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Development of a Integrated Air Cushioned Vehicle (Hovercraft)

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Abstract: *The design and development of a hovercraft prototype with full hovercraft basic functions is reported by taking into consideration, size, material and component availability and intermediate fabrication skill. In-depth research was carried out to determine the components of a hovercraft system and their basic functions and in particular its principle of operation. Detailed research in design was done to determine the size of component parts, quite in accordance with relevant standard requirements as applicable in the air cushioned vehicles (ACV). The fabrication of the designed hovercraft by using materials that are readily available by taking into consideration the economic constraints and time constraints. It also includes the testing process which includes the tweaking of various parameters that govern lift and thrust of the hovercraft. Further research is recommended to improve on the efficiency of the craft.*

Keywords: *Hover craft, air cushioned vehicle, hybrid vessel, hull, skirt, air box.*

I. Introduction

A hovercraft is a vehicle that hovers just above the ground, or over snow or water, by a cushion of air trapped under the body creating lift. Air propellers, water propellers, or water jets usually provide propulsion. This type of vehicle is known as air cushion vehicle(ACV).it is a craft capable of travelling over land, water or ice and other surfaces both at moderate speeds, and even it could hover at stationary condition. It operates by creating a cushion of high pressure air between the hull of the vessel and the surface below. Fig1 illustrates the operational principles and basic components of a typical hovercraft. Specifically for our hovercraft, has three main design groups: the lift, thrust, and steering systems. The arrangement of the hovercraft is similar to that shown in Fig 1

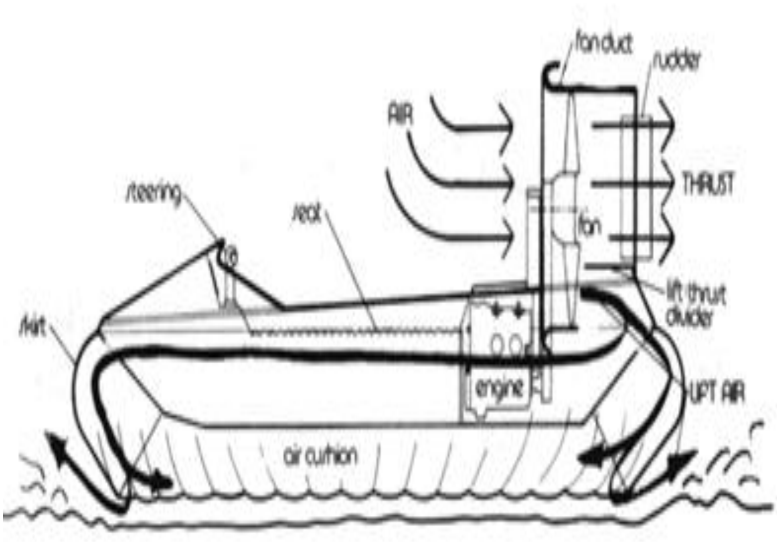

Fig 1: Air Cushioned Vehicle (Hover craft)

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 they typically hover at heights between 200mm and 600mm above any surface and can operate at speeds above 37km per hour. They can clean gradient up to 20 degree. Locations which 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 environment and terrain. In riverine areas, there is great need for a transport system that would be fast, efficient, safe and low in cost. Time is spent in transferring load from landed vehicle to a boat. With hovercraft there is no need for transfer of goods since it operates both on land and water. It is said to be faster than a boat of same specifications which makes it deliver service on time.

II. Principle Of Operation

The hovercraft floats above the ground surface on a cushion of air supplied by the lift fan. The air cushion makes the hovercraft essentially frictionless. The hovercraft relies on a stable cushion of air to maintain sufficient lift. The air ejected from the propeller is separated by a horizontal divider into pressurized air utilized for the air cushion and momentum used for thrust. The weight distribution on top of the deck is arranged so that the air is distributed the air from the rear of the deck throughout the cushion volume in an approximately even fashion to provide the necessary support. The skirt extending below the deck provides containment, improves balance, and allows the craft to traverse more varied terrain. We maintain the rigidity of the skirt by filling the air-tight skirt with the same pressurized air diverted towards lift. The skirt inflates and the increasing air pressure acts on the base of the hull thereby pushing up (lifting) the unit. Small air gaps are left underneath the skirt prevent it from bursting and provide the cushion of air needed. A little effort on the hovercraft propels it in the direction of the push [7]. Steering effect is achieved by mounting rudders in the airflow from the blower or propeller. A change in direction of the rudders changes the direction of air flow thereby resulting in a change in direction of the vehicle. This is achieved by connecting wire cables and pulleys to a handle. When the handle is pushed it changes the direction of the rudders.

III. Conceptual Design

Integrated lift and thrust hovercraft

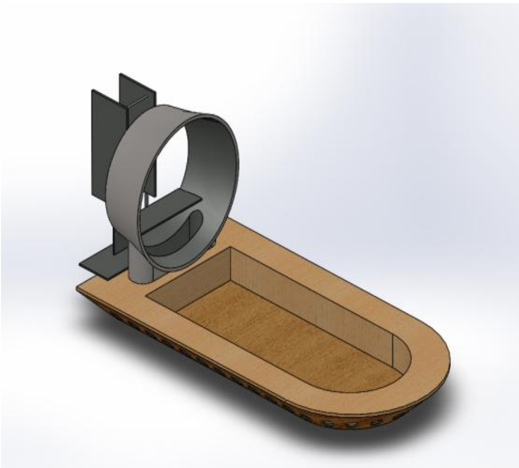

Fig2: Integrated Hover Craft

This design proposes an integrated system i.e. a single propeller is used for both the lift and thrust requirements. Here 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 will fulfil 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 as shown in Fig 2 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.

IV. Design Of Major Components

4.1 The hull, skirt calculations:

Our intention is to design a hovercraft for demonstration purpose. so a total weight of 200 kg is considered of this, 100 kg has been taken as passenger weight, and the remaining 100 kg as the hovercraft weight, which includes the weight of the base, the weight of the engine, impeller, shroud, the air box, steering mechanism, rudder system, the engine frame, the weight of the skirt, petrol tank etc.[3].

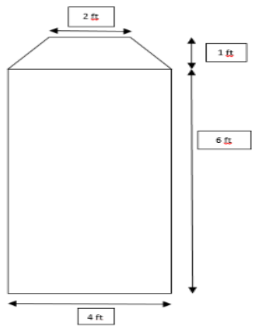

Fig3: Hull Dimensions

Total Weight = 200 kg
Length = 7 feet
Breadth = 4 feet
Area of Base, A = 28 sq.ft = 2.5 m^2
Cushion Pressure,

$$P_c = \frac{\text{Weight}}{\text{Areaofbase}} = \frac{200}{2.5} = 80\ \text{kg/m}^2$$
$$P_c = 80 \times 9.81 = 784.8\ \text{N/m}^2\ (\text{Pa})$$

Escape Velocity,

$$V_e = \sqrt{\frac{2 \times P_c}{\rho}} = \sqrt{\frac{2 \times 80}{1.16}} = 11.75\ \text{m/s}$$

Perimeter of Skirt
5.25 + 5.25 + 2.5 + 2.5 = 15.5 ft = 4.72 m
Hover Gap
50 cm = 0.05 m

4.2 Lift and thrust calculations
Escape Velocity,

$$V_e = \sqrt{\frac{2 \times P_c}{\rho}} = \sqrt{\frac{2 \times 80}{1.16}} = 11.75\ \text{m/s}$$

Perimeter of Skirt = 5.25 + 5.25 + 2.5 + 2.5 = 15.5 ft = 4.72 m
Hover Gap = 50 cm = 0.05 m
Escape Area, A_e = 4.72 x 0.05 m = 0.236 m^2
Volume of Air Lost = V_e x A_e = 11.75 x 0.236 = 2.773 m^3/s
This much volume of air is required to lift the hovercraft of the total airflow generated by the impeller, 33% is used to lift the hovercraft. This 33% corresponds to 2.773 m^3/s. So the total volume of air that must be generated is three times this quantity
Therefore,
Total Volume of Airflow required
3.33 x 2.773 = 9.23 m^3/s
Hence, we need to select an impeller that can provide us with pressure of 785 Pa and airflow of 9.23 m^3/s.

4.3 Splitter Area and Thrust Area

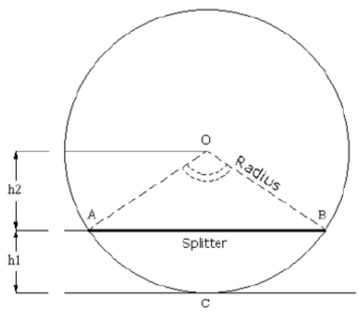

Fig 4: Splitter Area of Propeller

Area of the duct, $a_d = \frac{\pi}{4}\,(.9^2 - .2^2)$

$= 0.6048\ m^2$

For Splitter Height = 0.30 m

Splitter Area,

$$a_{sp} = \frac{1}{2}\,(\theta - \sin\theta\,)r^2\,, \qquad \theta = 140^0$$

$$a_{sp} = \frac{1}{2}\,\{(\left(140 \times \frac{\pi}{180}\right) - \sin 140\,) \times 0.45^2\,\}$$

$= 0.2419\ m^2$

Thrust Area, $a_{th} = a_d - a_{sp}$

$= 0.3629\ m^2$

Thrust Ratio = $\frac{a_{th}}{a_d} = \frac{0.3629}{0.6048} = 60.0\ \%$

Lift Ratio = $\frac{a_{sp}}{a_d} = \frac{0.2419}{0.6048} = 39.99\%$

4.4. Fan Selection

The selection of a suitable impeller is a relatively tough task. In an integrated hovercraft, the impeller is used to provide both, the lift as well as the thrust. Usually, industrial fans are used for this purpose. Some of the most important factors that need to be considered while selecting an impeller are the size of the impeller, the number of blades, the pitch angle of the blade, and the power required. The power source (in our case – engine) should be able to provide enough power to run the impeller at the required working conditions [6].

Formulae:

For a change in speed:

The Rotational Frequency Ratio

$$(k) = \frac{N_2\ \ (NewSpeed\ )}{N_1\ \ (OldSpeed\ )}$$

To change the parameters for the fan at the new speed we can apply the following laws,

Airflow (q), $q_2 = q_1 \times k$

Pressure (p), $p_2 = p_1 \times k^2$

Power (P), $P_2 = P_1 \times k^3$

In our case, we required a pressure of 785 Pa and airflow of $10m^3/s$. For selecting the fan we used sizing software called Multi-Wing Optimizer 7.0.1.144, provide by Multi-Wing India Pvt Ltd.

The specification of the impeller selected for our hovercraft is

900/3-6/31.5/PAG/5ZL

Breaking Down the Part Number Code:

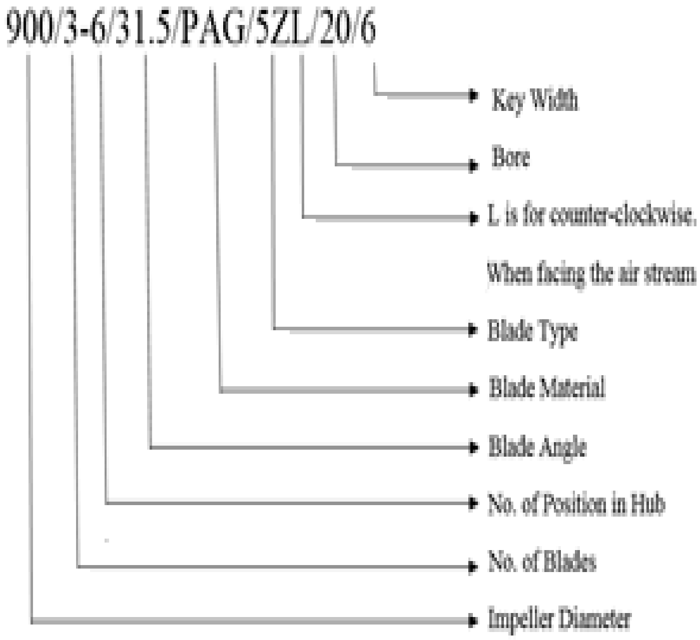

Fig 5: Breaking down the code

In the sizing software we input conditions such as Pressure required and airflow.

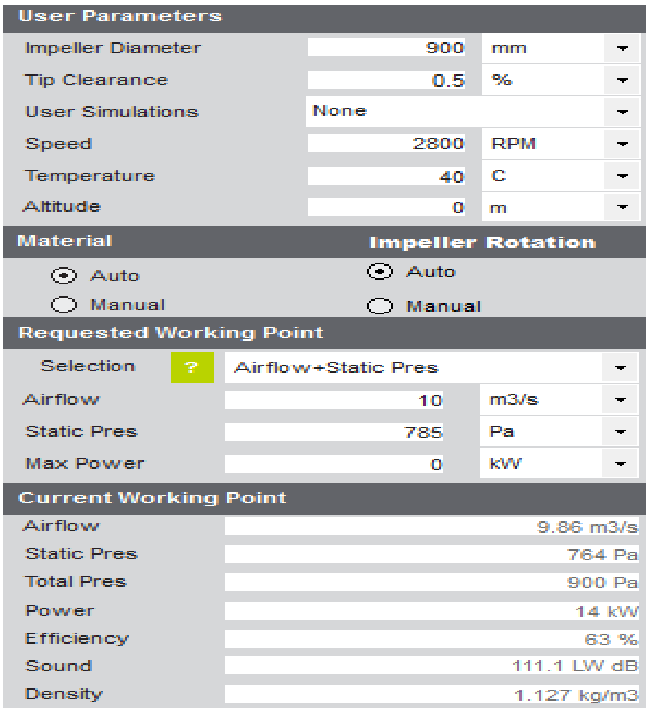

Fig 6: Sizing Software

Based on the data obtained from the calculation's the hovercraft has been modelled in the catia for understanding the 3-dimensonal design of how the hover craft looks like. The parts are modelled in individual workbenches and later on assembled.

Now the fabrication of the hovercraft (acv) is initiated. The materials availability according to the design is a big task.

V. Fabrication Of The Hover Craft

5.1 Hull:

Hull is made by sandwiching polystyrene sheets between plywood sheets; Industrial grade glue is used for this purpose. First plywood is cut according to the specifications given in Fig 7 glue is applied to a plywood sheet and 4 polystyrene sheets, and they are stuck together. Polystyrene sheets are kept horizontal to the plywood. Then another layer of polystyrene is adhered to the existing one to get required thickness, this time sheet are arranged vertical to plywood. Then another plywood sheet is adhered at the top. Prepared hull is kept under pressure overnight.

Fig 7: Hull

5.2 Air box:

We constructed two air boxes. One was of a height to divert 33% of the air driven by the propeller into the duct, and another one to divert 60% of the air. In the Fig 8 .First one was constructed by plywood of thickness 10mm and air tightened by applying fevicol glue at the edges. Second air box was constructed wooden pieces of 10mm thickness. Curved shape is cut in the wood, PVC sheet is fixed along the edges of the two curves with nails. Supports are provided at the base this makes the second air box. Both air boxes are used in the testing phase and appropriate one is selected.

Fig 8: Air Box

5.3. Skirt:

Skirt is kept along the craft and extra material is cut off. Both ends of useful part of skirt material is stitched so that it forms a loop. First, hole of 5mm are drilled along the hull, each 10 cm apart. Same is done on the aluminium sheets that are to be placed above the skirt so that it sticks to the hull completely. Skirt is held on the hull and holes are drilled at the same distance as before to match holes on the skirt, hull and aluminium sheets as shown in Fig 9. All three are fixed with the help of nuts and bolts. At the other end of the skirt is stitched so that a passage forms along the skirt, in which a rope is passed. Two ends of rope are tightened.

Fig 9: Skirt

5.4. Engine:

Engine mount is acquired from the scrap yard, we found that it does not support whole engine, but provides support to the base. Extra material of the mount is cut off to save the weight and to provide space for the new frame. New frame is constructed so as to support the upper part of the engine and hold two bearings that are kept parallel and aligned. Bearings house the shaft of diameter 25mm.diameter at one end of the shaft is reduced to 20 mm so as to fit into the fan hub. Manufacturer provided a 20 mm hole in the fan hub for the shaft to fit in, with a key of 6 mm. Shaft is also provided with the same dimension of key grove. Transmission consists of sprocket and chain arrangement. Sprocket is fixed on the shaft with Allen screws. Chain is fitted on the sprocket teeth and teeth on direct output of the engine. Bearing and frames so constructed that shaft is at the height of 475mm from the hull, or the centre of the duct. Washers are fitted so as not to leave the chain slack. Engine, engine mount, transmission assembly parts are fitted together to form power house assembly. This power house assembly is fixed on the hull 4 M10 bolts. To absorb the vibrations of the engine 4 rubber pads, 2 pads for each leg of the mount, of 8mm thickness are provided between engine mount base and hull.

Fig10: Engine Assembly

Fig 11: Final Assembly of the Hovercraft

VI. Result

The hovercraft was lifted and was propelled by the thrust system. It was able to carry one person of weight 75 kg and hovered with an air cushion of 70 mm .Manoeuvrability was achieved with the steering system.it covered a distance of 100 m in 20 sec which results in a speed just less than 20 km/hr.

VII. Conclusion

The concept of a hovercraft is very simple, but the actual construction of it is a tough task. The calculations involved are complex and they should be extremely accurate. The weight should be evenly distributed and the centre of gravity should be properly identified. The experience gained by doing this project taught us a lot about many things. It helped us understand a lot of concepts and saw those concepts put to use. After the hovercraft was built, a lot of testing and tweaking was required to make it work. All the testing and tweaking actually tested our patience and dedication towards the project. After days of up's and down's, the hovercraft finally hovered and was working fine.

VIII. Future Scope

The intension is to understand the basic principle of a hovercraft and to fabricate the same keeping the constraints such as monetary constraints, time constraints etc., in mind. The hovercraft attempted was a primitive one and as many aspect that needs to be optimized in the future such as

- Vibration and noise reduction
- Minimization of fuel consumption, etc.

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