Design, Development, and Fabrication of a Mini-Hovercraft

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Abstract - *The hovercraft is a highly stable vehicle capable of muti-terrain travel. It works on the principle of using the 'cushion effect' of air to generate lift from interaction with the ground and hence is also called an air-cushioned vehicle (ACV). The main aim of this paper is to introduce a low-cost design of a hovercraft and elaborate on the methodology used for fabricating a working prototype. The hull design, based on the half-Rankine body, was purposefully chosen to reduce the effects of aerodynamic drag and improve fuel efficiency. The prototype was envisaged to travel at a moderate speed on both land and water with high aerodynamic stability and was designed for a load of 130 kg. In addition to the methodology of fabrication, design considerations and the results obtained during trial tests are discussed throughout the paper. Finally, the limitations of the present design are mentioned, along with the scope for future development.*

Key Words: **hovercraft, cushion-effect, lift, air-cushioned vehicles, half-Rankine body, aerodynamic drag. fuel efficiency, stability**

1. INTRODUCTION

Hovercraft or air-cushion vehicle (ACV), is an amphibian vehicle or craft, designed to travel over any sufficiently smooth surface supported by a cushion of slowly moving, high-pressure air ejected downward against the surface close below it. It was invented in 1950 by British engineer Christopher Cockrell. Essentially, all practical systems use skirts to follow the terrain and contain the air. But recently, hovercrafts have been developed which can work without any skirt. Traditional hovercrafts use one or more different engines to run fans, which provide enough force to levitate the vehicle. There are separate engines for providing thrust to the vehicle. However, the objective of the present hovercraft is to carry lightweight goods (< 50Kg.). Instead of using an engine for levitation, a leaf blower or pressurized air from pipelines (in industries) is used. The levitated vehicle does not move on the cushion of air, but the power developed reduces the area of contact of the hovercraft with the ground to a minimum. This considerably reduces the friction on the board and hence the transmission of weight becomes much easier.

The propeller shown must be designed for a vehicle as typically a fan for creating vortices to mix the air, reducing the ejected air's translational kinetic energy to provide the necessary lift and thrust. Typically the cushioning effect is contained between a flexible skirt. Hovercrafts are hybrid vessels as they typically hover at 200mm and 600mm above any surface and can operate at speeds above 37km per hour. They can clean the gradient up to 20 degrees. Locations that are not easily accessible by landed vehicles due to natural phenomena are best suited for hovercrafts. Today they are commonly used as specialized transport in disaster relief, coast ground military, and survey applications as well as for sports and passenger services. Very large versions have been used to transport tanks, soldiers, and large equipment in hostile environments and terrain. In riverine areas, there is a great need for a transport system that would be fast, efficient, safe, and low in cost. Time is spent transferring load from a landed vehicle to a boat. With a hovercraft, there is no need for the transfer of goods since it operates both on land and water. It is said to be faster than a boat of the same specifications which makes it deliver service on time.

2. METHODOLOGY AND FABRICATION

This design proposes an integrated system i.e. a single propeller is used for both the lift and thrust requirements. In this design, the air from the shroud is split to cater to two requirements i.e. for the lift and thrust. 40% of the air is split and directed towards the base which fulfills the lift requirements and the rest of the air is used to propel the hovercraft thereby fulfilling the thrust requirements. The salient feature of this design is that it requires only one source of power i.e. only one engine for thrust and lift [4] and therefore this design becomes an economically better option. However, there are issues in this design such as air distribution that require further attention.

The thrust for the hovercraft is provided by the propeller system at the rear of the hovercraft. The thrust developed by the hovercraft primarily does two functions: (i) it overcomes the drag on the vehicle, and

(ii) provides the forward motion of the hovercraft. The thrust of the hovercraft depends on the payload carried by the hovercraft, engine power, rotating speed of the propeller, and propeller parameters such as diameter, pitch, blade angle, etc.

2.1 Propeller Design and Engine Selection

A two-blade propeller of diameter 1.15 m was constructed using wood. By assuming values of propeller diameter (by comparing with existing models) and by knowing the forward velocity required (design criteria), the required propeller data is reverse calculated.

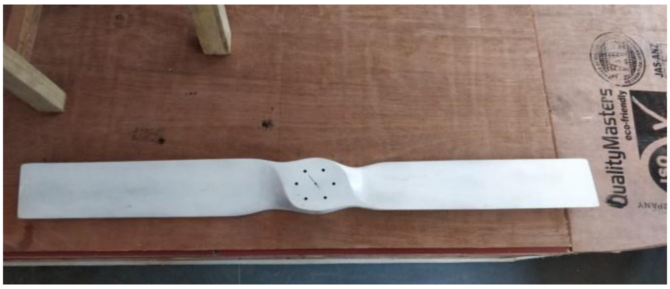

Fig -1: Finished wooden low-pitch two-bladed propeller

After fabricating the propeller, the casing of the propeller was designed and fabricated using sheet metal. The casing diameter was chosen as 1.16 m, in order to account for a clearance of 5 mm between the propeller tip and the casing. The clearance between the casing and the tip is extremely vital; as it minimizes losses at the tip of the propeller and also reduces the free annular area that could possibly contribute to back pressures, thus affecting propeller efficiency.

Before starting fabricating the hovercraft, it was necessary to calculate the power required for the hovercraft engine. The power-to-weight ratio of the hovercraft depends on certain factors, namely: (i) outlet velocity from the skirt (ii) hover height, and (iii) hull dimensions. By assuming an initial payload of 200 kg, the power required for the engine was calculated and was found to be in the range of 6 to 8 HP.

Fig -2: Fabrication of propeller casing

As per our initial calculations, we disassembled an engine from a Kawasaki Boxer bike. The Kawasaki Boxer engine is a 4-stroke, air-cooled SI engine that comes at a peak power of 8.2 HP at 7500 RPM. The engine has a capacity of 100 cc and produced a peak torque of 8.05 Nm at 4500 RPM. This engine was initially decided to act as the prime mover of the hovercraft. After further study and calculations, it was determined that the power of the engine must be within the range of 12-15 HP. This was in order to account for the different losses that could possibly occur considering the fact that we used an old and repeatedly driven engine. Moreover, the propeller would ideally run at speeds in the range of 2000 – 4000 RPM, while the Boxer engine only provides its peak power at 7500 RPM (which cannot be practically attained while driving the hovercraft). Thus, we decided to shift to a better and more powerful engine. Finally, based on our power requirements, we purchased a TVS Suzuki Shogun engine, which comes at a peak power of 14 HP at 8500 RPM and has a capacity of 108.2 cc while providing a peak torque of 11.4 Nm at 8250 RPM. This engine was cleaned, and then further subjected to modifications and further fine-tuned. The exhaust port diameter was increased and a C-D kit was assembled at the exhaust in order to boost engine power. Finally, the modified engine produced a power of 18-19 HP at 8500 RPM.

2.2 Cowling Duct Design and Hull Fabrication

Since the hovercraft use a single engine for both lift and thrust, a separate system for supplying air to the hovercraft skirt was found to be necessary. Thus, a cowling duct system is used in this design to trap air from the propeller and divert it into the hovercraft skirt. The area of the trap can be calculated by knowing the inlet and outlet velocities of the skirt and equating the volume flow rates into and out of the skirt. These parameters are to be finally decided only after ground testing of the assembled engine-propeller setup..

The hull is made by forming a base of polystyrene sheets above the plywood sheets. Industrial grade glue was used for the same purpose. The base of the vehicle is a combination of rectangular and semi-circular plywood pieces of width 6mm, with polystyrene sheets kept horizontal to the plywood. Another plywood sheet was adhered to on the top, and the prepared hull was kept under pressure overnight. The plywood pieces were cut according to dimensions and glue was applied to the plywood and polystyrene sheets. The dimension of the rectangular piece that made up the base was 6 feet x 4 feet and the radius of the semi-circular piece was 2 feet. These sheets were joined with help of adhesive along with a butt joint. The chamber was constructed next, for which new plywood boards of 12 mm thickness were joined perpendicularly to the base. The height of this chamber was selected to be 30 cm. For the proper passage of air through the chamber, holes of 8 cm were drilled throughout the structure. To construct this chamber, two multi-wood sheets of 6 mm width were bent to form the curved piece of the semicircular portion on the front side of the hull base. All the structures were clamped to the base using L- clamps. In order to distribute the load evenly and to support the top portion of the hull, plywood pieces of 12 mm thickness were used to construct a frame of 5mm breadth throughout the periphery of the structure. The height of the air chamber trapping the outlet air of the propeller was calculated precisely to be about 58 cm from the base of the hovercraft hull. Plywood boards of 12 mm thickness were used for the construction of this chamber. This air chamber also accounts for the support of the propeller casing and the rudders which are connected to the steering.

We constructed an air box, in order to divert 60% of the air driven by the propeller into the duct. It was constructed with plywood of thickness of 10mm and air tightened by applying fevicol glue at the edges. A curved shape was cut into the plywood and PVC pieces were fitted along the edges of the two curves to divert the air coming from the propeller.

Fig -3: Assembling the hovercraft skirt

2.3 Engine Assembly

The engine mount was acquired from a scrap yard, which we found to be inadequate to support the whole weight of the engine. Extra mount material was cut off to save weight and provide space for the new frame. The new frame was constructed so to support the upper part of the engine and hold two bearings that are kept parallel and aligned. The bearings house a shaft of diameter 25mm. The diameter at one end of the shaft was reduced to 20 mm so as to fit into the fan hub. A 20 mm hole was provided within the fan hub for assembly with the engine output shaft, along with a key of 6 mm. The transmission provided consists of a reduction gear arrangement with a reducing gear ratio of 1:3 from the engine to the propeller. The bearing and frame were constructed to keep this shaft at a height of 0.65m from the base of the hovercraft hull, Washers were then fitted so as not to leave the chain slack. The engine, engine mount, and transmission gears were finally assembled to form the powerhouse assembly. This powerhouse assembly was fixed on the hull using four M10 bolts. To absorb the vibrations of the engine four rubber pads, a pair for each leg of the mount, each of 8mm thickness, were provided between the engine mount base and hull.

Fig -4: Modified Shogun engine for the hovercraft

3. CALCULATIONS AND APPROXIMATIONS

Our intention was to design a hovercraft for demonstration purposes. so a total weight of 130 kg was considered as the design load, taking into account the weights of the base, engine, impeller, shroud, air box, steering mechanism, rudder system, engine frame, skirt, petrol tank, and other miscellaneous components.

Dimensions of the rectangular portion of hull base = 6 ft x 4 ft

Radius of a semi-circular portion of hull base = 4 ft

The cushion pressure of air in the skirt, P_c, was calculated as follows -

$$P_c = \frac{Design\ Load}{Area\ of\ Base} = \frac{130}{2.8} = 44.98\ \text{kg/m}^2 = 44.98 \times 9.81$$

$$= 441.3\ \text{Pa}$$

The exit velocity from the hull air chamber to the skirt was calculated as follows -

$$\text{Exit Velocity (Ve)} = 2 \times \frac{Pc}{\rho} = 2 \times \frac{44.98\ Pa}{1.16\ kg/m3}$$

$$= 77.6\ \text{m/s}$$

The hovering gap, *h*, (the distance above ground over which the hovercraft hovers) was taken as 0.015 m for design calculations.

From the calculated values and the available range of engines within our budget, we decided upon a 100cc

Kawasaki Boxer engine which has the following specifications-

- Peak power: 8.2 Ps (6.03 kW) at 7500 RPM
- 8.05 Nm at 4500 RPM
- 4 stroke, single cylinder, naturally air-cooled SI engine.

After further study and calculations, it was determined that the power of the engine must be within a range of 12-15 HP. This was to account for the different losses that could occur considering that we used an old and repeatedly driven engine. Moreover, the propeller would ideally run at speeds in the range of 2000 – 4000 RPM, while the Boxer engine only provides its peak power at 7500 RPM (which cannot be practically attained while driving the hovercraft). Because of this, we decided to shift to a better and more powerful engine. We procured a more powerful, TVS Suzuki Shogun Engine with the following specifications:

- Peak power: 14 BHP at 8500 RPM
- 11.4 Nm at 8250 RPM
- Displacement: 108.2 cc
- 4 stroke, single cylinder, naturally air-cooled SI engine.

Table -1: Calculated Design Specifications

Design Specifications			
Design load	130 kg	Engine Power	12 HP
Hull base area	2.89 m^2	Engine Capacity and Peak Torque	108.2 cc 11.4 Nm at 8250 rpm
Inlet velocity of air (lift)	20 m/s	Skirt Perimeter	6.93 m
Escape velocity of air (lift)	77.6 m/s	Cushion Pressure (skirt)	441.3 Pa
Propeller Diameter	1.15m	Propeller Casing Diameter	1.16m

We designed a two-dimensional skirt structure using the Designer Modeler package of ANSYS in order to study the pattern of holes to be made in the skirt. We then performed the meshing of the designed two-dimensional skirt models by using projections and face mapping features, We performed a fluid flow analysis on the geometry by providing boundary conditions such as fixed wall- no-slip condition at the bottom section of the control volume and wall boundary with symmetry conditions on the other three sides of the flow domain. The pattern of holes was simulated for different positions; on circles of different radii from the center of the hovercraft skirt. The ideal pattern of holes would give the optimal value of lift coefficient, C_L.

Performing this simulation gave us a brief idea of how air would be distributed within the skirt and how it would possibly flow through it when fully inflated. It also provided us with scope for further study of airflow within the skirt of the hovercraft.

From analytical calculations, we evaluated the ideal position of the pattern of holes in the skirt. Referring to [2], we arrived at a mathematical formula for calculating the angle through which air must deviate through the skirt holes to provide optimal lift; given by,

$$\tan\theta = \frac{h.\Sigma Aholes}{t.Aplatform}$$

By substituting the given data in the above equation,

Hover height, h = 0.015 m

$\Sigma Aholes$ = 3.57 m^2

$Area\ of\ platform$ = 2.89 m^2

t = 0.5 m

we got an optimal value of θ as 65 degrees.

We then calculated the ideal position of the pattern of skirt holes in the skirt using geometric deductions, and the position of the holes was decided to be along the periphery of a circle at a radius of 19 cm from the center of the skirt section.

In an engine test, we ran the propeller at various speeds, from starting condition to full throttle. An anemometer was placed just behind the propeller slipstream, at various distances from the propeller center to get its velocity readings. The readings are given below in Table-2.

Table -2: Slipstream velocity readings

Distance from the center (in cm)	Measured velocity readings (m/s)
0	4
17	20.26
32	21.6
51	13.86

By averaging the values of velocity for different positions, we obtained an averaged slipstream velocity value of 17.4 m/s.

4. RESULTS AND DISCUSSION

From calculations, we were able to determine that the lesser the exit velocity, the more the cushioning effect on the hovercraft. Low-speed air coming out of the air outlet hole means greater time for the air to be retained below the skirt; leading to greater cushioning.

Power calculations show that our hovercraft can possibly be lifted by a 6 HP engine, assuming a payload of 130 kg. As the thrust for the hovercraft also comes from this engine and also considering losses from an old engine, we decided to raise the requirement bar up to 12-13 HP. This is the reason why we finally decided not to use the Kawasaki Boxer engine, but the engine of the more powerful Shogun instead.

By computational analysis and analytical calculations, we were able to determine the optimal position of air outlets which provides the maximum and optimal value of lift coefficient. This is the position where we placed the outlet holes of the skirt during fabrication and testing.

Propeller design was undertaken with utmost care. Existing propeller designs were analyzed, and the basic dimensions were decided accordingly. The propeller diameter was taken as 116 cm and a low pitch angle of 18 degrees was chosen. The two-bladed design was considered by taking into account efficiency, cost-effectiveness, and power requirements.

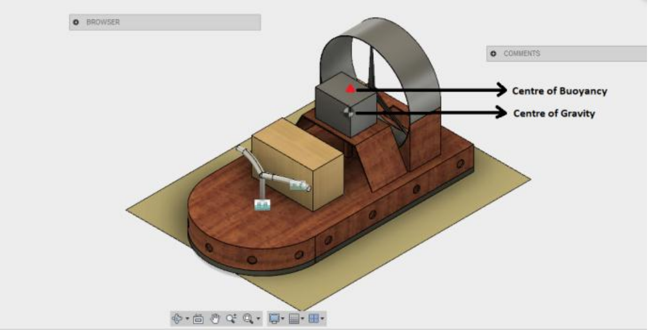

Fig -5: CAD model of the prototype showing the computed positions of the center of gravity (C_g) and the center of buoyancy (C_B)

We calculated the entire weight of the system, including all components, sub-components, and systems, and added to it the passenger weight to get the total design payload. The entire load needed to be carefully distributed about the hull of the hovercraft; for which we generated a CAD model of the design on the Autodesk Fusion 360 Workspace through which the values of the center of gravity (C_g) and center of buoyancy (C_B) were computed. This helped us design the hull of the hovercraft using stability calculations, which ensured that the vehicle would be stable during its forward motion and not slip.

Fig -6: Finished model of the working prototype

5. CONCLUSIONS

The concept of a hovercraft is very simple, but its actual construction and design is an arduous task. The calculations involved are complex and demand high-level accuracy. The weight was taken care to be evenly distributed and the center of gravity needed to be properly identified. The experience gained by doing this project gave us plenty of lessons to learn beyond the scope of a classroom. More importantly, it helped us understand a wide range of complex concepts and how to put them practically into everyday use. After fabrication, the prototype was subjected to plenty of tests and trial runs to ensure that no error went unnoticed to our attention. We designed and fabricated the hovercraft with a lot of design and budget constraints, and this was evident in the efficiency of the final prototype as well.

The project was completed within a total expense of USD 500 and was mostly fabricated using locally-available scrap material. We noticed that the fuel efficiency and range of the vehicle could be drastically improved if the skirt air pressure is sustained at constant levels for a prolonged duration of time with minimum losses in air leakages through L-joints of the hull structure. Plywood although cheap, added a lot of extra weight to the design, thereby requiring a trade-off in the design payload for the same engine and efficiency. Through air-flow simulations, we were able to understand aspects of the hull design that could be refined further (rounding/filleting sharp edges, re-designing the cowling area) to make the hovercraft more aerodynamic and therefore, more efficient.

In the next prototype development stage, we plan to improve the hull design with better ergonomics and aerodynamic considerations, using lighter and more durable composites like fiber-reinforced plastics for hull construction. The two-bladed low-pitch propeller was chosen during this stage of development to be the best option due to budget constraints, however; the improved prototype is planned using a costlier, but nevertheless, a more-efficient three-blade propeller design. Added features like a more responsive steering system and improved braking mechanism using drag are also being designed for the next stage.

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