waterway steel ships. Design of structures has been made according to regular practice of shipbuilding in the Amazon region. As an example, characteristics of steel have been selected according to local availability, both in terms of yield stress, by using steel with minimum yield point of 235 MPa, and nominal dimensions for plates and stiffeners, by referring to imperial units.

The two main plans of the ship's structures have been specified, that are the midship section design shown in Fig. 11 and the plan of the transverse frames.

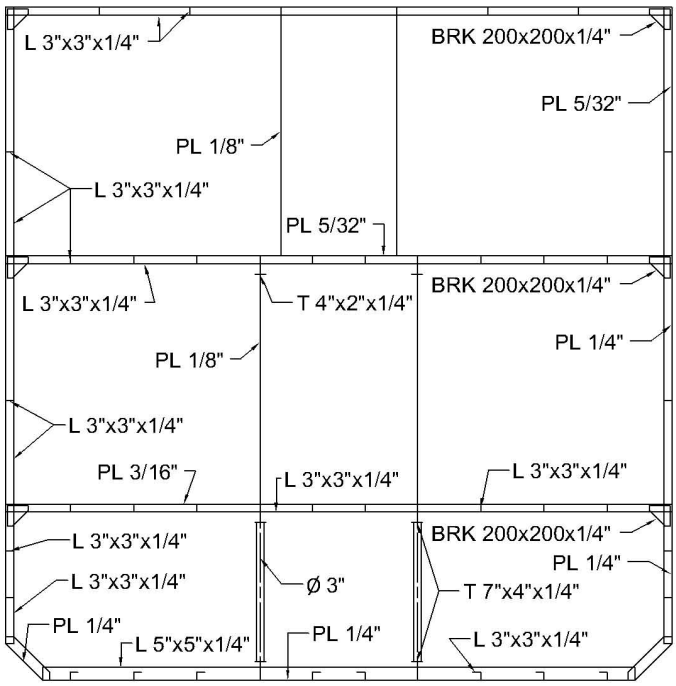

Figure 15: Midship section plan

All loads have been derived by making reference to the maximum mean draught TS, fixed at 1,20 metres. For the most part of the ship's length, plates have been reinforced by longitudinal stiffeners placed at small interval between each other and supported by reinforced large-spaced transverse frames, in order to contain the hull's weight while preserving hull's strength.

Checking of stability and buoyancy criteria

Stability and buoyancy of the clinic ship have been verified under the more strict additional requirements given by the Bureau Veritas for passenger ships. Two series of analysis have been carried out, regarding intact and damage condition of the ship in different loading cases.

Stability has been checked by considering both static (initial stability) and dynamic principles, and by making reference to list due to crowding of passengers, lateral wind pressure and turning circle moments. Damage analysis refers to the event of flooding of any of the watertight compartments one at a time – so giving to ship the "one compartment flood ability" status.

All requirements have been satisfied by a proper positioning of transverse watertight bulkheads and tanks. Main tanks for fuel oil and water have been located along the middle line plane of the hull, in order to reduce flooding volume in case of damage (by regulation, maximum transverse extension of expected damage is equal to B/5) and to keep the ship transversally upright when flooded. Equilibrium of the ship in the final stage flooding of one of the considered case studied is shown in Figure 16.

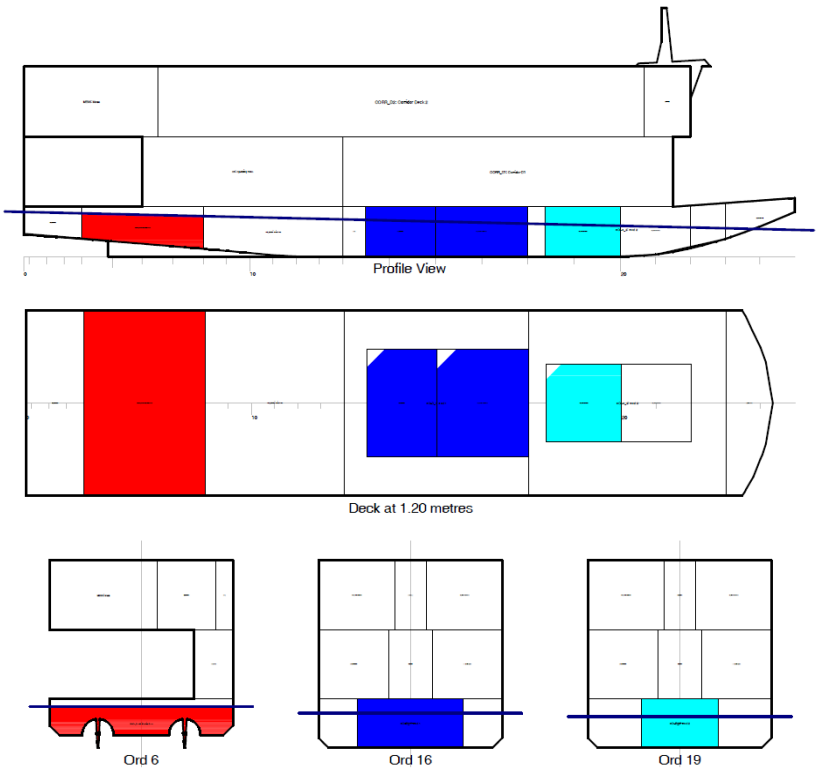

Figure 16: Final Equilibrium of the ship when flooding the compartment aft of the Engine Room.

Propeller and propulsion plant design

Propellers and propulsion plant have been studied on the whole, making reference to ship resistance predictions in shallow water carried out by applying systematic series for inland navigation barges by Zotti [15].

After a preliminary analysis on hull's resistance, the size of power plant has been defined in about 450 kW, value which led to consider appropriate to split the propulsion power on two propellers, in order to keep down the propeller diameter, which may not exceed hull draught with proper allowances. Two independently powered propellers have been considered as a good solution to increment manoeuvrability. Moreover, redundancy in propulsion system makes the ship more intrinsically safe.

After fixing the propeller diameter and redesigning the afterbody, a new propeller was selected, considering the new aft geometry constraints. The propeller selected is from the Wageningen B-Series. This series of propeller may not provide the most adequate propeller for this kind of vessel or navigation range, but it represents a valid approach for the engine selection. Specific propeller design should be done aiming to improve η_0, and reduce cavitation as much as possible, for these propellers have a high thrust load. Propellers with a higher skew are recommended.

Heiner recommends the application of Kort-Nozzles, for they can yield gains of 25% more compared to regular propellers without nozzles, depending on ship speed, wake coefficient and power load of the propeller. In spite of this gain, nozzles are not always advised in the Amazon basin. This is due to the debris transported in the river that may arrive to the nozzle, and block the propeller. Also, caution must be taken when choosing the application of jet drives. Vegetation may reach the water intake and block it. It is imperative that a study of the routes and seasons of service of the vessel is done before choosing any special propulsion device.

In earlier approach, the propeller had a diameter of 0.93 m, and for the vessel to reach 10.50 kts, 230kW had to be delivered to the propeller to make it rotate to 10.55 rps. The current selected propeller has 1.00 metre of diameter, and to reach the same speed, 224 kW have to be delivered to it, to make it rotate to 9.83 rps. The fact that the propeller must develop lower revolutions per second to achieve the same speed means that the propeller will have less cavitation, the rpm will be lower, leading to reduced fuel consumption and lower emissions.

Equipment and outfitting design considerations

The criterion of easiness and plainness has been followed for the equipment and outfitting design, both for the accommodation and safety systems, according to the local standard practice for river ships. A specially attention has been paid on the environment, so an eco-friendly equipment has been set up for the ship, including a plant for sewage treatment, fittings for reducing fuel spills and a deposit of garbage.

As for the navigation bridge equipment, an improvement of the actual status has been considered as highly advisable.

CONCLUSIONS

The "Clinic Ship Project" is a successful example of cooperation project, whose attempt is to concretise an academic education programme with application, in behalf of the local communities, of the new knowledge acquired by young people during their academic studies carried out at the two cooperating Universities.

As for the technical aspects, being the design of the clinic ship at a preliminary stage, it is susceptible to improvements, such as further improvements in the hull shape and the propulsion system, and open to further studies to check the manoeuvrability and the particular case of the beach landing.

Also, it must be noted, that this is a concept design, and the arrangement of the main deck, which holds the medical precincts can be modified according to the kind of service needed.

It is worth saying that design of such specialized ship for such an extreme environment is a very difficult task, made a little bit more troublesome by regulations not ease to be used.

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