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Design of a Wind Propelled Planning Hull Craft for Shallow Water Operation

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Abstract: During recent flash floods, Sri Lanka Navy rescue teams met with many circumstances where they could not use their Dinghies even with a short tail Out Board Motors (OBM) due to submerged obstacles at unprecedented depths. Therefore, designing a planing craft with rescue capability deemed a national necessity. This study explains the designing of a wind powered planing hull craft to operate in shallow waters during natural calamities like flood situations to move where stagnant water masses with uncertainly small depths. A speed boat with performance such as gaining top speed, achieving acceleration timing, turning characteristics, course keeping ability at top speeds, etc. are quite challenging which measure the overall performance of the boat. Preliminary analysis on the issue was made by the naval engineers who were attached to Sri Lanka Navy (SLN), where the case study was done collecting data after series of visits to flood affected areas. Size of the common alleyways in flood affected areas and their general flood height and the depths were calculated and hence size of the required boat with maximum allowable draft has been determined. Since the lesser capabilities of the SLN to finish a hull with required hydrostatic data seems costly a hull with required features determined and purchased to match with a suitable engine and a wind propeller with a suitable steering and protection mechanisms. Therefore, the purpose of this exploration was defined, then researched and designed a light weight flat bottom Fiberglass hull craft propelled by air for carrying out rescue missions during floods. Finally, subsequent study was conducted of hydrostatic and hydrodynamic forces, position of centre of gravity (CG), engine matching and propeller matching to the hull. The newly designed airboat is distinctive, and it can be operated at a wide range of both steady and moving waters.

Keywords: Air-boat, Sri Lanka Navy, Out Board Motors, Offshore Petrol Vessels, Centre of Gravity.

Introduction

In recent years, airboats have been proven that they are capable to handle floods, shallow water operations, and ice rescue tasks, in effectively and efficiently. Consequently, they have fully-fledged with safety practices and developed the reputation among public. History is evident that the flooding was taken place in New Orleans following Hurricane Katrina, on 29th August 2005, and how airboats were effectively utilized to rescue thousands of flood victims. Further, thirty airboats were deployed to evacuate more than 3,000 patients and medical staff from four downtown New Orleans hospitals in less 2 days (Colten, et. al., 2006).

In Sri Lankan context, it was experienced that the flash floods swept across western region of the country in two occasions during the year 2016 and 2017, which crippled the day today livelihood of the general public in flooded impacted areas. Further, reaching to victims of the havoc and survivors with accessible means was the enormous encumbrance confronted by the Sri Lanka Navy (SLN). Subsequently, the nation had to pursue assistance from neighbor countries to carry out search and rescue operations, to safe guard the victims.

SLN is a rational and unified force, that performs duties on waters around the island effectively and defence national interests. Further, a mission of SLN is very clear and conduct prompt and sustainable combat operations and rescue missions at sea in accordance with the national policies. Moreover, SLN was starting its fleet from smallest fiber glass dinghies, which deployed mainly in inland waters and harbor protections. Subsequently, an introducing Offshore Petrol Vessels (OPV) to the SLN fleet and deployed in blue and green waters as the first line of defence (De Silva-Ranasinghe, 2009).

Numerous forms of rescue boats be existent to navigate over flooded water. An airboat is the best example of such a rescue craft with multiple usage. Normally, these flat bottom-hulled airboats are driven by fans, with utilization of air flow. Further, this water crafts are comparatively compact and able to maneuver in shallow water conditions. Moreover, a hull of this rescue boat is made-up by either aluminum or fiberglass materials (Leppek, 2012). Both aluminum and fiberglass hulled airboats can be effectively used in low-water conditions, compare to 'Out Board Motors' (OBM) driven watercraft. Though, several drawbacks are identified in these airboats operations. Specially in open waters, these types of airboats are extremely difficult operate, if currents, waves or windy conditions developed (Giassi and Maisonneuve, 2004).

SLN had experienced that the rescue teams met with many circumstances where they could not use their Dinghies even with a short tail OBM due to submerged obstacles at unprecedented depths. Therefore, primary analysis on the issue was investigated by the naval engineers who were responsible to research and development of the Sri Lanka Navy (SLN), where the case study was done collecting data after series of visits to flood affected areas. Size of the common alleyways in flood affected areas and their general flood height and the depths were calculated and hence size of the required boat with maximum allowable draft has been determined. Since the lesser capabilities of the SLN to finish a hull with required hydrostatic data seems costly a hull with required features determined and purchased to match with a suitable engine and a wind propeller with a suitable steering and protection mechanisms. Finally, SLN engineers were identified and decided that the designing a planing craft with rescue capability deemed a national necessity. Therefore, the purpose of this exploration was defined, then researched and designed a light weight flat bottom fiber glass hull craft propelled by air for carrying out rescue missions during floods.

Methodology

Material Selection and Design of Hull - Fiberglass was chosen to make this airboat hull due to low cost and the availability of infrastructure facilities related to fiber works at SLN premises. Thickness and type of the hull were decided based on the criteria such as the terrain on which the airboat will be used, total weight of cargo, passengers, and size of the airboat. The flat bottom hull was selected for this airboat while considering rescue tasks and easy handling during floods (Giassi and Maisonneuve, 2004).

According to preliminary design, construction of the airboat was begun with the fabrication of a hull in figure 1. The polyester was selected as the suitable material to construct the hull due to low cost, light weight and minimal elongations. Further, this fiberglass material is directly affecting for the reduction of a friction against rubbing surface of the hull, and improved fuel efficiency. Since the weight factor of the airboat is one of the very important criterion in this design, weight of the boat was maintained essentially less than 350 kg to fulfil the requirement of easy handling during floods.

The length of the boat is restricted to 12’ 10” and maximum breadth is curtailed with 7’. The height is 1’ 08” with both sides angled out, at an angle determined from the difference in the beam and bottom widths of the hull in figure 2. Fabricating a transom is vital, and considered as the back panel of an airboats hull. Consequently, the angled sides are generating additional depth to the hull and an increase in the displacement. Therefore, it leads to improve the capacity of the airboat which can carry more number of passengers. In this hull depth changing process, the center of gravity is shifting to rear side of the airboat and set up more stable conditions. A maximum transom is 20” and maximum depth of nose is 16”, in this hull design and provide sufficient elevation of the bow above waterline for safe passage. Further, it allows adequate clearance in the situation where the airboat would encounter rough or choppy water that could potentially come over the bow (Tinkham, and Tinkham Sherman, 1977).

Salient features of air boat

Length	- 12’ 10”
Max Breadth	- 7’
Height	- 1’ 08”
Total weight	- 350 kg
Cage Diameter	- 5’ 08”
No of persons	- 02
No of rudders	- 02
Rudder angle Max	- 60º
Speed	- 17 knots (Approx.)
Air propeller Diameter	- 134 cm
No of blades	- 03
Loading capacity	- 150 Kg

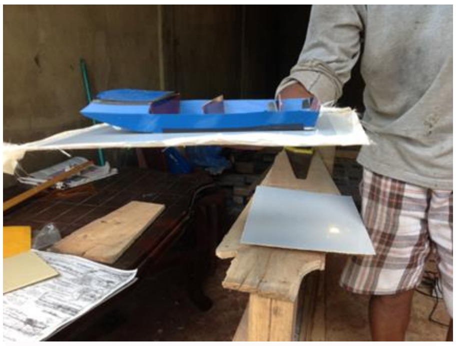

Figure 1: Scaled Down Fiberglass Hull

Figure 2: Fiberglass Hull

Propulsion System - A propulsion system is consisted of an engine, propeller, and rudders. Many options are available to select suitable engines for design airboat. Both aircraft and automotive engines are generally used for airboats, to achieve design speeds. The rotations per minute (rpm) is the major parameter that specified by the airboat propeller manufacturers to select the suitable propeller for airboat. Further, the size, shape and martial of propeller are the key factors for achieving maximum rpm during airboat operations. Aircraft engines generally operate at rpm of 3,000 or lower. Therefore, a less horse power compatible aircraft engine and three blades Carbone fiber propeller is matched and fixed with this airboat to accomplish, the assign task by SLN in figure 3 (Fritsch and Diehl, 1926).

Engine Specifications

Engine HP	- 35 HP
Engine weight	- 45Kg
Engine RPM (Idle)	- 1200
Engine RPM (Max)	- 3600

Figure 3: Engine mounted to the airboat

Seating Arrangement - This airboat was designed to carry one passenger and the operator. The operator's seat is in back, and elevated above the passenger. In addition, it was centered widthwise, therefore that the center of gravity in the widthwise direction is on the centerline of the hull which maintain the stability of the boat. An all-round visibility of the driver is very important during close proximity operation, therefore, the driver's seat is located in little elevated position compare to passenger seat. Further, another mandatary requirement is to position the seat that minimizes the length of the cables for the throttle and clutch. Consequently, it is reducing shifter and rudders connecting linkage length. A drivers seating framework was constructed out of steel composite material with fiberglass seat in figure 4 (Leppek, 2012).

Figure 4: Seating arrangement of airboat

Drive Unit, Rudders and Shroud - Drive unit framework was encompassed with mild steel tubing. According to the size of the engine, size of the tubing was matched to construct the structure. Subsequently, a propulsion system was fixed to the hull structure by mild steel frame. Then, the engine framework was fixed to the runners located on the floor of the hull by bolts. The fan guard was connected to the engine framework. In this design, there is no reduction gear box and the propeller is directly coupled to the engine. The whole frame work is connected to the propeller shroud and engine structure. Split clamp collars are located on either side of the bearing blocks, and these collars hold onto the propeller shaft and limit forward and backward movement. Sizing of the propeller shaft and support framework, along with the bearing blocks and split clamp collars is reliant on the amount of thrust produced by the propeller (Leppek, 2012).

Propeller guard scale was determined depending on the size of the propeller is used for the airboat. In this construction of the propeller shroud consisted of mild steel and tubing that is used to create a framework for the guard. Major rings of shroud were made by 1” pipes and supporting elements were fabricated with ½” pipes. Spacing of the tubing used for the framework was kept wider with a wire mesh (12 gauge) in figure 5.

Figure 5: Propeller guard

This airboat was fixed with two rudders for easy operation. A sink coated sheet was utilized to develop these rudders with an airfoil shape. Subsequently, a push/pull cable or a connecting linkage was attached to a directional control stick located next to the driver's seat which allows the operator to control the movement of the rudders in figure 6. By controlling the movement of the rudders, the operator is able to steer the airboat by directing the airflow from the propeller. An acceleration pedal is located on the floor in front of the driver permits them to control the speed of the airboat. This throttle pedal was connected to the engines fuel system, and it regulates the amount of fuel entering to the combustion chamber (Sun and Faltinsen, 2007).

Figure 6: Rudders

Principle of Operation - According to the Newton's third law of motion, the propeller exerts a force on the air and pushing it backwards behind the boat. Simultaneously, the air exerts a force on the propeller and move the airboat forward. Further, a motor fan is apparently the propulsion of choice for most planing hull flat bottomed craft, with vigilant hull integration, and it leads to reduce power requirements relative to an open screw propeller. Moreover, rudders are fixed an above the water line which create a favorable propulsion / hull interaction (Savitsky, 2003).

Calculations of Powering - The following expression at the equation (1) can be stated to quantify generated force by the airboat (Sun, H. and Faltinsen, O.M., 2007).

$$F = ma \quad (1)$$

The following expression at the equation (2) can be stated to enumerate initial velocity and final velocity of the airboat.

$$V = u + at \quad (2)$$

The following expression at the equation (3) can be stated to estimate drag force by the water.

$$F_{drag} = \frac{1}{2}\rho C_d A V^2 \quad (3)$$

Where,

F is force

m is weight

a is acceleration

u is initial velocity

V is final velocity

t is time

F_{drag} is dragging force

ρ is density of water

C_d is drag coefficient

A is cross section area of the hull, up to water line

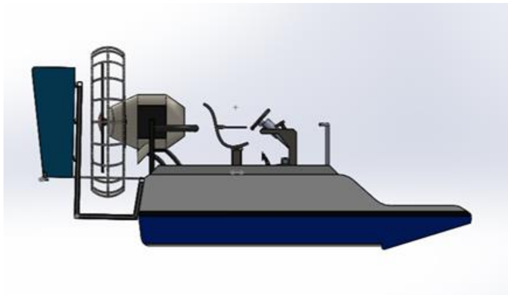

Figure 7: Schematic of airboat

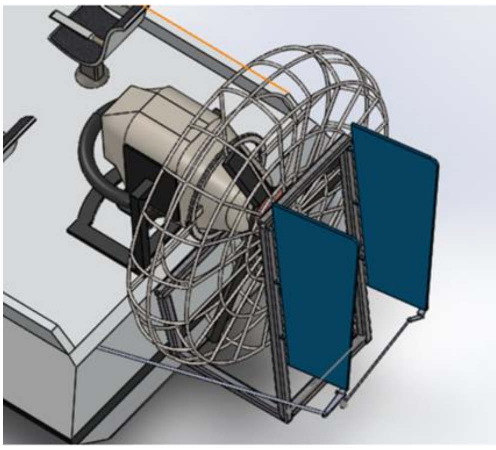

Figure 8: Schematic of airboat drive unit

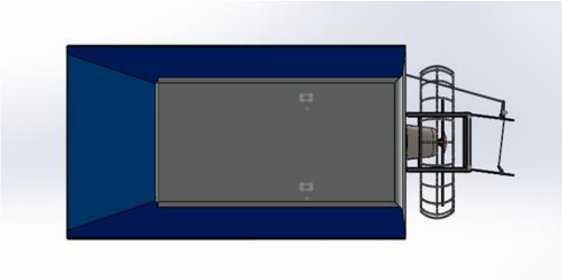

Figure 9: Schematic of airboat steering system

The final velocity of the airboat (V) is determined by equation (4).

V=15 knots = 0.514 × 15 = 7.7 m/s
Where U = 0
ρ = 1000 Kgm^{-3}
C_d = 0.5
A = 0.19 m^2

Net Force (F_n) = Force (F) + Dragging Force (F_d) (4)

The net force of the airboat (F_n) is determined by equation (16).

F_n = (7.7/20).500 + {0.5 x 1000 x 0.19 x $(7.7)^2$}
F_n = 192.5 + 2816.275
F_n = 3008.775
Power (P) = F_n× V (5)

The power of the airboat (P) is determined by equation (5).

P = 3008.775 × 7.7
P = 23167.5675 W
P = 23.17 kW
Adding 10% Safety factor =(23.17+2.317)kW
= 25.487 kW
Converting to HP = 25.487/ 0.742
= 34.15 HP

Considered the propeller efficiency up to 95% and selected 35 HP engine suitable for air boat.

Results

Speed Trails - The speed trails were conducted in two occasions with different load conditions. In initial trail was carried out with light load conditions for two hours in figure 10. Consequently, speeds of air boat were obtained by handheld GPS and details in table 1.

Figure 10: Conducting a half load trails

Table 1: Light load condition parameters

Load Condition (kg)	Engine rpm	Speed (knots)	Remarks
425	1800	6	Heavy vibration
	2400	8	Bit vibration
	3000	12	Bit vibration
	3600	15	Bit vibration, belt slipped

Figure 11: Conducting a full load trails

Maneuvering Trails - A maneuvering trial was carried out to determine the maneuverability and directional stability of the airboat. Further, the trails were extended up to carry out a direct and zig-zag movements of the airboat in both light and full load conditions in figure 12.

Figure 12: Conducting a maneuvering trails

Discussion

According to classifications of fiberglass resins, it is generally divided into three types, such as polyester, vinylester and epoxy. Each one is having a prominent place in the boat building venture. In this design, the polyester is chosen to fabricate this airboat hull due keep the airboat in light weight condition with more strength.

An air craft engine was fixed with this airboat due high fuel efficiency, light weight, very less maintains and greater power to weight ratios. Further, there was no gear box in this design and an engine was directly coupled with a propeller to minimize a top weight. This propeller was matched with the engine, as per assigned task by SLN. The propeller is made up with carbon composite material and comprised with three blades, including flat tips to regulate the rpm below 3000. In general, the maximum tip speed of a propeller is around 890 feet per second. Though, airboat operators are ensuring that the tip speed should not be reached to maximum value, in all time to avoid sudden occurrence of failures. In addition, it naturally gives the maximum thrust during this maximum tip speed, same time developed trust could be lost, in quick intervals due aerodynamic occurrence of the propeller and then it leads for catastrophe.

In the process of speed trails, a great amount of ambient noise and bit vibrations were observed. Subsequently, all the engine mounting bolts were tightened and brought down the vibration into minimum level. The driving belt was slipped twice at when engine approaches 3600 rpm. Though, it was fixed after tightening the belt by adjustable pulley.

A maneuvering trail was little complex compared to speed trails, and observed that the bow of the hull moved through the water with less resistance prior to the airboat planing out. Then airboat was carried out sharper turns and zig zag movements and checked behavior of the airboat. Finally, it was suddenly reduced the speed and quickly the wake created by the hull and splashed against the transom and fair amount of water came over the gunnel. Both occasions of trails, airboat speed was restricted to 15 knots, to avoid reaching maximum tip speed of the propeller.

Since this design is compatible for accommodating approximately 12 passengers, research and developments are underway to develop an airboat with 2 passengers. This airboat is novel product for Sri Lanka and versatile to operate in rescue work, during floods. It can be easily transfer for flooded area by a vehicle and handled it by four men, without making any complexities. Further, this boat can be easily maneuvered, in both steady and moving waters, without risk. Besides, an endurance is quit high and can be operated at continuance six hours in a single stretch. Finally, this airboat is suited to operate in uncertain small depths, even the flood is receding.

Conclusion

It is recommending that to fix suitable silencers to minimize ambient noise during the operation. Further, recommended to fix a splash guard with a height of 15 cm on top of the transom to minimize splashing during sudden stops of airboat. Furthermore, recommended to fix a fire extinguisher one of the legs of the driver seating structure, to use in case of emergency. Finally, operability of this air boat was very good in both steady and rough waters and provides sustainable solution for rescuing victims during flood situations.

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