Preliminary Concept Design of an Affordable Coastal Patrol Craft for Sri Lanka Navy

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Abstract – *The post-war role and the mission of Sri Lanka Navy has become more multi-dimensional. Newer challenges such as piracy, fisheries law enforcement, human trafficking, drug trafficking, and marine pollution prevention have become major focus areas for Sri Lanka Navy. To successfully counter these new challenges the Navy has broadened its spectrum of operations by forming the Sri Lanka Coast Guard and more recently forming its first Marine Battalion. With the introduction of these new units, there will be an increased demand for a new fleet of patrol crafts. Due to budgetary constraints a cost effective way to approach this situation is to design a single class of patrol crafts that has multi mission capabilities which can perform most of the operations carried out by the Sri Lanka Navy, Sri Lanka Coast Guard and the Marine Battalion. This research paper is about designing an affordable multi mission capable patrol craft, utilizing modularity concept and a planing hull design. The initial step in this design process was to get an understanding of the Sri Lanka Navy, Coast Guard and Marine Battalion fleets and the specific missions of each service. Then key design parameters such as length, endurance, maximum speed were recognized through this initial research. Then a similar ship analysis/market survey was carried out to select other principal dimensions and coefficients of form. After all the key design features are decided, a preliminary concept design of the ship hull form was created utilizing design software. Further analysis was carried out to generate initial hydrostatics and stability curve of the vessel, and resistance and powering calculations. Since cost reduction is the most vital aspect in this study to become an affordable design a lot of emphasis was put on the modularity concept and the learning curve concept.*

Keywords - **Planning hull, Patrol craft, Cost effective, Modularity**

I. INTRODUCTION

After three decades of brutal war Sri Lanka Navy is broadening its horizons and improving the capabilities to become a professional and more competent naval force. In this scenario expanding the naval fleet is one of the key priorities for the Navy and improving the contemporary naval design is of paramount importance in this context. The primary goal of this research paper is to come up with a preliminary concept design of a coastal patrol craft that could fulfil most of the current mission requirements of the Sri Lanka Navy and the Sri Lanka Coast Guard. These missions cover a wide range of maritime safety, maritime security and maritime stewardship aspects. Since each of these missions require specific design features or specific qualities such as high manoeuvrability, ability to reach high speeds, shallow draft etc. It is important to have a thorough understanding about all the missions carried out by the Navy and the Coast Guard. These missions include but not limited to coastal patrol, search and rescue operations (SAR), anti-terrorism operations, reconnaissance, logistic/resupply, medevac, amphibious missions, oil spill response, drug interdiction operations, humanitarian assistance, law enforcement, peacekeeping, illegal immigrant interdiction and non-combatant evacuation operations.

If Navy and Coast Guard is planning to design multiple classes of crafts (patrol craft, rapid response boat, life boat, amphibious landing craft, etc.) catering to all these requirements, it would be a costly and time consuming endeavour. Therefore designing a single class of vessel that could perform most of the aforementioned missions a lot of expenditure could be saved during the preliminary design stage, and also during the manufacturing stage.

To achieve cost effectiveness, efficiency and multi mission capability a couple of design concepts will be explored in this preliminary concept design study. A planing hull model will be utilized in this preliminary study due to its ability to achieve high speeds, and also its efficiency in planing mode. The concept of employing mission specific removable payload modules will also be utilized in this design to economize the space of the vessel while enhancing the multi mission capability of the Coastal Patrol Craft.

A. Planing Craft

The definition of planing, i.e. "*Planing is the mode of operation for a waterborne craft in which its weight is predominantly supported by hydrodynamic lift, rather than hydrostatic lift (buoyancy)"* According to [3], the planing hull has evolved to overcome the inherent hydrodynamic limitations associated with high-speed operation of the traditional displacement hull. When increasing the speed of planing hull, developed positive dynamic pressure support to decrease the draft. Hence craft can attain higher speeds despite of wave generated. The principal parameters affecting the performance of planing hulls [3] are:

- Length-beam ratio, *LP/BPA,* where the mean beam over chines *BPA = AP/LP.*
- Size-weight ratio, defined by the coefficient
- Longitudinal position of CG from center of area of *AP.*
- Deadrise and its variation along the length.
- Longitudinal curvature of buttock line *BPA/4* from CL.
- Shape of chine in plan.
- Shape of sections.

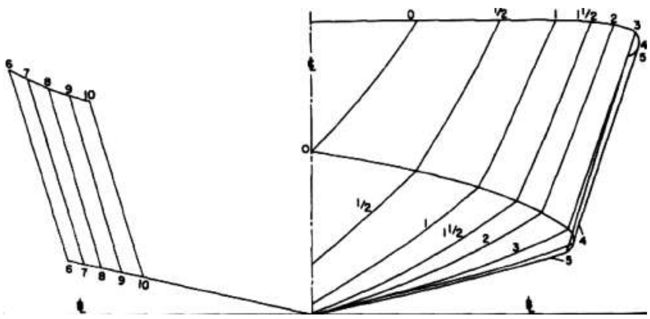

Figure 1: Lines of stepless planing hull-series 62 [3]

A theoretical approach to planing craft design is undertaken especially by Savitsky (1964) and by Hadler (1966). Savitsky brought out formulas for calculating the lift and drag forces while Hadler presented a method to predict the hull performance using Savitsky's formulas to calculate hydrodynamic forces and open water diagram to evaluate the propeller forces [3].

As a reliable approach to this study, Savitsky (1964) and Hadler (1966) studies are helpful formulating our design in a systematic way.

B. Concept of Modularity

The concept modularity is a novel concept that is being employed in modern naval forces as a mean of reducing the vessel size while retaining multi mission capability. The basic idea of modularity is instead of permanently fitting a vessel with equipment required for all the missions, there will be a space or spaces assigned in the vessel that could accommodate mission specific removable payload modules (medical equipment, oil spill response equipment, extra weaponry and ammunition, SAR equipment, etc.).

These mission specific payloads could be easily fitted and removed and are of the same standardized size. The only difference in these modules will be the content of each of the module. The payloads could be stored, and maintained in naval bases around the country, always in standby condition. Thus when any emergency occur a patrol craft or crafts could be fitted with the required module immediately and deployed. As patrol crafts often operate as a flotilla they could respond to a situation that requires different mission capabilities simultaneously by fitting different mission payloads on each craft.

Even though mission specific mission module is a relatively novel design concept, it has been proven successful and has been employed by some of the most advanced naval forces around the globe [8, 9]. A couple of examples for the utilization of this concept are the StanFlex modules used by the Royal Danish Navy (Kongelige Danske Marine, KDM) and the Littoral Combat Ship mission modules used by the United States Navy [8, 9].

StanFlex modules were first introduced in the 1980s, by the KDM as a solution to the successful replacement of several classes of minor war vessels with a single class of multi-role ships. These modules are standardised containers that could contain weapon systems and equipment. These modules can be easily fitted in to and removed out of the empty slots on board the ships. Due to the success of these StanFlex modules most of the KDM ship classes employ this concept [8].

Littoral Combat Ships are one of the smaller warships of the United States Navy and was designed in order to counter small surface craft attacks, and for counter terrorism operations. The speciality of this ship is its ability to respond to a wide array of situations utilizing its mission specific modules [9].

Figure 2: Modular mission packages of the Littoral Combat Ship [9]

C. Effects of Learning Curve

Since cost-effectiveness is one of the major driving factors in this design process, it is necessary to emphasize on the rationale behind designing a single class of patrol craft that has multi mission capabilities instead of designing several classes of patrol boats to perform specific mission. Firstly this could save cost during the preliminary designing stage, since there will be only one final design that will be implemented. But the major cost savings will occur during the manufacturing stage.

During the manufacturing phase the principle of learning curve will decrease the manufacturing cost of the follow up boats due to the experience gained during the manufacture of the earlier boats. Spicknall (1995) states that "*The traditional experience curve model of learning and improvement is founded on the presumption that individuals and organizations learn and performance improves solely as a result of experience gained through repetition of similar lines.*" This article also provides an experience curve function as;

$$y_n = a.n^b$$
(Eq. 1)

Where;

n	Number of units of interest
y_n	Objective measure of the performance
a	Value of y for the first unit produced
b	Exponent derived from regression analysis of historical data [7]

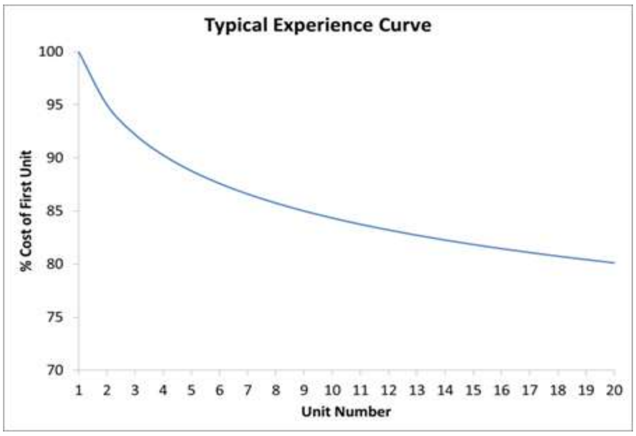

Figure 3: Typical experience curve [7]

Figure 3 shows a typical experience curve where a=100%, and b=-0.074. This learning curve indicates that to exploit the full advantage of the experience gained through the repetition and specialization, a considerable amount of units has to be produced. Thus it is better to design a single class of patrol boats, and keep manufacturing them while making them multi mission capable through modularity than designing multiple classes of boats to meet specific mission requirements.

II. METHODOLOGY

A. Top Level Requirements

During the first phase of this research the top level requirements or the key parameters such as the length, endurance, and maximum speed of the Coastal Patrol Craft were identified based on the mission requirements of the Navy and the Coast Guard. Since it is unrealistic to design a vessel that fulfils each and every one of these mission requirements, compromises and trade-offs were made accordingly. The three top level requirements identified as the most important in this initial phase were the endurance, maximum speed, and the length of the patrol craft. During this initial research stage we identified the need of a new Coastal Patrol Craft for the Coast Guard and the Marine Battalion, the two newly formed branches of the Navy. The missions of these two branches are highly likely to be in the coastal waters for the next few years until they become fully fledged organizations with offshore capabilities. Thus the maximum endurance required for these patrol crafts are approximately 200 NM. Since the missions of both these units include rapid action and rapid deployment, (Ex: drug interdiction, anti-piracy missions, amphibious missions etc.) these boats should be able to achieve a maximum speed of approximately 40 knots. In order to achieve this maximum speed, it was decided that the design of the patrol craft has to be a planing hull. Planing hull design will also result in a decrease in the draft and this is also critical especially since marines usually engage in amphibious operations and this design could operate in shallow water conditions. Since these boats are coastal patrol vessels the crew size will be around 10-15 (crew and troops) and thus the projected length of the craft is around 10-12m. These parameters are the three top level requirements that were utilized as the key parameters of this research. Based on these three parameters a market survey and a similar ship analysis were carried out to determine the other dimensions of the Coastal Patrol Craft.

During market survey/similar ship analysis nine boats were selected as potential parent hull for the Coastal Patrol Craft. These boats mostly included military vessels but a couple of commercial vessels were also selected based on the performance of their planing hulls. The particulars that were focused on this preliminary study were the length, beam, displacement, maximum speed, cruising speed, endurance/range, propulsion power, crewing, whether the boat carried armament, planing hull or not, employed a rigid inflatable collar or a foam collar or not, and finally the missions carried out by these boats. The dimensions that were obtained during this market survey/similar ship analysis were catalogued and then compared using ratios. These ratios included maximum speed vs length, length vs beam, beam vs draft, power vs. displacement, and displacement vs. draft etc. The aim of this process was to select principal dimensions of the Coastal Patrol Craft that are within acceptable limits. One of the major difficulties faced during this process was the lack of market survey data regarding the planing aspects of the selected similar boats. Design data regarding deadrise angle, chine, aspect ratio, location of Longitudinal Center of Gravity, coefficients of forms were virtually non-existent for the selected vessels. Thus theoretical knowledge was used in determining those parameters during the design of the hull model. Based on the available dimensions of the similar boats the Small Unit Riverine Craft (SURC) of the United States Marine Corps was selected as the principal parent hull for the design of the Coastal Patrol Craft.

Table 1: Key particulars of parent hull [6]

Patrol Craft	Key Parameters and Details
Length	12 m
Beam	3.1 m
Draft	0.61 m
Displacement	9.8 LT
Max. Speed	39 kts
Cruising Speed	35 kts
Range (nm)	250> nm
Propulsion Power (hp)	880 hp
Complement	2 crew, 16 troops
Armament	3 mounts for heavy machine gun and smoke launchers
Planing Hull	Yes
Rigid Inflatable Collar	Foam collar
Missions	Maintain Control of rivers and inland waterways, command and control, reconnaissance, logistics/resupply, medevac, counter-drug operations, humanitarian assistance, peacekeeping, and non-combatant evacuation operations

After selecting the parent hull the key parameters such as; length, beam, draft, depth, displacement, deadrise angle, chine width, and coefficients of form were roughly determined. The comparison of ratios based on the other similar vessels and theoretical study on the planing hull design features were also considered in selecting these preliminary parameters. During the design of the hull form model using a software, (in conjunction with a plug in) some of these parameters were altered.

Table 2: Preliminary design particulars of the Coastal Patrol Craft

Length Overall	12 m
Beam on Deck	3.8 m
Depth	1.6 m
Displacement	8 Tonnes
Deadrise angle at transom	15
Deadrise angle at the mid body	18

After modelling the hull preliminary hydrostatic particulars, stability analysis and powering calculations were obtained based upon the parameters. As this research progresses in to more detail a comprehensive analysis for hydrostatics, stability, powering, weight, and cost estimation will be carried out. At this stage this design remains a preliminary concept design and may undergo change accordingly as the research progresses.

III. RESULTS AND DISCUSSION

The aim of the research paper was to come up with a preliminary concept design for a Coastal Patrol Craft for the Sri Lanka Navy and the Sri Lanka Coast Guard. The preliminary design of the model was done utilizing software while another software was used as a plugin. The hull form creation was conducted based upon the similar ship analysis/ market survey and theoretical study on planing hull.

A. Resultant Hull Form Particulars and Hydrostatic Data

From the initial input of preliminary design particulars mentioned in Table 2 a preliminary hull form was created and a lines drawing of the Coastal Patrol Craft was obtained. Also some other key parameters of the hull form were obtained from the software when the Coastal Patrol Craft is in displacement mode. These hydrostatics data look satisfactory and the coefficients of form were all within general limits.

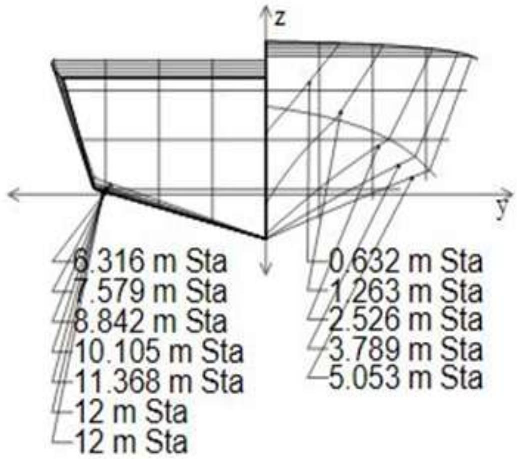

Figure 4: Initial Body Plan

Table 3: Resultant hull form particulars obtained from Orca 3D

Length Overall	12.04 m
Beam Overall	3.8 m
Depth Overall	1.57 m
Waterline Length	11.25 m
Waterline Beam	3.13 m
Navigational Draft	0.64 m
LCB	6.81 m
TCB	0.0 m
VCB	-0.18 m
Wetted Surface Area	32.59 m^2
Waterplane Area	29.21 m^2
Block Coefficient	0.346
Prismatic Coefficient	0.743
Coefficient of Waterplane area	0.831

B. Stability Curve

Utilizing the software a stability curve was obtained for the Coastal Patrol Craft. The righting arms of the boat was calculated for angles from 0 degrees to 90 degrees and the graph below indicates the stability of the vessel is satisfactory.

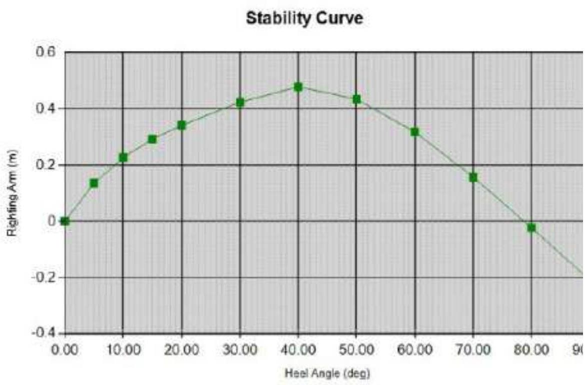

Figure 5: Stability curve of the Coastal Patrol Craft

C. Resistance and Powering Calculations

After the hydrostatics and stability analysis a resistance and powering analysis was conducted utilizing a software tool. The software uses the Savitsky method to calculate the resistance and power of the vessel. The propulsion efficiency was assumed to be a 50%, design margin was provided as 15% for the calculations. Both these values were chose as a conservative effort to gauge the performance of the hull form in extreme conditions. From these calculations total resistance at 40 knots was calculated to be 22.6 kN and the power required was calculated to be 930 kW (1265 HP) which is slightly higher than the expected value. When the propulsion efficiency is increased to a more realistic 60% the required power reduces to a 1050 HP. Below is the power vs speed curve provided by the software.

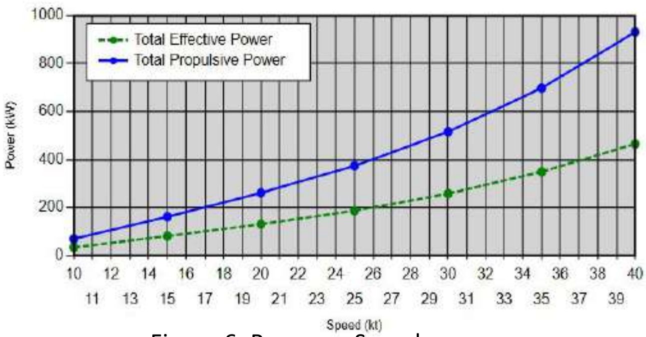

Figure 6: Power vs Speed curve

D. Key Design Decisions

During the design phase some key design decisions were made to ensure the hull form is compatible with the initial goals stated earlier. Our primary design parameter that was set aside as the uncompromising factor is the length of the patrol craft. Due to the range of missions that is expected be covered by this Coastal Patrol Craft, it was decided have a relatively large craft with a length of 12 m. Another factor that impacted this decision was the proposed mission module concept. A longer boat is the better option to accommodate these modules without cramping the deck space.

A design parameter that was based upon theoretical study rather than similar ship analysis was the deadrise angle of the boat. The deadrise angle is generally determined by the speed and the sea state that the planing vessel is intended to operate in. For coastal crafts this angle craft is generally between 15 to 20 degrees. The faster the vessel moves the higher the deadrise angle should get to soften the impact during slamming. Thus for the Coastal Patrol Craft the deadrise angle was selected to be 18 degrees at mid body gradually decreasing to 15 degrees at the transom

Another parameter that was selected based on theory is the placement of the LCG. According to [3], the LCG location has to be 6% L_p abaft of the center of the A_p.

Where;

L_p	Chine length
A_p	Chine area

For the Coastal Patrol Craft the LCG was approximately calculated to be around 7.2 m from the origin. During the design process a value of 6.8 m was chosen as the LCG to reduce the trim. This could have also had an impact on the relatively high power requirement.

Modularity concept is one of the key design aspects that were kept in mind while designing this hull form. The length and the relatively large beam of the Coastal Patrol Craft were selected mainly to accommodate the mission modules. The modules will be fitted abaft of the centroid of the chine area (near the LCG) to make the vessel trim by the bow aiding the planing of the vessel. Also all the different mission payloads will be approximately of the same weight. The size of the mission module was determined to 1.5m x 1.5 m x 1.0 m as an initial estimation. In addition to the cost savings during the design and manufacturing phase modularity will save cost during the operational phase. During the operational phase the requirement of training for the crew will be less because all the patrol boats will be of same class due to familiarity and experience gained. In the subsequent studies more emphasis will be laid on the design of the actual mission modules and their content based on the mission.

Some other design features that were considered during this preliminary concept design study were, adding a foam collar to the vessel and utilizing a stepped hull form. The form collar would have enhances the stability of the vessel by increasing the reserve buoyancy and the stepped hull form is known to improve planing performance at higher speeds. Both these ideas were deemed too expensive for this particular study after further research.

IV. CONCLUSION

Since Sri Lanka is an island nation, the naval forces of the country have an immense duty and an undeniable responsibility to safeguard its waters and facilitate the commerce and communication. The key resource of any navy is their naval fleet and the capability of a nation's fleet is a huge morale booster not only for the navy but also for the commercial fleet. Sri Lanka Navy is now on the brink of becoming a fully professional navy and upgrading the naval fleet will definitely have a huge impact on realizing this goal. However as a developing country budgetary constraint will always be a hindering factor and cost effectiveness is a must in this scenario. Everybody in decision making level has to look into this project as open minded individual. Any logical suggestions to improve this patrol craft is most welcome.

This study was intended to be a feasibility study and preliminary concept design before going into full scale model. Major concerns of this study were, identifying the basic particulars, key features and role of the patrol craft. Savitsky (1964) and Halder (1966) studies and some of the software associated calculations were used as our based to determine the planing hull characteristics.

Cost saving methods such as utilizing experience curve and modularity while staying away from complex hull geometry such as stepped hull concept were considered extensively in this study. These concepts can minimize the cost for different classes of crafts, meet organizations goals and reduce familiarization and training cost, since it is indigenously undertaken with available technical support from the identified key personnel. Hence flow of knowledge within the Navy will mitigate the training cost for this kind of a project. In addition to that designers are within the Navy, huge amount of cost saved to the Navy.

One of the areas that will be addressed during the future studies are improving the hull shape to reduce drag and bring the power requirement of the vessel to less than 1000 HP for a propulsion efficiency of 50%. Also determining the actual shape, dimensions, content, and the location of the mission module will be carried out subsequently. Incorporating an inflatable collar or a foam collar will be further researched without compromising the main aim of this design of cost reduction. More analysis such as a comprehensive weight and KG study, structural analysis, cost analysis and a seakeeping analysis will also be carried out in addition to the hydrostatic, stability, resistance and power analysis.

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