AN AIRBOAT FOR RURAL RIVERINE TRANSPORTATION AND MANGROVE MARINE ENVIRONMENT APPLICATIONS

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ABSTRACT

The present works describe the design and initial performance study of a prototype airboat for riverine transportation, including mangrove habitat applications, with particular reference to Sarawak, East Malaysia. Many local rural riverine transportation and marine habitat studies are limited due to tide-line dependent and the limitation of conventional blade type marine engine. The use of airboat could ply at the local everglades areas and shallow waters; however the conventional airboat having flat bottom hall may at times not suitable in the narrow mangrove habitat which generally has extended roots. In the present study, our boat was custom designed with Shallow-Vee hall shape, employing a 2-stroke engine. Experimental results have shown that the new airboat built has good performance and balancing capability. Subsequent simulation study employing PROLINE software suggest that 2 passengers as the optimum number for the airboat overall performance (optimum performance and stability), coherent with the experimental trials. Compared with conventional air boats, the new boat design is likely to have two added advantages: (1) relative cheap cost and affordable in development, and (2) shallow-Vee shape design is more suitable then the wider flat bottom shape type due to narrow mangrove habitat, where the shallow mangrove trees generally having roots in the water and extended roots on the water surface.

KEYWORDS: *Rural riverine transportation; Swallow rivers, Mangrove habitat; River engineering; Low-tide delta; Boat performance; Modeling*

1. INTRODUCTION

Unlike other developed urban areas, the usage of water transportation is very important in the nearshore marine habitat and riverine areas of Sarawak, Malaysia (Fig. 1), especially in the rural areas that could not be assessed by normal means of car transportation, such as the delta (Fig. 2a) and mangrove habitat (Fig. 2b). Many parts of these areas are also swamp and shallow especially during low tide in the delta regions (Fig. 2a and Fig. 2c). Thus the conventional blade type marine engine is not feasible for use during low tide. Unlike conventional boats, airboat's propeller is above the water thus it could easily move around on the swampy, shallow and everglade areas. Furthermore, wave generated from conventional boats is known to be able to cause unwanted river bank erosions, see e.g. Gerald et. al [1]. As such, the airboat could be used during low tide situation for rural riverine transportation. Moreover, airboat could be considered as one of the promising low cost but robust methods outlined by, e.g. Steve et. al [2] useful for field survey of coastal and riverine habitats.

The use of airboat in ice and water rescued emergencies environments had been reported by Dumment [3]. It had been found that airboats could minimize risk to responding personnel and reduce the time required to perform life saving operations by a quantifiable figure of 50-80%. Compared with the cost of an ambulance, the author concluded that an airboat, which cost around US$ 25,000-40,000, could be considered as an inexpensive investment under ice water environment. According to Dumment [3], the airboat is more stable and less maintenance cost than a hovercraft. Here, it is to be noted that the working principle of airboat and hovercraft are quite similar where the wind thrust acting backward generated by the propeller of airboat and hovercraft causes the vessel to move forward. They are only different in the base construction to provide air cushion in the later. Racine et al. [4] reported that airboats had been used in Alaska particularly in the interior regions. The capability of the airboats to traverse wetlands with sensitive vegetation and soils makes them different from ordinary watercraft. Thus they suggested airboats should be considered as a separate category of off-road vehicles by the managers of public lands. James [5] reported that airboat was able to bounce over broken ice at frozen Mississippi River for hydro survey application.

During the winter months, solid or broken ice becomes too hazardous for the hulls of the conventional survey boats but airboat has the ability to navigate over it.

A study of the shallow-water static performance of an amphibious power-augmented ram vehicle model has been undertaken by Matveev and Soderlund [6]. The recovered thrust of the vehicle model and pressure under the model platform were measured for variable propulsor thrust, loading conditions, and water depths. A mathematical model was developed accounting for the water surface depression under the platform and for reaction and frictional forces between the hulls and ground thus provided reasonable estimates for the recovered thrust and the under-platform pressure.

Khan and Das [7] introduced a sensitivity analysis which enables the designers to determine the influence of random variable responsible for the assessment of ship structures. The method taking account of the combined horizontal and vertical bending moments; the study shows the importance of the contribution of the design variables towards the uncertainty of the limit state function.

In the current work, the primary aim is to design an affordable airboat for used in shallow river transportation for novel application i.e. mangrove riverine areas, and especially during low-tide period. This mangrove habitat with exposed roots (e.g. see Fig. 2b) may sometime not quite friendly even for conventional air-boat having flat bottom shape. Recently, our research team had commissioned and conducted tests on the airboat as shown in Fig. 2d. Results from the current study have shown that the airboat together with the Samurai engine, after some modifications, showing good performance and balancing capability under local mangrove or low-tide riverine conditions. The simulation study, employing PROLINE software, conducted subsequently suggest that two passengers (with total load capacity of 650 kg) as the optimum number for the airboat overall performance with good stability as far as local conditions are concerned.

2. THE SARAWAK RURAL RIVERINE CONDITIONS

The Sarawak rural riverine conditions consist of various types of nearshore marine-related areas which include delta plain, mangrove habitat and low land water areas (Fig. 1). According to Staub et al.[8], the Rajang River delta plain covers an area of 6500 km2 and peat deposits can up to 15 m thick, occur in this delta plain. During low tide period, large area of delta with peat along the river bank (see e.g. Fig. 2c) made conventional boat hardly to operate. Tides are semidiurnal within the delta plain of the Rejang River and its influence extends about 120 km inland. Conventional boat can only be used for a maximum of 12 hours per day and this condition is very inconvenient to the riverine peoples. Tides along the Sarawak coast are corresponding to the widening and shallowing of the shelf, Staub et al. [8]. As an example in the Bako National Park, the conventional boats are not able to reach the jetty during the low tide period. They are only able to stop at the beachside to fetch the visitor. As a result, it creates a great inconvenience to the visitors and effect the tourism sector.

The above mentioned situations could be solved by airboat application. However, some shallow mangrove riverine habitats (see e.g. Fig. 2b), may sometime not quite friendly even for conventional air-boat having flat bottom shape. This is due to the difficult mangrove habitat with roots in the water (e.g. Fig. 3c) and exposed roots on the surface (e.g. see Fig. 2b). Shallow-Vee shape design therefore is selected in the current research endeavor.

3. DESIGN DESCRIPTION OF THE AIRBOAT

During the design stage, numerous factors including application types, stabilization (balancing), vibration, speed and cost of construction of boats all need to be considered, Brewer and Edward [9] .

In the present study, the hull of our boat was designed with Shallow-Vee shape at the front as shown in Fig. 2d and Fig. 3. As a result, this reduced pounds in wave for the comfort ability of the passengers. Size of the airboat is 4.3 ×1.8 meter that can accommodate 2 to 5 persons with total load capacity of 650 kg to 700 kg. The 143.5 kg hull is made from light weight fiberglass to minimize the load. This lighter boat results in less water resistance thus easier to move around and has minimum impact on the sensitive local ecology. Steel rail was built along the boat, as shown in Fig. 3b, such that the engine frames could easily be adjusted to desired distance, viz. whether forward or backward. During the testing, the distance of the central gravity and central buoyancy can be adjusted easily so that the performances of the airboat can be improved with respect to center gravity and center of buoyancy. Frame is also made from steel as a means to safeguard the pilot and the passengers from the propeller. Propeller used for the airboat is fixed pitch with two blades wooden aircraft types. The diameter length of the propeller is 141.5 cm.

Propeller of the airboat is installed about 90.5 cm from the bottom of the boat to generate powerful thrust. The engine used is an affordable small 4wd Suzuki Samurai 540cc, 2-stroke engine. Fig. 3c is a typical schematic sketch of a narrow mangrove habitat versus the Vee Hall Shape Boat outline. It is to be noted that the mangrove root directions would be varied from one tree to the other.

4. EVALUATION OF THE ENGINE AND AIRBOAT PERFORMANCE

Tachometer of optical sensor type (Table 1) is used to measure engine speed (rpm) and the speed rotation of crankshaft. The fuel consumption was measured in two conditions, i.e. without load and with propeller. This allowed comparisons to be made. The wind speed generated is measured using an anemometer (Table 2). Fuel efficiency is dependent on numerous factors including vehicle weight, size and load, Thiessen & Dales [10]. It depend on the best combination of power, fuel economy and emission control.

Table 1. **Tachometer specification**

Model	AF-VA 6
Velocity Resolution	0.01 m/sec
Weight (less batteries)	31.0 g
Operating Environment	0°C to 80°C
Accuracy	±1% of reading ±1 digit

Table 2. **Anemometer Specification**

Model	Extech Instrument 461895
Measuring range	Contact: 5-99999 rpm
	Non-contact:1 -20000 rpm
Sampling Time	Contact: 1 sec (over 6 rpm)
	Non-contact: 1 sec (over 60 rpm)
Temperature	-200C to 70 0C
Sensing Distance	up to 0.6 m
Accuracy	±0.05% of reading (or ±1 digit)

5. COMPUTER SIMULATION

A hull stability analysis software, Prolines 7, is employed to evaluate and simulate the stability of the airboat. The aim includes to determine the transverses and longitudinal location of the vessel's center of gravity and displacement in an unloaded and loaded condition; and to verify its intact stability. Detail discussions of the software can be found, e.g. in Scheltema et al. [11] and Biran [12]. Airboat hull parameters such as displacement, length, beam, location of center of gravity, location of center-of-flotation, bow, stern and mid cross-section shapes, topside flare, bow and stern overhang, and trim are important (Biran [12]). Once hull surface is created, the resulting design was analyzed with a basic set of functions, which allow the review of hydrostatics, wave and friction drag, GZ Curve, curve of areas and the curve of wetted lengths in accordance to Bole [13]. Finally, the vessel was deliberately heeled to varying angles in order to perform a series of calculations. The boat dimensions were recorded with the vessel out of water, and freeboards were measured while the vessel is afloat.

6. DISCUSSIONS OF RESULTS

6.1 RESULTS FROM PERFORMANCE STUDY

According to Thiessen & Dales [10], the speed (rpm) measurement is important to understand the engine condition, for both commissioning and testings. In our airboat commissioning study, on idling position i.e. without propeller, the engine of the airboat was tested to be able to run approximately 900 rpm on average, whereas on top speed, it could reach up to 6000 rpm. These results came close to the data given in the Suzuki Samurai manual, which are 950 rpm for the idling position and 6500 rpm for the top speed.

The fuel consumption vs. time at low speed and high speed conditions were recorded and presented as in Fig. 4a. Fuel consumption is increased with time of operation. It is shown that the fuel consumption at high speed is higher than at lower speed. From the measurement of experiment, as the rpm of the engine increases from 2500 to 3000, the fuel consumption rate increases from 2.9 ml/s to 6.6 ml/s. In other words it indicates that below 2500 rpm, the engine performed better and has relative less fuel consumption. Here, it is to be noted that although the 2-stroke engine used has better power-to-weight ratio, it consumed more fuel partly due to possible incomplete combustion. On the other hand, 4-stroke engine or diesel engine could generate a larger torque with more complete and clean combustion, but with both size and weight disadvantages.

Figure 4b shows the plot of wind speed generated vs. engine speed (RPM). Wind velocity measurement was carried out while the engine of airboat is pulled out from the hull. The wind speed is found to be almost linearly proportional initially to the RPM of the engine's shaft. From the plots, it is shown that there is a rapid increasing from 1500 rpm to 2000 rpm and gradually increases with rpm thereafter. These trends agree with others' findings, e.g. Benson's study [14] where wind velocity was found increases in engine until it reaches a maximum level where increasing of rpm will not produce stronger wind; limited by propeller's size.

Figure 4c shows that the airboat speed increases with time and reach maximum at around 15 km/h for a typical field test at a swampy test pond near to the old campus area. According to Newton second and third laws, airboat speed is depending on the thrust generate by the propeller to the backward. The airboat speed also is dependent on the load of the boat, water and air friction as well as the surrounding.

6.2 RESULTS FROM COMPUTER SIMULATION

In order to find out the optimum number of passengers for our design, the boat was subsequently simulated with different number of passengers, i.e. 1 to 5 passengers. Thus, five sets of different hydrostatics data were analyzed and plotted as in Fig. 5. The average weight of adults in Malaysia is assumed 68.27 kg. The total weight is therefore 551.52 kg and it keeps increasing with addition of passenger to 824.60 kg with a maximum of 5 passengers. The draught increases with weight, from 289.63 mm to 357.8 mm from the baseline. However, the LCB value decreases from 2.823 to 2.748, due to the seating of the passenger at the front or near bow. As a result, the LCB go nearer to bow. VCB, vertical centre of buoyancy increases with the draught. Plots of hydrostatics properties vs. draught are presented in Fig. 5. As shown in Fig. 5, there is not much increase in coefficient of Prismatic, block and waterplane as changes depend on the hull shape. When the wetted hull surface area is increased, the water friction and drag were found increasing simultaneously. This causes the airboat to obtain greater horse power to move forward. The values for BMT, BML, GMT and GML are decreasing as the number of passenger increases. This means that the more passengers onboard, the less stable the airboat becomes. The airboat stability is therefore found optimum with 2 passengers onboard as far as present situations is concerned, this confirmed with our field testing. Thus, airboat with 2 passengers is used for the subsequent simulation works.

6.3 SIMULATION WITH DIFFERENT TYPES OF HULLS

Full-scale experiments on boats are generally very expensive [15-17]. Therefore, for the investigation of the effect of different types of hulls for comparison purpose, only simulation works were conducted in the present study. For completeness purpose, three types of hull have been simulated [18] to show their hydrostatics and stability performance. Figure 6 show the Shallow-Vee, Flat bottom and Modified hull designed with B-splines drawing; with stations, waterlines and buttock lines views.

Result from the simulation conducted show that both wave and friction drag increase together with the increased of velocity for all hulls investigated, given in Fig. 7a and Fig. 7b respectively. Shallow-Vee hull shows a higher drag value than the other two. As shown clearly in Fig. 7b, the Modified hull has the largest friction drag and wetted surface area. It is followed by the Flat Bottom while Shallow-Vee has the smallest friction compared to the other two types of hulls. As a result, the Shallow-Vee design can move relatively freely in swampy condition.

A great deal amount of stability information can be found by inspection on Fig. 8, plots of righting angle vs. heeling angle for the 3 types of hulls. The range of positive righting arm for Flat Bottom hull is from 0 degree to 47 degrees. The positive range of Shallow-Vee hull is from 0 degree to 69 degrees. The Modified hull has the same positive range of stability arm. This indicates that the Flat Bottom has smaller heeling angle of positive restoring force. The Shallow-Vee hull and Modified hull have the same angle of vanishing which is equal to 69 degree. It is greater than angle of vanishing for Flat Bottom which is only 47 degree. The maximum GZ is obtained by drawing a tangent to the highest point in the curve. Thus Modified hull has the maximum righting arm, 0.102 from angle 18˚ to angle 24˚ whereas Flat Bottom has a greatest GZ of 0.065 at angle 22˚ to 24˚. However, Shallow-Vee has the smallest righting arm GZ with only 0.055 at angle 46˚ to 48˚. In view of the stability arm value, Modified hull is more stable than the other two and Flat Bottom is more stable than Shallow-Vee. Modified hull able to present a higher initial stability which greatest value of GZ at smaller heeling angle. The area under the righting arm curve is a measurement of the airboat's righting energy. Figure 8 shows that stability energy of Flat Bottom is less than Shallow-Vee and Modified hull has the greatest stability energy as it has the largest area under the righting arm curve. This implies that the Modified hull has the greatest resistance energy to resist the dynamically applied load.

Quantity of Metacentric Radius (BM) is depending of ship geometry. Figure 9 shows the value of BMT of the airboat. Initially, the heeling angle from 0˚ to 20˚ degree, Modified hull has the largest value of BM, which it has around 0.85 largest ratio of waterplane moment of inertia to the volume of displacement. Besides that, Flat Bottom hull is greater that BM value of Shallow-Vee hull. The value of BM is decreases with the heeling angle. The waterplane moments of inertia reduce with the increasing of volume of displacement. Metacentric height (GM) is a very crucial factor to evaluate the airboat stability. Any loss in GM is a loss in stability, according to Derrett [17]. In Fig. 10, the value of GM is positive which means that the airboat is still in stable equilibrium. The Modified hull shows the highest value of GM indicating the greatest initial stability.

7. CONCLUSIONS

The main contribution of the present paper is to provide useful affordable-cost, custom design information of our vehicle especially for swallow riverine transport applications and mangrove habitats investigation. It was found that our simple yet novel airboat not only low cost but provides suitable method useful for field survey of coastal habitats including mangrove applications as well as other riverine transportations. The performance of our air boat, however, could be appreciably improved by better overall design and associated construction to suit local difficult conditions. Full scale trials with more detail simulation study could be conducted for further improvement. Nonetheless the performance characteristics of the airboat presented here are already near to a level it could be useful for practical applications in local mangrove habitat and rural riverine conditions.

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NOMENCLATURE

BM	Metacentric radius (cm)
CB	Centre of buoyancy
GML	Vertical separation of the longitudinal metacentre and centre of gravity.
GMT	Vertical separation of the transverse metacentre and centre of gravity.
GZ curve	The curve of vessel righting arm (GZ)
RPM	Revolutions per minute (RPM)
VCB	Vertical centre of buoyancy

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Fig. 1: Map of Sarawak, East Malaysia, depicting the near shore marine habitat (Rejang Delta Plain), mangrove habitat (e.g. at Bako) as well as the flood-prone areas (e.g. Bau) at Sarawak Kanan River.

Fig. 2: Various local maritime environments. (a) A typical delta view during the low tide (b) Mangrove habitat: Roots of the shrubs are above the water level causing difficulty for plying of conventional airboat during low tide (c) Swallow river: Peat along the river bank can cause difficulties during low-tide for conventional boats. The airboat constructed showing the second author was moving freely in the swampy area.

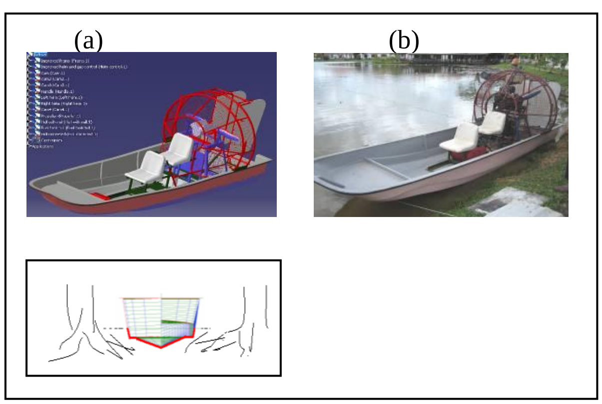


Fig. 3: The airboat design investigation. (a) Water level is analyzed by the CATIA design software program (left picture); (b) rail is installed on the airboat for ease of frame adjustment (right picture); (c) a typical schematic sketch of a narrow mangrove habitat versus the Vee hall shape boat outline

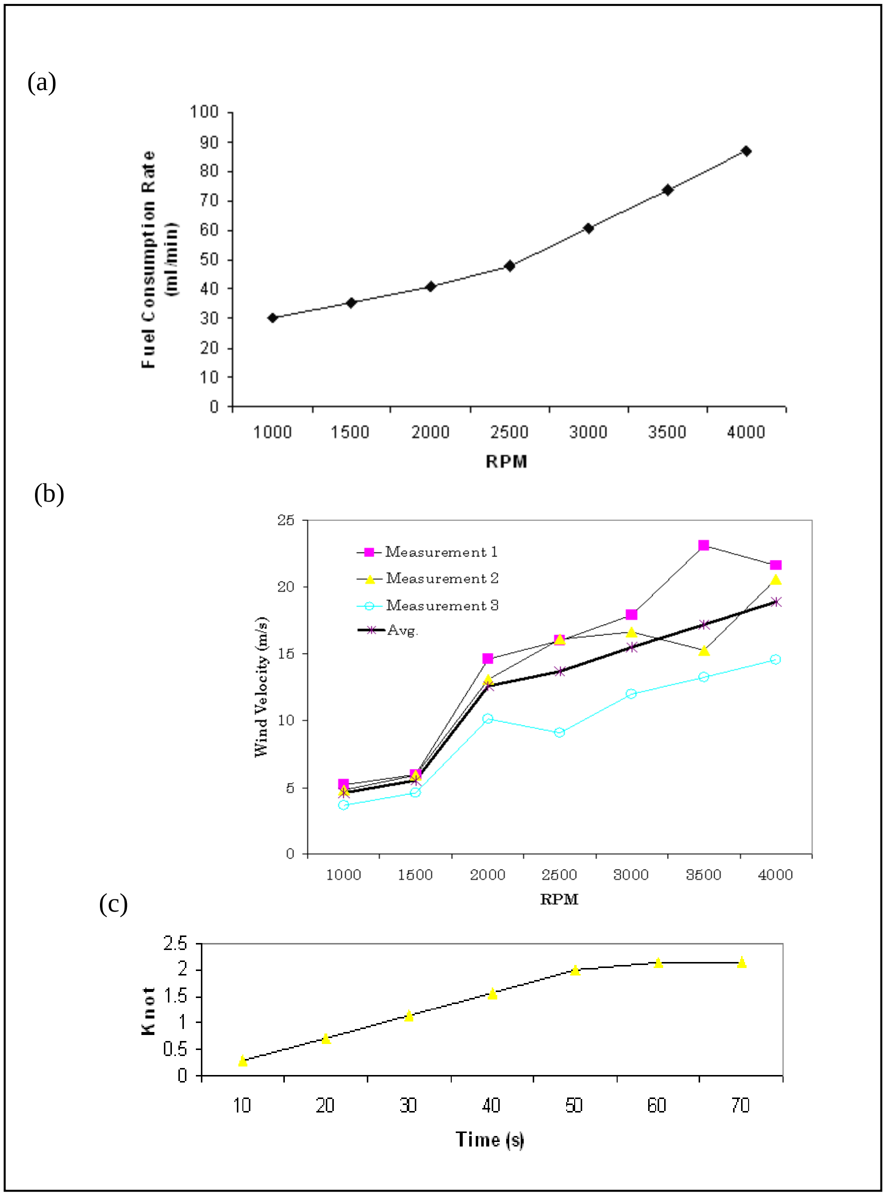


Fig. 4: Some typical airboat performance tests (a) typical fuel consumption rate vs. rpm; (b) Wind speed vs. rpm; and (c) airboat speed vs. time.

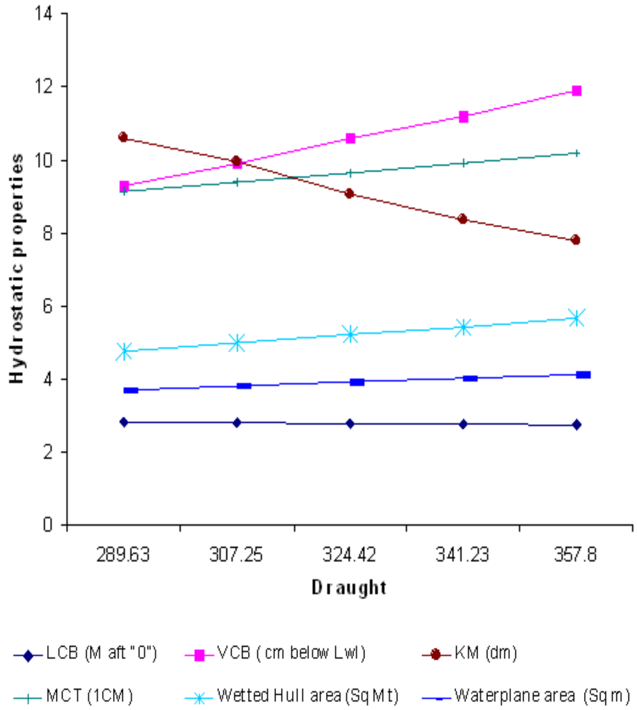


Fig. 5: Hydrostatics curves

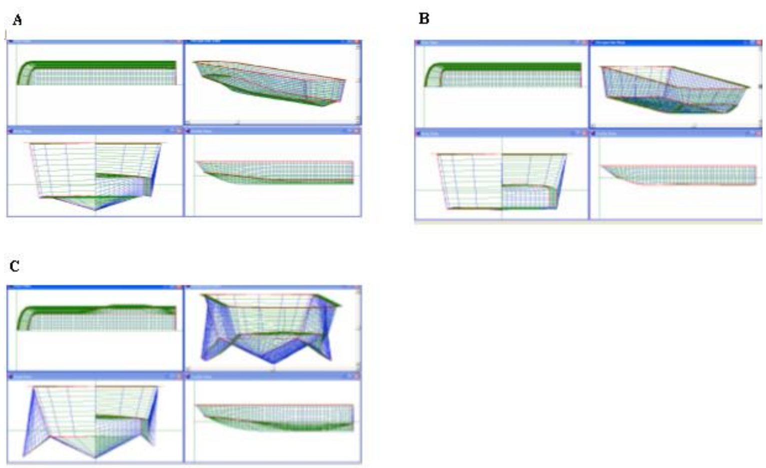
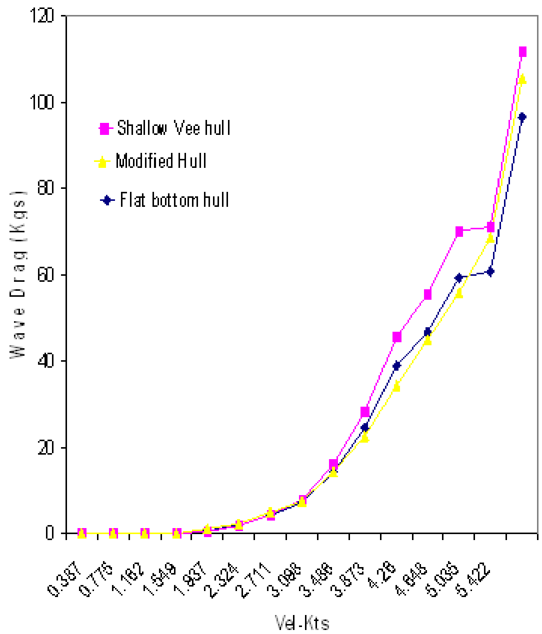


Fig. 6: Various hall types drawn with B-splines drawing. (a) The Shallow-Vee; (b) Flat Bottom; and (c) Modified hull.

(a)



(b)

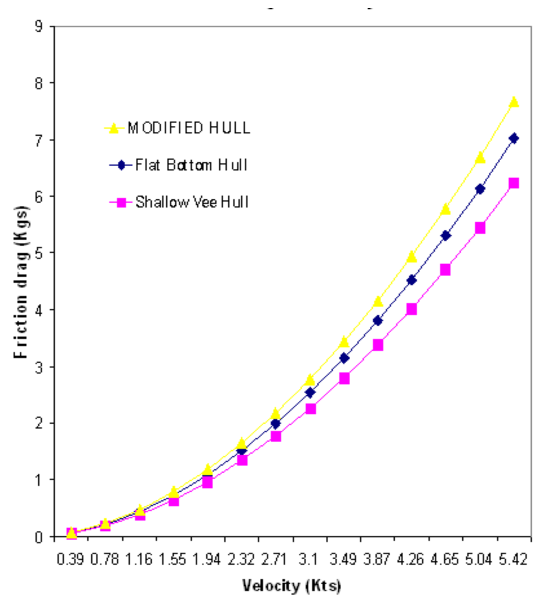


Fig. 7: The wave drag and friction drag as a function of velocity (a) The wave drag vs. velocity (b) . Friction drag vs. velocity

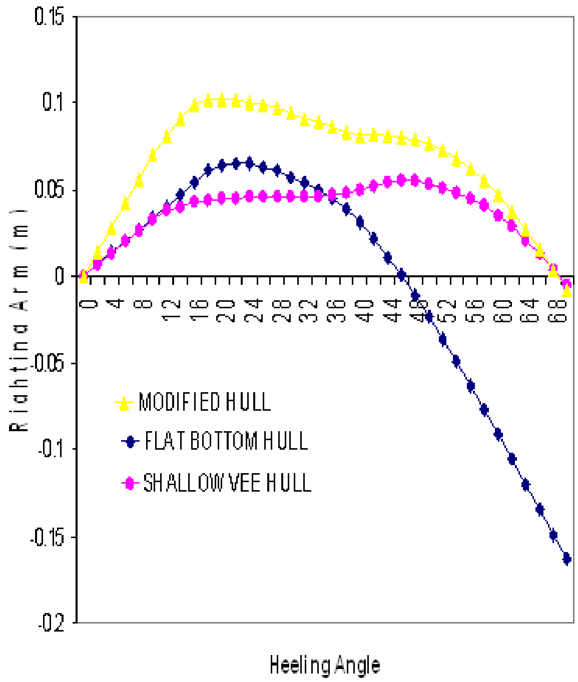


Fig. 8: The value righting arm Vs. heeling angle curves

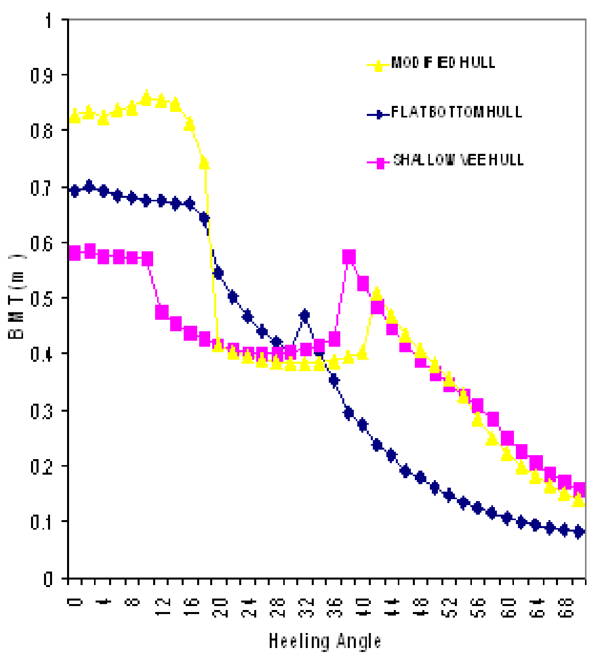


Fig. 9: The value of transverses of BM versus heeling angles

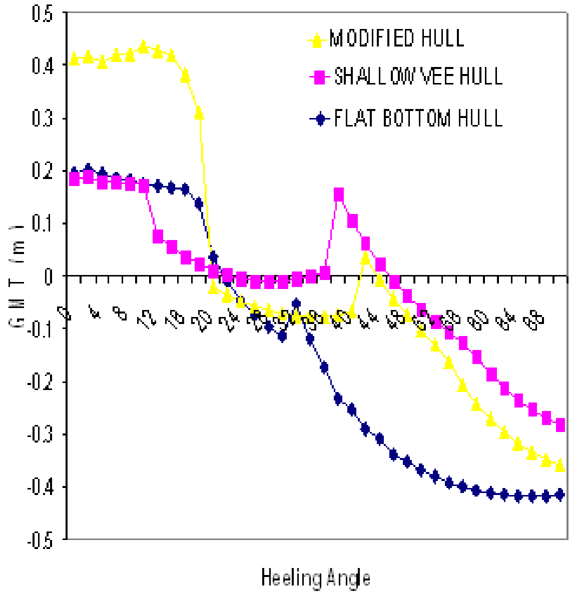


Fig. 10: The value of transverses of GMT verses heeling angles