STUDY ON DIFFERENT CONCEPTS FOR DESIGN OF A COASTAL RESEARCH VESSEL

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SUMMARY

The design of any vessel is a series of compromises which trade off one property for another. Catamarans are particularly appropriate in the size range from 45 to 170 feet, where they offer many of the advantages of considerably longer conventional vessels in a shorter, wider, shallower draft, fuel efficient package. Designing and using modern catamarans is lot like designing and using aircraft where strength/weight considerations are crucial. Weight control is essential for good and safe performance offshore. Blind application of monohull design ideas has lead to the creation of a number of needlessly heavy (and thus expensive) catamarans with poor sea keeping. Fuel load takes the place of science cargo as the primary weight to be hauled, which in turn requires larger engines to achieve the design speed and range, which requires more fuel and so on. The design spiral then diverges from well-proven wholesome, catamaran design practice.

This paper signifies the importance of catamaran hull form benefits as a research vessel and the reasons for selecting this hull form. Study is also done on the spacing between the two hulls with symmetrical demihull and asymmetrical demihull. Resistance, working deck space, operating cost options are the primary factors in determining catamaran hull form as the most efficient out of the comparison between monohull and catamaran. This paper signifies the effect of bulbous bow [9] in reducing the resistance components and increasing the volume of displacement for a given set of constraints.

1. INTRODUCTION

A research vessel is a ship designed and equipped to carry out research at sea. Research vessels carry out a number of roles. Some of these roles can be combined into a single vessel, others require a dedicated vessel. Oceanographic research vessels carry out research on the physical, chemical and biological characteristics of water, the atmosphere and climate, and as such, are required to carry equipment for collection of water samples from a range of depths, including the deep seas, as well as equipment for hydrographic sounding of the seabed, along with numerous other environmental sensors. As the requirements of both oceanographic and hydrographic research are very different from those of fisheries research, these boats often fulfill a dual role.

The scope of this paper involves study of requirements projected for the design of an advanced Coastal Research Vessel and preparation of alternative concepts say, Monohull, Catamaran & SWATH hull forms and merits of each. As per the mission requirements and the constraints, parametric study is done for three different types of hull forms say, monohull, catamaran with symmetrical demi hull and catamaran with asymmetrical demi hull [10]. Different hull materials like steel and aluminum had been used for accomplishing the mission requirements within the given constraints. Resistance prediction is done for all three set of hull forms for a length of 30m & Block Coefficient, C_b=0.45. This paper studies the effect of spacing between two hulls on powering prediction. The significance of bulbous bow is also shown in this paper. The optimized hull form within the constraints is selected.

1.1 SEA KEEPING & MANEUVERING:

These research vessels will be distinguished from their predecessors by several important features. Increased station keeping ability using dynamic positioning, improved performance of acoustic systems, and the use of fiber optics and other sophisticated winch and wire systems will allow these vessels to support many new and exciting research and education projects. These vessels will be designed to extend the seasons and weather that this class can safely and effectively operate in. Innovative weight handling and winch systems will improve the ability to deploy and recover equipment in higher sea states with less intervention by people on deck. Design features that will increase sea-keeping ability will also make these vessels and the people working in them more effective.

1.1 (a) SEA-KEEPING

Sea keeping is the ability to carry out the mission of the vessel while maintaining crew comfort and safety, and maintaining equipment operability. It is an important design criteria to maximize the sea-kindliness of these vessels and maximize their ability to work in sea state four and higher within the constraints of their overall size. The use of bilge keels, anti-roll tanks or other methods to reduce the motions of these vessels should be incorporated in the designs. In sea state four (1.25 – 2.5 m wave heights) these vessels should be able to:

- Maintain underway science operations at 9 knots

- Maintain on station operations 80 % of the time, including:
  - CTD operations 90% of the time
  - Mooring deployments 75% of the time
  - Coring operations 50% to 75% of the time
  - ROV operations 50% of the time
- Limit maximum vertical accelerations to less than 0.15 g (rms)
- Limit maximum lateral accelerations to less than 0.05 g (rms) at lab deck level
- Limit maximum roll to less than 3 degrees (rms)
- Limit maximum pitch to less than 2 degrees (rms)

These motion criteria specifications should be verified as adequate and achievable during the earliest concept design phase. Otherwise, other motion criteria that result in ship motions that allow personnel and equipment to work effectively can be utilized during the concept design phase as long as the intent of the above sea keeping specifications is not sacrificed.

1.1 (b) STATION KEEPING

Station keeping is the ability to maintain a position and heading relative to a station or track line that allows the mission of the vessel to be completed. The Regional Class Research Vessel should be able to maintain station and work in sea states up through 4 (1.25 – 2.5 m wave heights) at best heading.

Dynamic positioning, using the best possible and multiple navigation inputs, should be possible, in both relative and absolute references in the following conditions:

- 25 - knot wind
- Sea state 4
- 2 - knot “beam” current

The maximum excursion allowed should be ± 5 meters (equal to navigation accuracy) from a fixed location for operations similar to bore hole re-entry and up to ± 20 meters for operations through sea state 4 at best heading.

DP system design and operation should minimize noise, vibration, and adverse effects on the operation of acoustic systems as much as possible, and these issues should be evaluated early in the design process.

2. BACKGROUND

2.1 MONOHULL

Monohull as research vessels have represented the stock-in-trade from the fifteenth century European voyages of exploration until the late twentieth century. Even now, the monohull concept has significant advantages over other hull forms in many applications. Although the SWATH, catamaran, and other "modern" hull forms are increasingly common, the versatility and economy of the monohull design ensure that it will continue to play a major role in the fleet of small research vessels. Despite their numerous advantages, monohull suffer from the perception that multihull represent the state-of-the-art and are therefore inherently safer, more comfortable, faster or just plain better as proposed by H.E. Sauders [1].

In monohull design, the form of the hull is essential in determining the stability of the vessel so that there are strong limits on the fineness ratio (hull length/hull beam at the waterline). Destroyers, for example, are near the upper fineness ratio limit in order to gain a greater hull speed and fuel economy, but suffer poor roll stability and are thus notoriously uncomfortable in rough conditions.

2.1 (a) ADVANTAGES

Significant advantages of the monohull as compared to SWATH and multihull designs include:

- Low acquisition cost
- Efficient use of enclosed volume
- Propulsion system flexibility
- Excellent maneuverability
- Low relative maintenance

2.1 (b) DISADVANTAGES

Having discussed the advantages of the monohull design, it is now appropriate to touch on the disadvantages, which are:

SEA KEEPING

The relatively large water plane area, an advantage when considering weight growth, is a negative factor when considering the issue of sea keeping. Greatly simplified, we can generalize that a vessel will react to the dynamic input of swells and waves proportional to the water plane area - increased area will result in increased ship motions. Methods for reducing motion are well established and include both active and passive systems. Active systems include fin stabilizers and rudder control, both of which are controlled by sensors measuring and responding to vessel motions. These active systems are very effective when the vessel is operating at speed, but the effectiveness is greatly reduced as vessel speeds are reduced. The complexity and cost of active roll reduction systems have generally precluded their use in small research vessels.

DECK AREA

Working deck area and laboratory space are the premier commodities on any research vessel. For equal length vessels, multihull have a clear advantage, often up to 30%, in working deck area and lab space.

2.2 CATAMARAN

Catamarans or twin hull vessels are used as research boats, crew boats, excursion boats, passenger ferries, survey boats, police/rescue boats and patrol/reconnaissance boats. For all these types of craft, the payload is a small fraction of the total displacement. A planing boat is severely restrained in its use by sea conditions. Catamarans can be designed to behave better in such seas and also provide large deck area for use. For catamarans at low speed, the emphasis is on deck area whereas at high speed, hydrodynamics plays an important role. Catamarans have a potential for large deck area per tonne of displacement and there is the possibility of achieving higher speed. Stability without weight is the main thing that makes multi-hull vessels more attractive than mono-hull vessels.

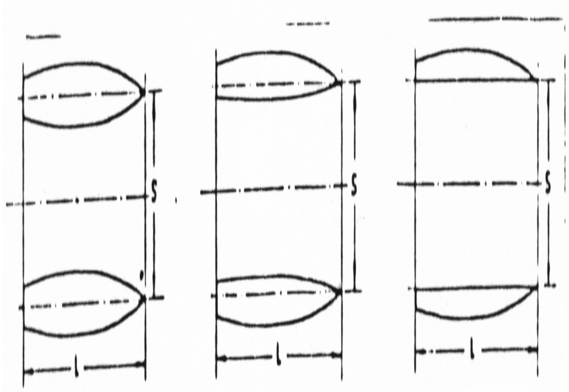
In a twin hull vessel or catamaran, the hulls are abreast of each other. The individual hulls can be symmetric about their own centerlines and also about the catamarans centerline. Such catamarans are symmetrical catamaran. If the individual hulls are unsymmetrical about their own centerline, but symmetrical about the catamarans centerline they are referred to as asymmetric catamarans [2].

Catamarans are divided in two catagories depending on their geometric features:

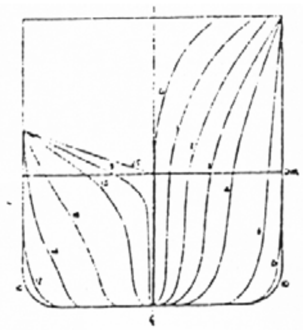
- Symetric Half Hulls
- Asymmetric Half Hulls [10]

Asymmetric Hulls are also divided in two catagories:

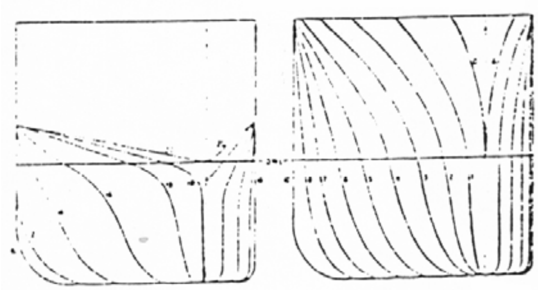
- Single Sided Asymmetric Half Hulls
- Double Sided Asymmetric Half Hulls



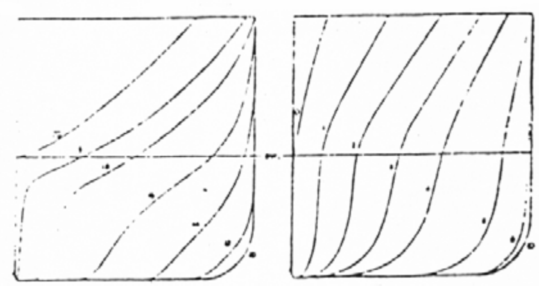
Symetric Half Hull   Asymetric Double Sided   Asymetric Single Sided



Symetric Half Hull



Double Sided - Asymetric Half Hull



Single Sided - Asymetric Half Hull

2.2 (a) ADVANTAGES

The basic advantages [3] over mono-hull vessels can be listed as follows:

- By dividing the displacement of the vessel between two hulls, the displacement length ratio is lowered for each hull and the hulls may be designed for minimum resistance at high speed with no regard to stability of each.
- The transverse separation between hulls gives large moment of inertia of the water plane and hence, the catamaran has high transverse stability.
- At displacement speeds, the separation distance between the two hulls can be adjusted such that the interference between the waves of the inner sides of both hulls is favorable and wave resistance is reduced. At planing speeds, since there is no wave

resistance, separation distance is immaterial.

- The useful deck area is greater than that of a monohull of equal length.
- The steering of vessel is easy because of the wide separation of its propulsors.
- The freedom of designing the layout is greatly enhanced due to large deck area and stability.

2.2 (b) DISADVANTAGES

The basic disadvantages [3] over mono-hull vessels can be listed as follows:

- If not designed carefully, there is a large total resistance at low speeds due to increased wetted surface.
- The cross-structure between the demi-hulls has to be properly strengthened and hence, payload to structural weight ratio becomes low and less competitive.
- There is severe wave impact on the bottom of the cross-structure while moving in a seaway. To keep this bottom of the cross-structure high above the water surface, large variations of draught are not permissible. Therefore, catamarans have a heavy restriction on payload. Normally, payload should not exceed about 10 percent of the total displacement.

2.3 SWATH

The small water plane area twin hull (SWATH) [4] vessel is a displacement ship having two demi hulls. Each demi hull is made up of a semi-submerged hull resembling a body of revolution and a strut which pierces the water surface. The separation between the demi-hulls is bridged by a box cross-structure. Thus the SWATH ship combines the favorable features of catamarans and semi submersibles. This enables the SWATH ship to retain the essential advantage of a large deck area combined with controlled motion and reduced wave making drag by placing its displacement well below the water surface.

The application of SWATH technology for small research vessels should be considered during the planning phase of new or replacement ships. The principle of the SWATH ship is that submerged hulls do not follow surface wave motion, and struts supporting an above water platform have a small cross-section (water plane) which results in longer natural periods and reduced buoyancy force changes. The result of all this is that SWATH ships, both in theory and performance; demonstrate a remarkably stable environment and platform configuration which is highly attractive for science and engineering operations at sea [2].

2.3 (a) ADVANTAGES

Steadiness in a disturbed seaway: It is well confirmed that a properly designed and built SWATH ship will substantially reduce motions induced by moderate to high wave conditions. SWATH ships can be designed to suffer only one-half to one-fifth of the heave, pitch, and roll motions of a monohull of equal displacement in seas driven by wind speeds over 20 knots. Furthermore, SWATH ships can be configured such that motions are nearly independent of wave direction relative to the heading of the ship, both underway and deadin-the-water.

More useable enclosed volume and deck space: The most advantageous SWATH hull form is such that its greater beam leads to large deck area and usable volume in respect to total displacement.

Ability to maintain speed in high sea states: The amelioration of slamming by high waves allows SWATH ships to steam at speeds not possible in comparable monohulls. The submerged hulls running below wave motion, and the main hull elevated by the slender small water plane columns (struts), together with some other design tradeoffs can make moderate size vessels relatively immune to slamming.

2.3 (b) DISADVANTAGES

Excessive draft: Since the chief benefit of SWATH designs depends on having their buoyancy compartments well below the disturbed sea surface, a deeper draft is required for similar sized monohulls. This can be lessened by the variable draft design.

High propulsion power: The greater wetted surface of the submerged hulls causes greater frictional resistance and total drag at low and moderate speeds. At higher speeds, the lower wave-making drag of a properly designed SWATH lessens this disadvantage.

Weight sensitivity: Because of the small water plane area and wide separation of its buoyancy compartments, a SWATH design will tend to have larger trim and heel excursions than will have a monohull. The SWATH ship also will experience greater draft changes (about four times greater) than an equivalent monohull. SWATH vessels have a very limited ability to accept a wide variety of science mission loadings. Since such wide variation in mission equipment is characteristic of oceanography, this limitation may be a significant disadvantage.

3. DESIGN METHODOLOGY

3.1 MISSION DEFINITION [12]

The first step in the design of a research vessel is to define the scientific mission requirements (SMR) as foreseen. Guidelines for developing the requirements were adapted from university National Oceanographic Laboratory System (UNOLS) developed by the association of American Universities engaged in oceanographic research. The SMR for the Coastal Research Vessel (CRV) has been developed on the basis of the UNOLS system.

The concept design explored is based on the requirements projected by the SMR.

The following parameters are considered as "drivers" with respect to ship size, design and cost. They are

- Lab space & Deck Space
- Science staff
- Vessel's Basic Dimensions
- Speed
- Propulsion & Power Requirements
- Range & Endurance
- Stability

In this paper, an attempt is made to evaluate and eventually incorporate the Scientific Mission Requirements for the vessel Vis-à-vis each of the above key parameters.

The major concern of potential users of research vessels is that the platform be capable of supporting a wide variety of equipment and activities. The principal theme reiterated time and again was that the need for a flexible ship to handle ever larger and more varied pieces of equipment and that enhanced sea-keeping ability, which would extend the useful working time at sea.

3.2 DATA COLLECTION

Several catamaran ships whose parameters are near to the mission requirement are collected.

L.O.A (m)	Breadth (m)	Draft (m)	Speed (knots)	Fn	HP (KW)	F.O (Liter)	F.W (Liter)	Hull Type	Hull Material
23.9	8	1.5	12	0.403133	425	9000	1500	Catamaran	Aluminum
25	9	1.1	25	0.821176	1193.6	10000	1000	Catamaran	GRP
25.2	9.14	1.07	27	0.883344	1193.6	13800	1916	Catamaran	Aluminum
26.1	9	1.35	25	0.803686	1417.4	22000	1000	Catamaran	Aluminum
29.26	12.2	2.13	12	0.364343	566.96	37854	11500	Catamaran	Aluminum
30	10	3.5	12	0.359821	410.3	49000	11000	Catamaran	Aluminum
32	9.4	1	27	0.78389	1492			Catamaran	Aluminum
32.5	10.5	2.25	9	0.259279	300	43120	22000	Catamaran	Steel
35	12	3.32	11	0.305369	640	66640	32000	Catamaran	
36.65	13.7	2.2	11	0.298416	298.4	58877	12000	Catamaran	
40	15.5	1.6	14	0.36355	298.4	10000	2000	Catamaran	Steel
42.35	10.34	1.5	12.5	0.315464	375	39200	10000	Catamaran	

Table1:Data collection of catamaran research vessels

(# as per the existing ship data, it is clear that the overall beam of a catamaran (steel hull) is minimum 10.5m for L.O.A=32.5m.)

3.3 CASE STUDY

Case study is carried out for a Length of 30m and the breadth range of 9 to 9.5 m and draft of 2 m for initial set of constraints. Two hull materials were considered during this parametric study. Round Bottom Hull Form (NPL Series) [11] is chosen, as the operational range of Catamaran to be designed is between Fn = 0.32 to 0.35.

3.4 CALCULATION METHODS

3.4 (a) RESISTANCE:

For Monohull [5]

Resistance prediction for monohull is estimated by J.Holtrop & G.G.J. Mennen method, where the total resistance in coefficient form was:

$$C_T = (1+k)*C_F + C_W$$

Where,

C_F is frictional resistance coefficient calculated from ITTC 1957 correlation line

C_W is wave resistance coefficient

(1+k) is form factor

For Multihull/catamaran [6]

With reference to the paper "An Investigation into the Resistance Components of High Speed Displacement Catamarans" by Insel et al, the total resistance of a Catamaran in coefficient form was:

$$C_{tot} = (1+\varphi k)\sigma C_f + \tau C_w$$

Where,

C_f is from ITTC 1957 correlation line

C_w is wave resistance coefficient for demihull from holtrop method

(1+k) is form factor of demihull

Φ is to take account of pressure field change around the demihull

σ is to take account of velocity augmentation between the hulls

τ is wave resistance interference factor

For practical purposes, φ and σ can be combined into a viscous resistance interference factor β.

$$(1+\varphi k)\sigma = (1+\beta k)$$

So, $$C_{tot} = (1+\beta k)C_f + \tau C_w$$

The viscous interference factor β and the wave interference factor τ were derived from experimental data. $\beta = 2.3$(constant).

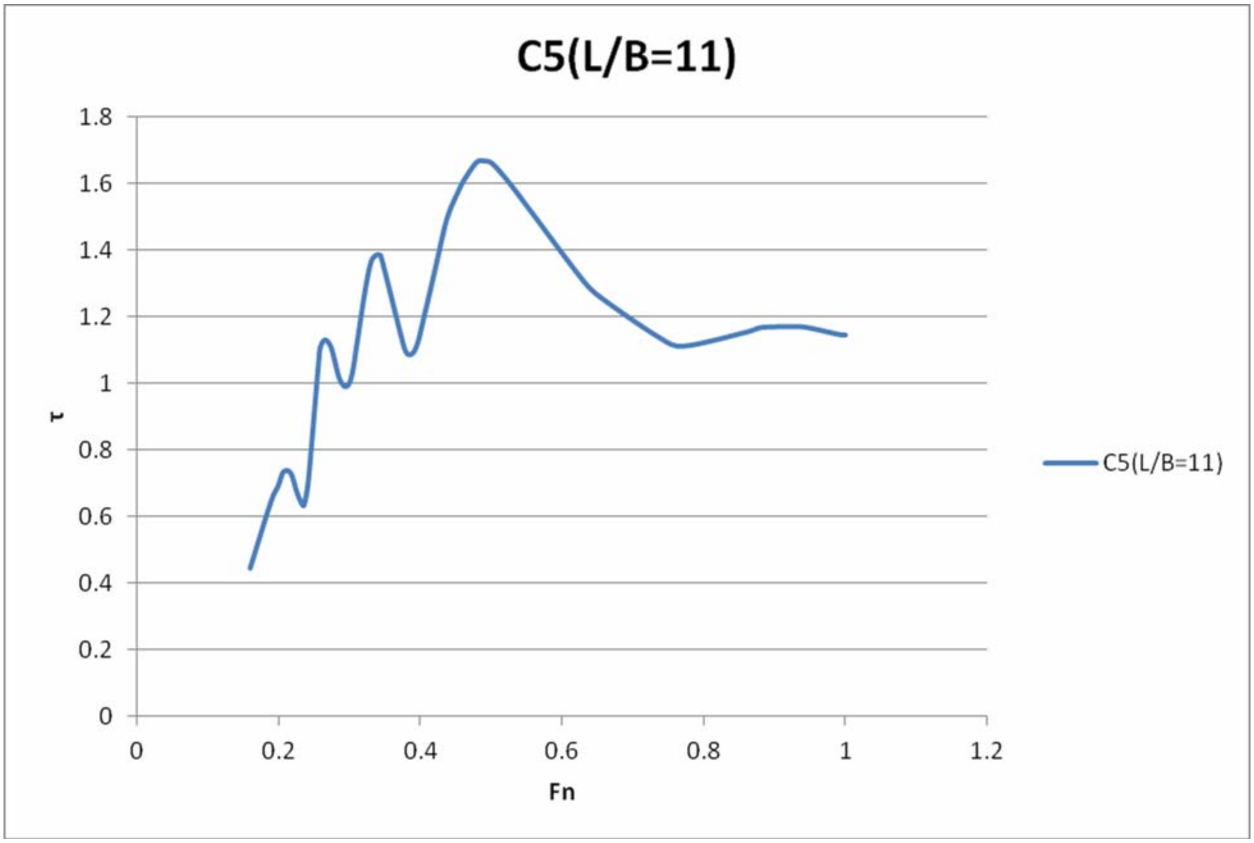


Figure 1: Wave interference factor, τ Vs Froude no, F_n

3.5 VARIOUS CONFIGURATIONS AND DIMENSIONAL VARIATIONS

Feasibility study is done for the following set of configurations and dimensional variations for different set of hull forms[11], say monohull & catamaran

S.No.	Type of hull	Length	Overall Beam	Single Hull breadth	C_B	Hull Material
1	Steel cat, symmetric demihull (Beam=9m)	30	9	2.8	0.45	Steel
2	Steel cat, symmetric demihull with bulb [9]	30	9	2.8	0.45	Steel
3	Steel cat, asymmetric demihull	30	9	3.2	0.45	Steel
4	Steel cat, asymmetric demihull (Beam=9.5m)	30	9.5	3.4	0.45	Steel

5	Al. cat, symmetric demihull	30	9	2.11	0.45	Aluminum
6	Monohull	30	6.5	6.5	0.6	Steel
7	Steel cat, symmetric demihull with bulb [9]	30	9.5	2.96	0.45	Steel

Table 2: Various configurations & dimensional variations for feasibility study

As per the above table, Power (KW), Lightweight (tons) [7] [8], Displacement (tons) & Margin (tons) are calculated for all the above options mentioned, which resulted in some of the feasible options as per the output given below.

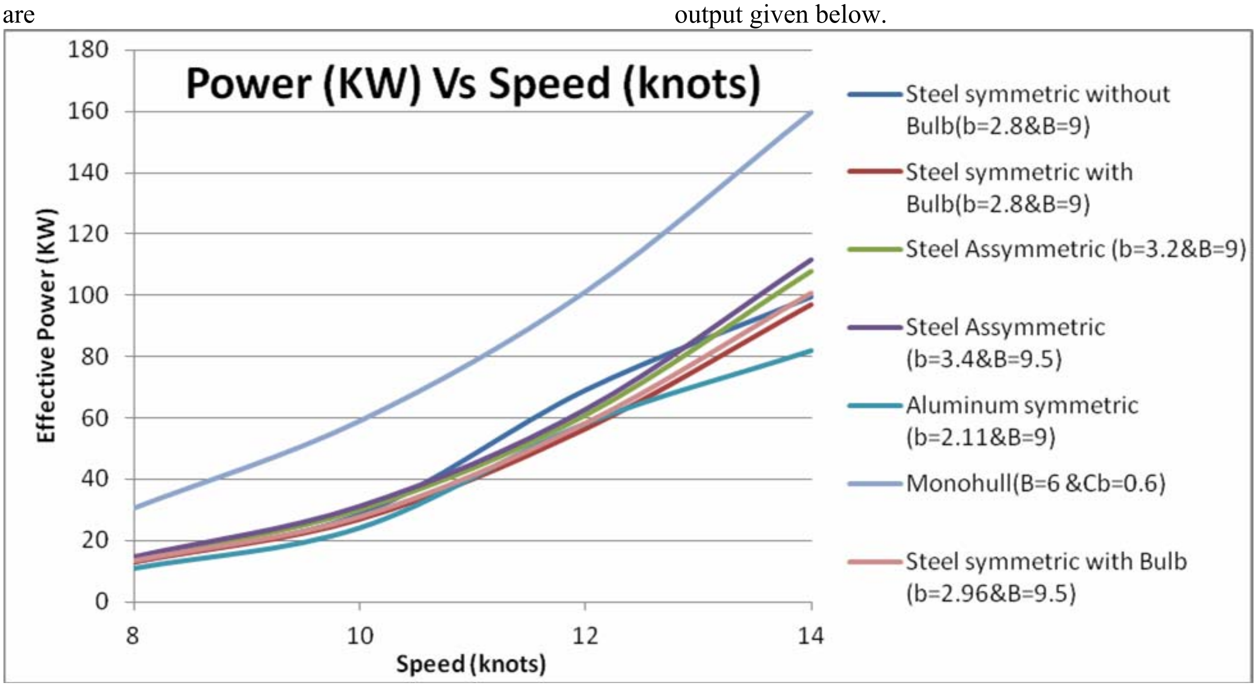


Figure 2: Power Vs Speed for the feasible options

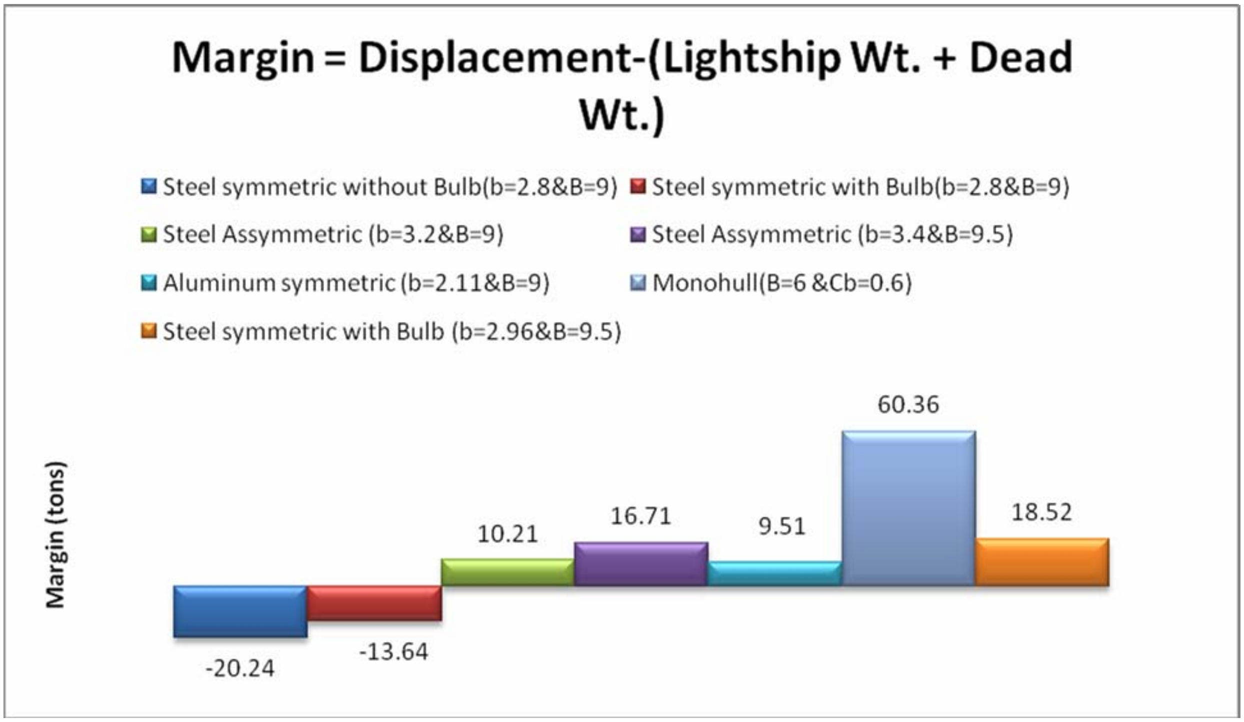


Figure 3: Margin for the feasible options

From the set of calculations, the feasible and non-feasible options are shown below,

S.No.	Type of hull	Length	Overall Beam	Single Hull breadth	C_B	Hull Material	Result
1	Steel cat, symmetric demihull (Beam=9m)	30	9	2.8	0.45	Steel	Not Feasible
2	Steel cat, symmetric demihull with bulb	30	9	2.8	0.45	Steel	Not Feasible
3	Steel cat, asymmetric demihull	30	9	3.2	0.45	Steel	Feasible
4	Steel cat, asymmetric demihull (Beam=9.5m)	30	9.5	3.4	0.45	Steel	Feasible
5	Al. cat, symmetric demihull	30	9	2.11	0.45	Aluminum	Feasible

6	Monohull	30	6.5	6.5	0.6	Steel	Feasible
7	Steel cat, symmetric demihull with bulb	30	9.5	2.96	0.45	Steel	Feasible

Table 3: Feasible & non- feasible options from the parametric study

3.6 HULL FORM SELECTION

From the above set of feasible options, one hull form need to be finalized from the fixed range of feasible options considered.

Total Fuel Oil per day (in tons), Power required per Engine (KW), Working Deck Space (sq.mt) & Fuel Oil Cost per day (Rs.) are the deciding factors in fixing the main set of dimensions.

So, an analysis based on the above deciding factors is carried out and the results are shown below

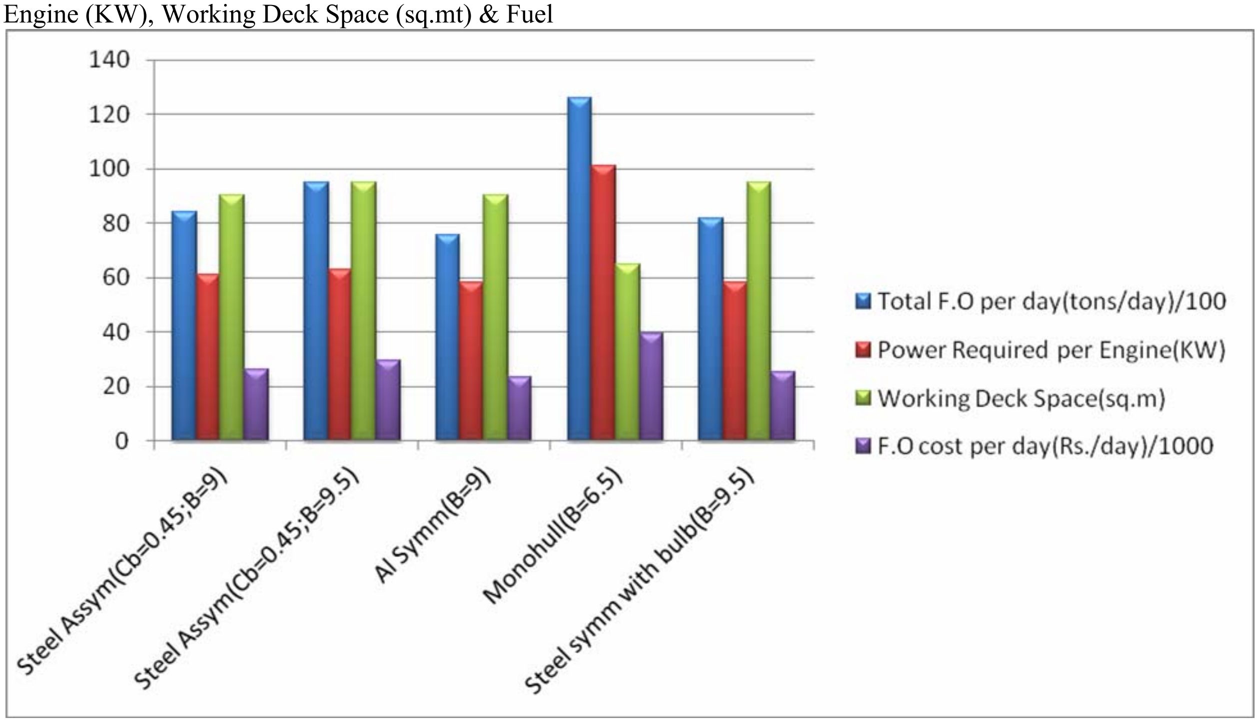


Figure 4: Study on various deciding parameters

So, as per the above calculations a Multi-Criteria Analysis is carried out which is shown below,

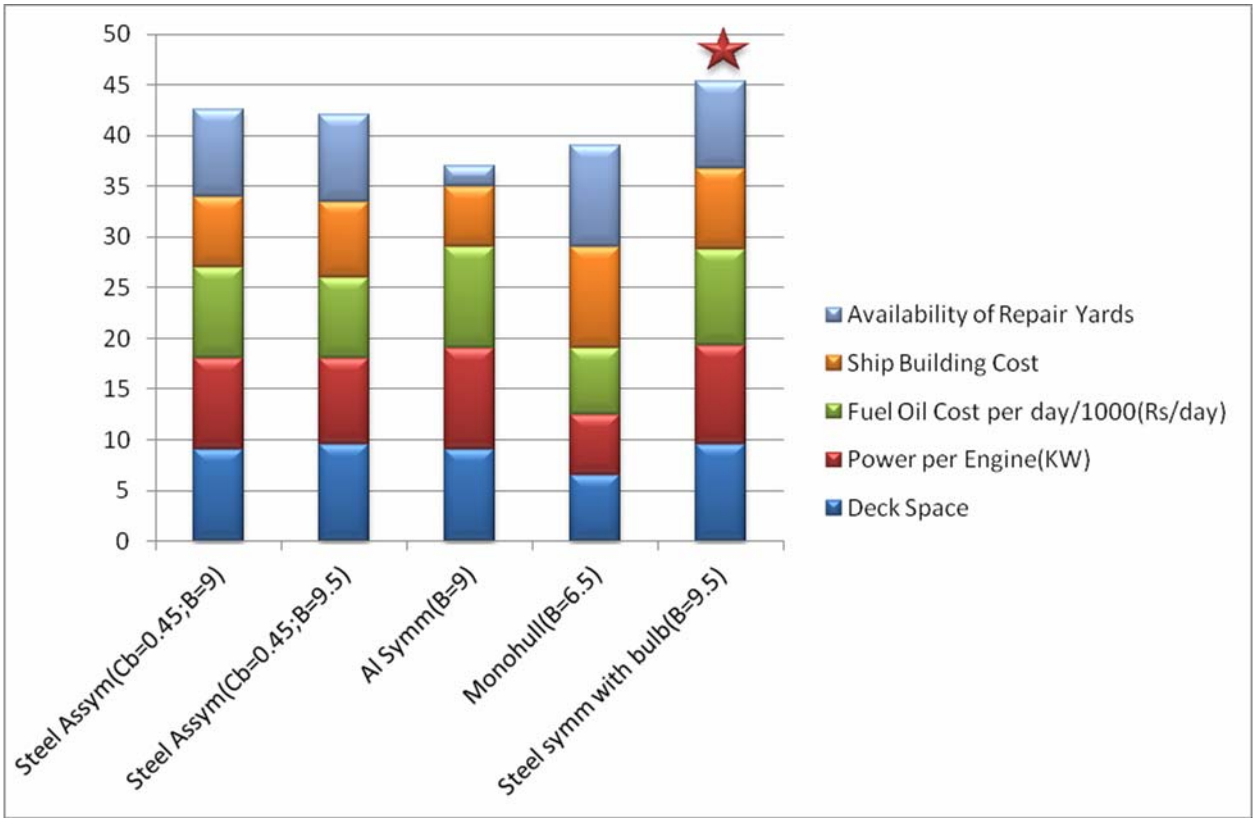


Figure 5: Multi-Criteria Analysis for different concepts

So, Steel symmetric Catamaran hull form with Bulbous bow [9] is selected from the above Multi-Criteria Analysis.

4. CONCLUSIONS & FURTHER WORK

In this paper study is done on the mission requirements and several coastal research vessels already existing and operating. Merits & demerits of monohull as research vessel and catamaran as research vessel are investigated. From the study of data collected about research vessel, the range of main parameters of the vessel is fixed. Based on the range of parameters, feasibility study for different configurations & dimensional variations for different hull forms is carried out. Study is done on the resistance, displacement, light weight & dead weight parameters with respect to length for a given speed and a range of block coefficient for different hull forms. From this study, a set of feasible options are identified.

Study on change in resistance for a hull form with bulbous bow[9] and without bulbous bow is carried out, from which it is concluded that the addition of bulbous bow may increase the frictional resistance, but reduce the wave resistance(which is a major part of total resistance for a vessel of Fn = 0.36) and increase the displacement. This makes a hull form with bulbous bow more feasible than a hull form without bulbous bow for a given set of parameters.

Study on fuel oil consumption/day and fuel oil cost/day for the available set of feasible options is carried out and the hull form with minimal fuel oil consumption per day and minimal fuel oil cost per day is selected. As a result, steel catamaran of symmetric demihull with bulbous bow is selected, from the set of feasible options.

This paper had addressed the concept of designing a new coastal research vessel, by considering different configurations and varying dimensions. In this thesis, the total resistance coefficient of a vessel is estimated by statistical power prediction method – J.Holtrop & G.G.J.Mennen method. The total resistance obtained by statistical power method of selected hull form need to be checked with the resistance values obtained from the towing tank test.

As a part of future work, the hull shape at forward and aft can be optimized, such that the separation drag can be reduced and as the bulbous bow considered for the present thesis is of cylindrical form, the shape can be optimized for reducing the wave making resistance. The results obtained from the towing tank test; need to be validated with the results obtained from Computational Fluid Dynamics (CFD) techniques. Much more detailed calculations need to be done for the later stage of design, by following the design spiral.

5. ACKNOWLEDGEMENTS

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