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Design and Development of Semi-Autonomous Amphibious Rover

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Abstract: An amphibiousRover (orsimply amphibian), isa vehicle that is a means of transport, viable on land as well as on water. It is made such thatit can work on both land as well as on water by simply providing it with a waterproof hull or raft skirt and perhaps a propeller. Design is made like an army tank on inventor software by using certain set of parameter such as load to be handled, dimension constraint, speed etc. Design of each and every component such as main chassis, motor, shock absorber, propeller etc. and the analysis of the same are done using AutoDesk inventor software. Fabrication of chassis and assembly of various components is done is shown in subsequent section below and analysis is also done. Alternative of hull is that floating body will be made up of inflatable cylindrical rafts which help the rover to ride inwater. Rover will have two motors which will be controlled by H-bridge method via wireless transmission for manual control using arduino. Jet drive inspired by hamilton jet drive is fabricated to propel the rover in water and it is fixed in extreme face of hull body.

Keywords*: Design, Control, Amphibian, Manned rover*

I. INTRODUCTION

Usually in older times rovers are built to run on ground and they are very helpful for humans to accept various challenges such as saving people due to natural disaster, in military, for surveillance purpose etc. But this kind of rover will not be useful underwater. Therefore it is necessary to use basic theories to design a rover which can run both on land as well as on water. We have built an amphibious rover which can go on water surface to clean any garbage or debris, used as life guard on beaches or in military application for surveillance purpose.Amphibious rover is derived from an amphibious cycle is a human-powered vehicle capable of operation on both land and water. Bicycle uses four rectangular air filled floats for buoyancy and is propelled using two fan blades which are attached to the spokes.

We have build an electromechanical arm which can be used to pick and place objects on land as well as in water. The rover is controlled control semi-autonomously by using GPS. We had use APM v2.6 microcontroller to fulfill this challenge which has integrated environment. The Add-ons such as heat Sensing Camera, Close Circuit Camera, are also added.

II. DESIGN OF VARIOUS PARTS

the objective is to achieve a compact design so entire C.G. of the model should be balance precisely. Alteration in position of the motor and gearbox assembly, suspension assembly and tensioned mechanism lead to the most compact design as per the dimension of the available peripherals such as motors, suspension system and gear box. Further the torque required to drive the pulley is calculated..Design of various parts is done on Autodesk Inventor. Specification of motor shown below is 250 watts 2750 rpm having 0.70 N-m of torque capacity.

Fig-1: MOTOR ASSEMBLY

This torque available is much less to drive the entire rover in addition to the payload to be carried. It is must to increase the torque on expense of speed so that rover can work smoothly in addition to payload.

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Therefore, we had used gearbox of gear ratio 1:30 to achieve this, by accomplishing this torque obtain is 21.23 N-m which is sufficient. Gearbox model is shown in the figure 2 below.

Fig-2: GEARBOX ASSEMBLY

The suspension system need to be designed congruously so that it can absorbs the shock from the supporting wheels evenly. Suspension model is shown in the figure 3 below.

Fig-3: SUSPENSION ASSEMBLY

After modelling of peripherals, modelling of main chassis is dominant. A chassis consists of an internal vehicleframe that supports a artificial object in its construction and use, can also provide protection for some internal parts. An example of a chassis is the under part of a motor vehicle, consisting of the frame (on which the body is mounted). mild carbon steel material is selected having concentric square section area which has high bending stress and can protect the entire peripherals inside it. Carbon steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.12–2.0%.

Main chassis should be strong enough to bear high compressive as well as bending stresses while in operation

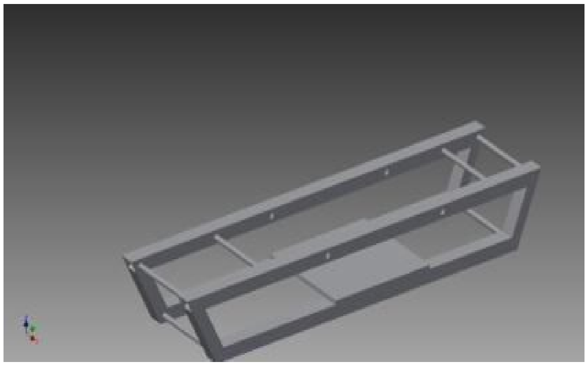

Fig-4: 3D VIEW OF MAIN CHASSIS

We selected the pulley to transmit the power from gearbox to caterpillar track. The material used for pulleys is nylon having high wear resistance. The pulley model is shown in fig-5 below.

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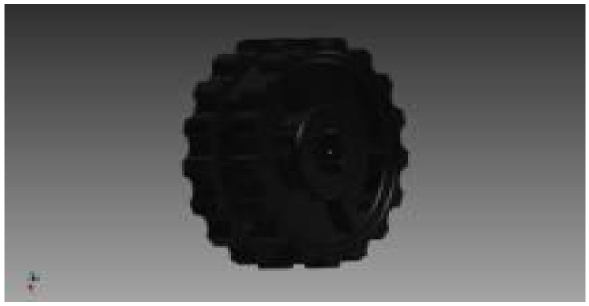

Fig-5: 3D VIEW OF PULLEY

After modelling all the peripherals, it's time to assemble all the components to get the final assembly. After assembly we will get the physical appearance of the model on computer before actual fabrication. Therefore, any changes can be done easily if it's to be done. One side of caterpillar track can withstand a load of 100kg easily. The final assembly of main chassis is shown in fig-6 below.

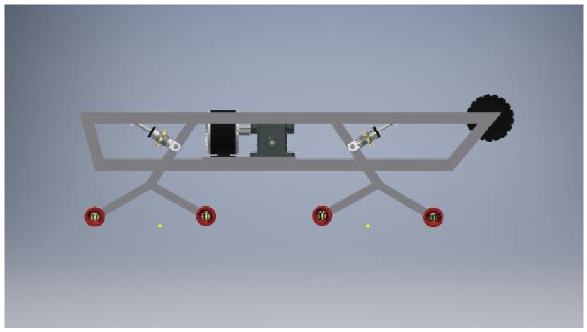

Fig-6: FINAL ASSEMBLY SIDE VIEW

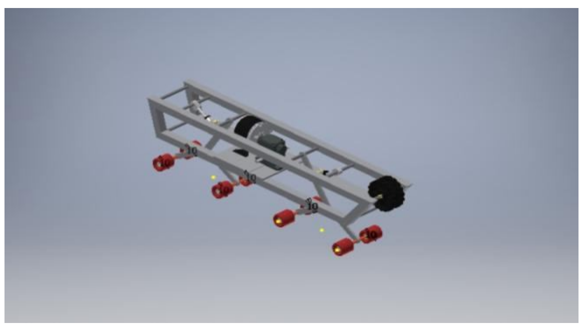

Fig-7: CATERPILLAR CHASSIS ISO VIEW

After modelling caterpillar chassis, next step is to assemble both caterpillar chassis by means of square pipe in between them as shown in below fig-8.

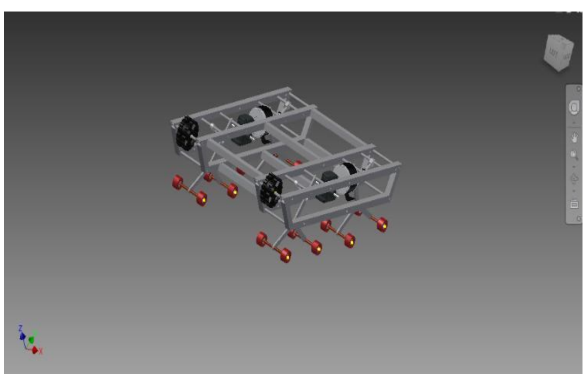

Fig-8: FINAL CATERPILLAR CHASSIS ASSEMBLY ISO VIEW

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Modelling is done as can be studied from above chapter and various peripherals components are designed. After designing and modeling all the parts and peripherals, fabrication is done. After assembling all the peripherals components result obtained is seen in below fig-9

Fig-9: VERITABLE VIEW

After getting basics design parameters of hull theoretically further design of a 3D hull on Autodesk Inventor is executed. Fig-10 below show a 3D model of hull.

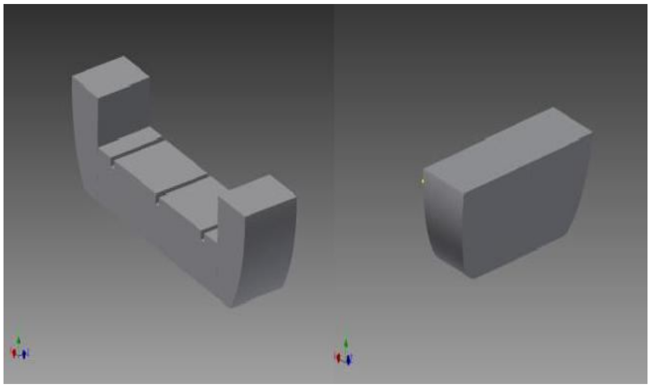

Fig-10: ISO VIEW OF HULL

After designing chassis and hull, assembly of hull with chassis is done which can be seen in below figure 11.

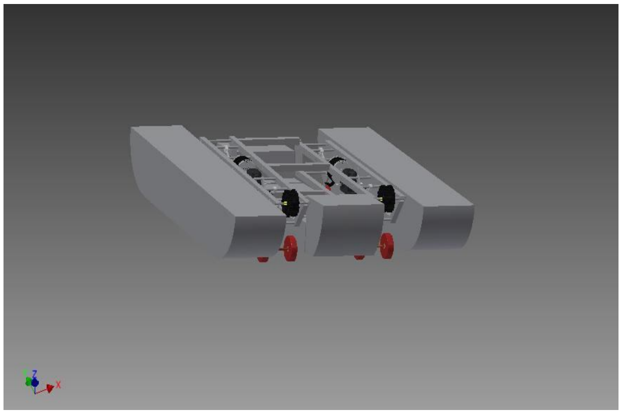

Fig-11: CHASSIS WITH HULL

Later on, we had designed jet drive inspired by Hamilton jet drive. Based on market condition we did reverse engineering is done to in order to obtained the efficiency of the jet drive and axial thrust too. In further chapter 4 calculation is shown. Based on the peripherals components available after market survey, modelling is done on inventor which can be seen in below fig-12.

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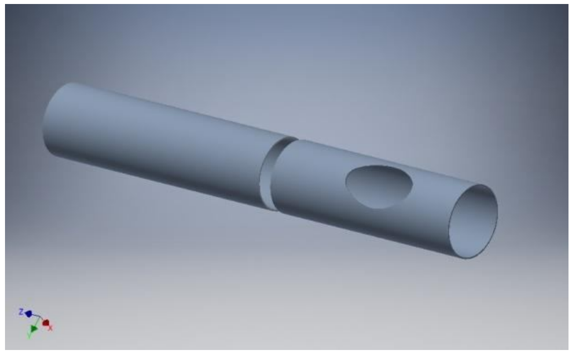

Fig-12: PVC PIPE OF JET DRIVE

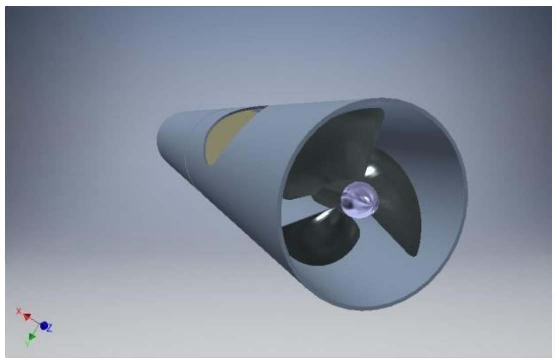

Fig-13: ISO VIEW OF JET DRIVE

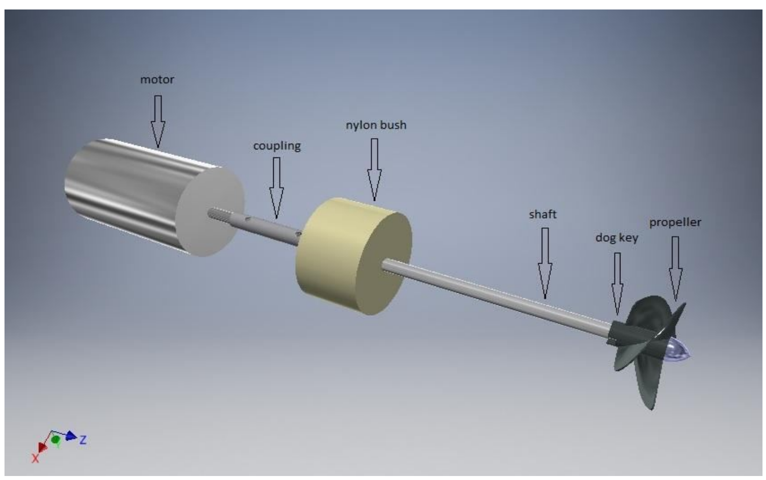

Fig-14: PARTS AND ASSEMBLY OF JET DRIVE

A. *Calculation*

1) Finding torque at output shaft of gearbox for a given motor:

Finding torque at output shaft Motor specification: E-bike Power=200 watt, N_1=2750 rpm

Torque developed is given by,

$$T_1 = \frac{60P}{2\pi N_1} = \frac{60\times200}{2\times3.14\times2750} = 0.707 \text{ N-m.}$$

We had use gear box to get output torque more

Gear ratio= I =30

$N_2=\frac{2750}{30}$= 91.66 RPM

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Now, torque available for this rpm

$$T_2 = \frac{60P}{2\pi N_2} = \frac{60\times200}{2\times3.14\times91.66} = 21.238 \text{ N-m.}$$

This much is the torque available at output shaft which is must **sufficient.**

B. Analysis of chassis

Software analysis and design includes all activities, which help the transformation of requirement specification into implementation. Requirement specifications specify all functional and non-functional expectations from the software. These requirement specifications come in the shape of human readable and understandable documents, to which a computer has nothing to do.

In addition to modeling the processes, structured analysis includes data organization and structure, relational database design, and user interface issues. Structured analysis uses a series of phases, called the systems development life cycle (SDLC) to plan, analyze, design, implement, and support an information system.

After designing all the parts and assembling all them, it is necessary to analyze the design for stress and strain. Application of 50kg of load is done on one side of caterpillar track and it was found that design is appreciably safe. The result obtained is shown in figure 11 below

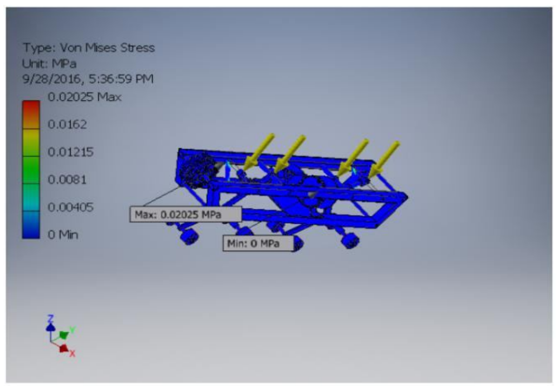


Fig-15: ANALYSIS OF CHASSIS

III. CHAPTER 4:- DESIGN SECTION OF AMPHIBIOUS PART

A. Terminology of hull

The hull is the watertight body of a ship or boat. Above the hull are the superstructure and/or deckhouse, where present. The line where the hull meets the water surface is called the waterline represented by 'w' in fig below.

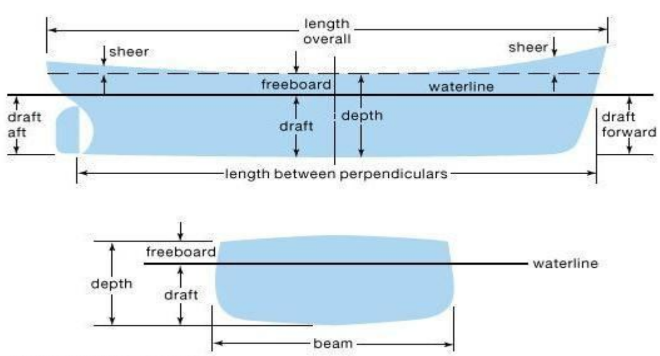
In order to understand the calculation of hull one should know the basics terminology of ships and plimsoll load line for maximum loading condition in different density of water.

1) *Terminology of ship:* The following are the standard terms used to describe the hull of the ship before it is put in the water. This few terms are basic and are as follow refer figure 11:-

a) *Depth* **-** Depth is the height of the hull from its highestpoint from its main deck to its lowest point.

b) *Beam* **-**It's width of hull at its widest point.

c) *Waterline* **-** It is the intersection of the surface of thewater ship is floating in with the sides of ship hull.



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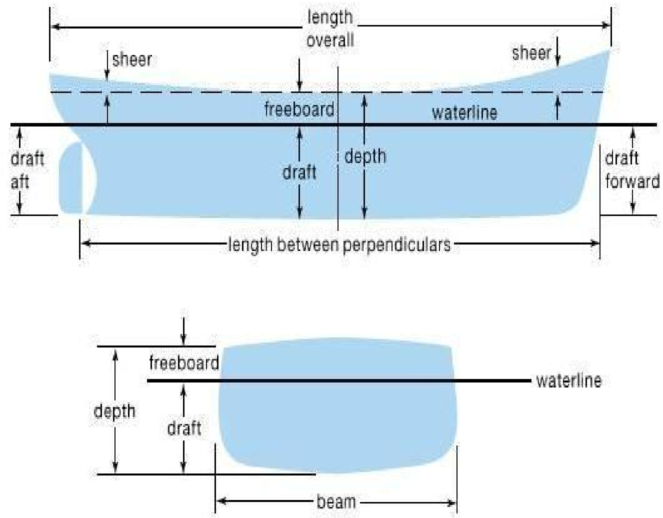

Fig-16: BASIC TERMS OF HULL

d) *Keel* - Keel is the principal structural member of a shiprunning lengthwise along the centre line from bow to stern to which the ship frame are attached.
e) *Draft* –It is the vertical distance between sea waterline and the keel of the hull i.e. vertical distance of the surface of hull under sea waterline.
f) *Forward perpendicular (FP)* - It is a vertical linedrawn at the intersection of the design waterline and the foreside of the stern of the hull.
g) *After perpendicular (AP)* - It is a vertical line drawn at the intersection of the design waterline and the aftermost point of the hull. For most commercial ship it is the point where generally rudder is located.
2) Design of Semi-Autonomous Amphibious Rover
a) *Midship*- It is the horizontal distance halfway betweenFP and AP.
b) *Length between perpendiculars (LBP)* - It is the totalhorizontal distance between the two perpendiculars i.e. AP and FP.
c) *Length overall (LOA)* - It is the total length of theship at its longest point.
d) *Freeboard* – It is the vertical distance which is freefrom water above sea waterline.
3) *Design of hull*

To design a hull it is necessary to find various factors which is important

Length/beam ratio, L_{BR}

$$L_{BR} = \frac{L_{WL}}{B_{WL}}$$

i.e. Length of Beam waterline $B_{WL} = \frac{L_{WL}}{L_{BR}}$

Take $B_{WL} = 0.225m = 22.50cm$

$$L_{BR} = \frac{1.20}{0.225}$$

= 5.33

Now, beam/draft ratio BTR effects on the resistance of boat

$B_{TR} = \frac{B_{WL}}{T_C}$, Taking $B_{TR} = 2.2$

Draft, $T_C = \frac{B_{WL}}{B_{TR}} = \frac{0.225}{2.2}$ =.1022m =10.22cm

Mid-ship co-efficient, $C_M = \frac{A_M}{T_C B_{WL}}$

Assume, $C_M = 0.785$, $C_p = 0.59, C_w = 0.70$

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Loaded displacement in KGs is

$M_{LDC} = 2 B_{WL} L_{WL} C_p T_C C_M 1025\ kg/m^3$ =2×0.225×1.20×0.59×0.102×0.785×1025

=26.217 kg/m^3.

B. Alternate of hull (Inflatable raft skirt)

An inflatable boat is a lightweight boat constructed with its sides and bow made of flexible tubes containing pressurized gas. For smaller boats, the floor and hull is often flexible, while for boats longer than 3 meters (9.8 ft), the floor typically consists of three to five rigid plywood or aluminumsheets fixed between the tubes, but not joined rigidly together. Often the transom is rigid, providing a location and structure for mounting an outboard motor.

Some inflatable boats have been designed to be disassembled and packed into a small volume, so that they can be easily stored and transported to water when needed. The boat, when inflated, is kept rigid crossways by a foldable removable thwart. This feature allows such boats to be used as life rafts for larger boats or aircraft, and for travel or recreational purposes.

The most common term for inflatable boats is "rubber boat" although rubber is usually no longer used in their construction. Other terms used include "inflatable dinghy", "rubber dinghy", "inflatable", "inflatable rescue boat", and "rubber duck".

A raft is any flat structure for support or transportation over water. It is the most basic of boat design, characterized by the absence of a hull. Although there are cross-over boat types that blur this definition, rafts are usually kept afloat by using any combination of buoyant materials such as wood, sealed barrels, or inflated air chambers (such as pontoons), and are typically not propelled by an engine.

C. Understanding the concept of buoyancy

In order to make rover float we need to displace amount of water equal to its weight, according to Archimedes principle.

Archimedes' principle describes the relationship between the buoyant force and the volume of the displaced fluid, but also the density of the displaced fluid i.e. Buoyancy = weight of displaced fluid.

We can write this principle in equation form as:

FB = ρ×V×g.

Where FB is the buoyant force, ρ is the density of the displaced fluid, V is the volume of the displaced fluid, and g is the acceleration due to gravity. It's very important to remember that the density and volume in

Design of Semi-Autonomous Amphibious Rover this equation refer to the displaced fluid, NOT the object submerged in it.

This equation is helpful because you can use it to determine the buoyant force on an object. For example, say you submerge an object in water and find that the object displaces 1.0 cubic meter of water. Water has a density of 1.0 kg/m^3, so now we have everything we need to determine the buoyant force acting on the submerged object because we have the volume and density of the displaced fluid. Consequently, we also have the volume of the object because this is the same volume as that of the displaced fluid.

To calculate the buoyant force, simply plug in the numbers. Now our equation reads: FB = 1000 kg/m^3 × 1000m^3 × 9.8 m/s^2. Once we do the Calculation, we find that the buoyant force equals 9.8 kg-m/s^2, which is the same as 9.8 Newton's.

If the weight of the object is more than 9.8 N, then the object will sink. If it is less than 9.8 N, the object will float. If it is equal to 9.8N then it will neither float nor sink.

D. Calculation of dimension of raft skirt

In order to calculate the dimension of raft skirt required, reverse engineering is essential.

Consider a total weight of rover in addition to extra payload is 140kgs. We need to displace a volume or weight of water corresponds to this weight in order to make rover float. As discuss in above section 4.2 that weight of the object should be less or equal to buoyancy force.

Let m=140kg, diameter of raft=0.35m i.e. radius=0.175m,

For floating, weight of body=weight of water displaced.

Weight in Newton = 140×10 = 1400N

Volume of water displaced= $\frac{weight\ of\ water\ displaced}{weight\ density\ of\ water}$

=

= 0.1428

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This much needs to be displaced in order to float the rover having weight 140kg in addition to extra payload.

Volume of water displaced by one raft

$= \frac{\text{weight of water displaced}}{\text{weight density of water}}$

=

= 0.0714

Let length of raft=1.5

Area ADCA= $\frac{\text{volume by one raft}}{\text{length of raft}}$

$= \frac{0.0714}{1.5}$ = 0.0476 m^2

This much is the area occupied to displace 0.0714 cubic meter of water by one raft

But area ADCA= area ADCDA + area of triangle ADC

$$= \pi r^2 \left[\frac{360-2\theta}{360}\right] + \frac{1}{2} 2r^2 \cos\theta \sin\theta$$

$$\theta = 90.94 \approx 90^\circ$$

0.0476= $(\pi \times 0.175^2)\left[\frac{360-2\theta}{360}\right] + 0.175^2 \cos\theta \sin\theta$ We get

Now draft length h,

h=r + r

=0.175 + (1.175 $\cos 90$)

=0.175 m =17.5 cm

It means that raft will have draft length of 0.175 m below sea water line or water line having load of 140kgs.

It means half of the portion of raft i.e. semicircular cross section of raft will be in water and rest will be above the water line.

If the load on the rover increases for same raft design then draft length will also increase and if load is less than 140kgs then draft length will be in between 0.175m depending upon magnitude of load.

E. Design of jet drive

1) *Construction and working of jet drive:* A water jet generates propulsive thrust from the reaction created when water is forced in a rearward direction. It works in relation to Newton's Third Law of Motion – "every action has an equal and opposite Design of Semi-Autonomous Amphibious Rover reaction". A good example of this is the recoil felt on the shoulder when firing a rifle or the thrust felt when holding a powerful fire hose. Put simply, the discharge of a high velocity jet stream generates a reaction force in the opposite direction, which is transferred through the body of the jet unit to the craft's hull, propelling it forward

IV. CONSTRUCTION

The design shown above consist of two compartment

A. Motor compartment

It consists of motor and coupling which has to be isolated from water outside the jet body. A nylon bush is made of required dimension to isolate or separate the two compartments as it is very important because we don't want water to enter into motor compartment. We used speb 7 a liquid solvent to stick and provide transition fit the nylon bush to the PVC pipe. Thus, separating the two compartments. On other end of motor compartments we did the same. We had wrapped and stick leather on motor body so that it provide the necessary damping action in operating condition.

B. Shaft compartment.

It consist of propeller shaft, propeller (rotor) and stator (not installed in our case). The propeller shaft has key on which the propeller is fitted. Finally this compartment is fitted on nylon bush with motor compartment. Nylon bush separate the two compartments and there is a hole in center through which propeller shaft passes from motor compartment to propeller compartment. It doesn't allow any leakages from propeller to motor compartment and prevent mechanical vibration of propeller too.

1) *Working of jet drive:* In a single hull (a hull at an extreme side) the jet unit is mounted inboard in the both after and forward perpendicular section. Water enters the jet unit intake on the bottom of the boat, at boat speed, and is accelerated through the jet unit and discharged through the nozzle (not shown in this case) at a high velocity. The picture above shows where water

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enters the jet unit via the Intake. The pumping unit, which includes the propeller and Stator (not installed in this case), increases the pressure, of the flow. This high pressure flow is discharged at the nozzle as a high velocity jet stream. The motor shaft which is drive shaft attached to the propeller shaft by means of coupling to turn the propeller. Steering is achieved by driving the two jet motors in cross i.e. motor placed in front of right side of hull should start and motor place in back of left side of hull should start and vice versa. By doing this we rover will turn right and left taking axially turn. Reverse is achieved by starting two motors placed in front of either side of hulls. Thus, reversing of rover takes place.

2) *Specification of water jet components*

a) *Motor:* 24v 5amp 5000rpm
b) *Coupling:* 30mm length 60 mm hole
c) *Propeller:* 2" Rotating Diameter: 47mm / 1. 9";
d) *Pitch:* 40mm /1, inlet angle= 75 deg, outlet angle= 20deg.
e) *Pvc pipe:* 50mm outer diameter
f) *Shaft:* 60mm outer diameter

3) *Calculation of jet drive:* esign of Semi-Autonomous Amphibious Rover

Power of motor, P_1 = 60 watts
N = 1500 rpm
Diameter of PVC pipe (D) = 0.050m
Area of PVC pipe (A) = 0.0019625
Diameter of blade at inlet ( ) = 0.0025m
Diameter of blade at outlet ( ) = 0.0036m
Inlet blade angle ( ) = 68˚
Outlet blade angle (β_2) = 55˚
Width of blade at outlet, $B_2 = 0.0003m$

$U_1 = \frac{\pi \times D_1 \times N}{60} = \frac{\pi \times 0.0025 \times 1500}{60}$ = 1.96 $m/s \approx 2\, m/s$

$U_2 = \frac{\pi \times D_2 \times N}{60} = \frac{\pi \times 0.0036 \times 1500}{60}$ = 2.826 m/s From outlet velocity triangle,

$\cos(\beta_2) = \frac{U_2}{V_{r2}}$, $V_{r2} = \frac{2.826}{\cos(55)}$ = 4.92 m/s

$V_{r2}{}^2 = U_2{}^2 + V_{f2}{}^2$

$4.92^2 = 2.826^2 + V_{f2}{}^2$

$V_{f2} = 4\ m/s$

We had assumed the flow is axial

$V_{f2} = V_{f1} = V_2$

From inlet velocity triangle,

$\sin(\beta_1) = \frac{U_2}{V_{r1}}$, $V_{r1} = \frac{2.826}{\sin(68)}$ = 4.34 m/s

$V_{r1}{}^2 = V_{f1}{}^2 + x_1{}^2$

$4.34^2 = 4^2 + x_1{}^2$

$x_1 = 1.628\ m/s$

$V_{w2} = U_1 - x_1$

$V_{w2} = 2 - 1.628$

$V_{w2} = 0.372\, m/s$

$\tan(\alpha) = \frac{V_{f1}}{V_{w2}} =$

α = 84.72˚

$V_1^2 = V_{f1}^2 + V_{w2}^2 = 4^2 + 0.372^2$

V_1 = 4.5 m/s

Discharge at outlet,

= A× ×

Q_2 = 0.0019625×4× 0.0003

$Q_2 = 2.355 \times 10^{-6}\ m3/s$

$Q_2 = 2.355 \times 10^{-3}\ lit/s$

Now, axial thrust is given by

F = $\rho A V^2$

F = $\frac{1000 \times 0.0019625 \times 4^2}{4}$ = 31.4 Newton

Efficiency of jet drive is given by Rover velocity in water, U = 1.5 m/s $\eta = \frac{U \times F}{P} = \frac{1.5 \times 31.4}{60}$ η = 0.785

Efficiency of jet drive calculated is 0.785.

V. CONCLUSION AND FUTURE SCOPE

By gingerly studying the above chapters, one can easily get the rough knowledge on Amphibious Rover and can design their own chassis and ship hull or inflatable raft skirt depending upon their circumstances and requirements. The motive of the paper was to deliver how Amphibious Rover works, principles, methodology, selection of amphibious part and engineering behind it. Calculation done in above chapter 4 for hull and as well for inflatable raft skirt is distinctive for the one who had to make their custom design deliberately.

A. *Future scope*

1) In future, anyone can adapt our design and overcome the difficulty of battery consumption.
2) Design of suspension system can be changed to provide more flexibility to the rover, because due to small diameter of supporting wheels suspension assembly is not much effective.
3) Controlling system can be improved in future and can be controlled using mobile via wifi or Bluetooth module or Xbee.
4) Design of track can be improved and custom design can be done because in our case we selected ready-made track which does not provide smooth operation as required. Design of Semi-Autonomous Amphibious Rover
5) Different hull design can be done to make rover run fast in water and by using jet drive system.
6) Fully electronics arm can be constructed so that it give better performance.
7) Overall size and weight can be compensated so that rover can work smoothly and efficiently.

B. *Due to some constraints our design has following Limitations:-*

1) E-bike motor used doesn't have gearbox which results in extra gearbox to increase the torque and occupying more space.
2) Ground clearance is very small and hence cannot be used as off road applications.
3) Speed of rover is small but on the other hand power is more.
4) Actuation of base arm of electromechanical arm is slow.
5) Motor of jet drive has low rpm, it requires high rpm motor.
6) Lots of mechanical vibration is present in jet system, which reduces the efficiency of jet.
7) In control, the whole system wobbled when transmitter is suddenly switched off.
8) Control system is complex.

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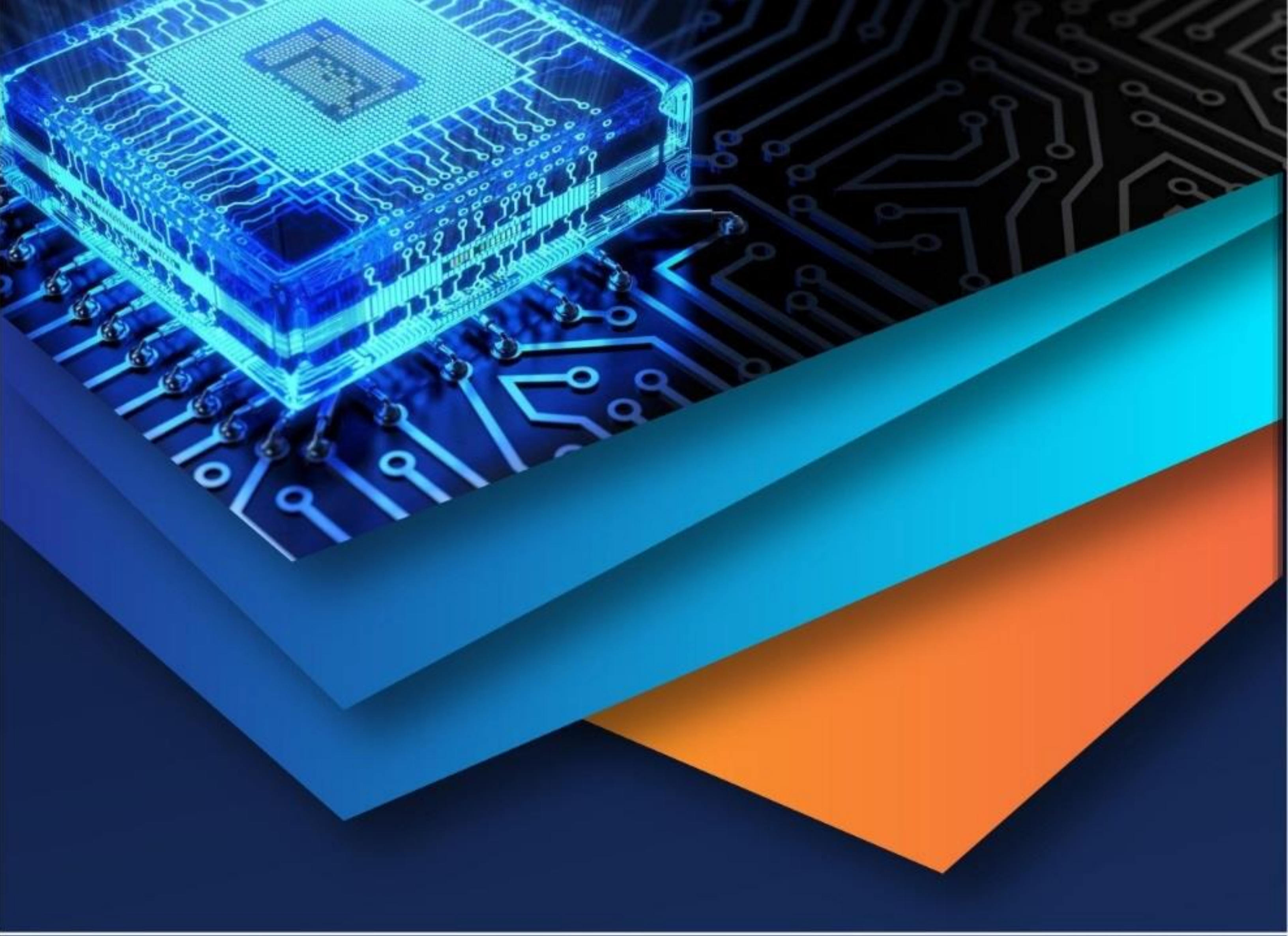

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