Concordia University

Final Project Report

Autonomous Hovercraft Design

ENGR 290 - Introductory Engineering Team Project

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I. ABSTRACT

The design and development of a simplified form of a physical hovercraft, in a team. for the ENGR 290 competition is described in this report. The purpose is for the hovercraft to finish a certain track that is constrained by various limits that must be adhered to during the competition. This report covers processes for generating ideas that include analysing the topic, brainstorming through conversation, and investigating through lecture materials, textbooks, and the internet. Three designs have been offered to meet the precise requirements. For each design, a model or prototype is created and then tested and evaluated using SWOT, WOT, AHP, and Matlab analysis. Based on the evaluation of the three designs, one final design is narrowed down. Reasons for changing design during the building of the hovercraft will be discussed.

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1.INTRODUCTION

A hovercraft can be considered as an air-cushion vehicle (ACV). The vehicle can transverse land, water, and some inclines up to 20%. It can be described as a flying plane, driving car and a floating boat in one vehicle. It hovers above ground from the air cushion produced underneath the vehicle. Hovercrafts have many advantages and disadvantages as well.

1.1 Document Purpose

The goal of this document is to show the specific requirements, needs and limits of our hovercraft for the competition. Along with the thought process used to come up with the best hovercraft design. The hovercraft design should be able to complete a given course autonomously, be able to lift off the floor and complete the course in less than 2 minutes.

1.2 Document Scope

The requirement needed for the hovercraft was described in the Engr290 hovercraft project documents. The document will narrow down 3 hovercraft designs to the best design out of the 3 designs the team came up with. It will test and analyse each design to pick the best design. Will demonstrate a timeline and progress chart of the team. The goal for the hovercraft is to use the least number of components while still being functional and quick.

1.3 Change Control and Update Procedures

During the actual building process of the hovercraft there may be slight adjustments or changes to the design to match what material and equipment are available to our team. The potential changes may be just a change of placement on the hovercraft. If any changes are needed or done it will be known in the final report and the reason for the change.

2.REQUIREMENTS

The following list highlights the requirements, in no particular order of importance, that will be used as guiding principles to conceptualise, simulate, prototype and implement our design.

2.1 Competition requirements

- Must complete the track in 2 minutes or less.
- Must be able to identify turns and take them.
- Must be able to identify the end of the track and stop when it reaches it.
- Must hover at a minimum of 3 mm above the obstacles on the track (from the ground).
- Must finish the track in 3 attempts.
- Must be able to fit inside the track, with enough headroom to manoeuvre (shown in Figure 1).

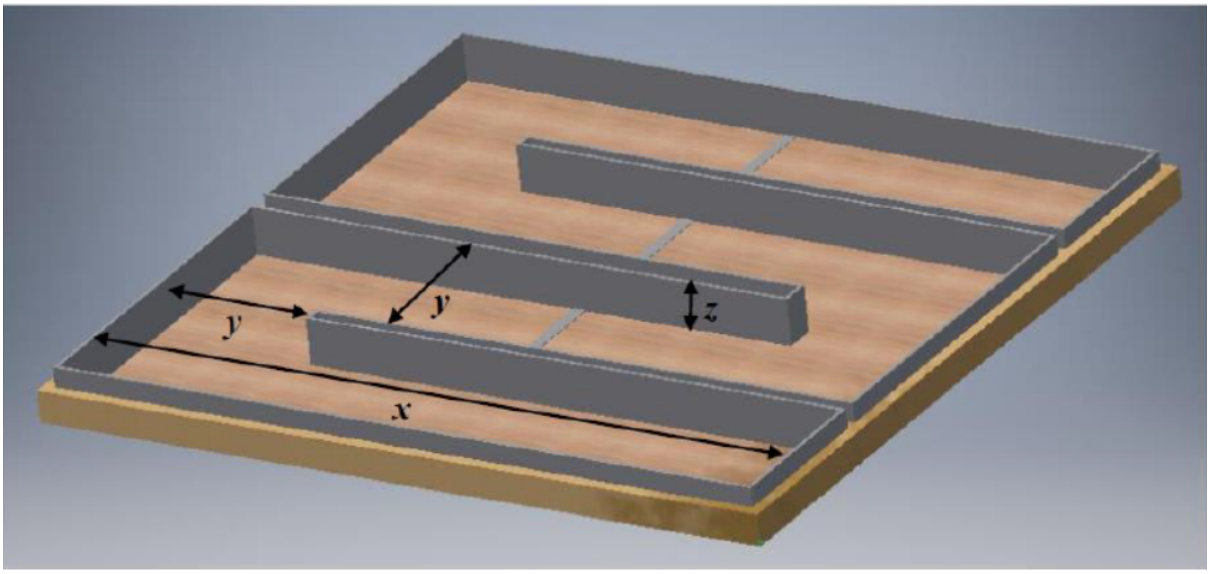
8 

Figure 1: Track of the hovercraft

2.2 Design requirements

- The front end shape of the hovercraft should be circular to facilitate going around corners.
- Have a width less than 50cm, preferably around 30 cm.
- Have a minimum of 3 designs
- We should analyse how each design moves and its operation to choose one design, using measurements and calculations.
- The 3 designs should be shown with the help of sketches and models
- The design should be original, and any inspiration should be shown.

2.3 Functional Requirements

Score = $d_{completed}$ /(N_c x t_{course})

Where:

- $d_{completed}$: Distance along the track that was successfully autonomously completed
- N_c: Number of components used. (Fans and servo)
- t_{course}: Time (in seconds) taken to complete the track (120s if not completed)

This formula is used to analyse the design we must get our score for the competition.

It is our goal to have a design with the highest score possible. To accomplish this, we want the longest distance travelled possible with the least number of components and the smallest time to complete the track. We have a total of 3 attempts to get the highest score possible. The time taken to travel the track is estimated for every design and taken into consideration when choosing the final design.

2.4 Design Constraints

- The designed hovercraft needs to support the primary loads of structure and sub systems for which a room for on-board components needs to be provided.
- Selection of batteries, to provide just enough energy to complete the track.
- Utilising the least number of sensors.
- Design should be balanced by measuring the dimensions of hovercraft with respect to Lift fans and thrust fans.
- Reducing the weight of hovercraft to ensure the lifting process by increasing the pressure inside the skirt.

In order to satisfy these constraints, the design process shown in 4.0 is considered

2.5 Specifications

- Must be able to navigate through specified tracks autonomously.
- Should use the least number of components possible.
- Must avoid collisions and should have the ability to get unstuck.
- Hover gap must be 3-5 mm to overcome the obstacles.
- Should be able to complete the track in under 45 seconds.

3.IDEAS AND RESEARCH

3.1 Ideas

After the first glance at the requirements listed in section 2.1, the factors of speed, turns, and obstacles stood out the most to us. Therefore, we shall endeavour to come up with a design that gives us a hovercraft which is fast, stable at and duration of making turns, and hovering at a minimum height of three millimetres above the ground.

The need of speed for our hovercraft implies that we must not hesitate in using the maximum number of forward-thrust factors; in this case, two fans, for creating the forward propulsion at a fast speed so that the time limit requirement is met. This then implies that we must find other ways to minimise the number of components. We did think about using three fans for propulsion and one fan for lift. But it became apparent to us that the hovercraft may become too heavy, with three forward propulsion and one lift fan, totalling in four fans altogether. This maximum number of fans would most likely mean using the most possible number of batteries. This 4-fan feature may result in a scenario where there may be a need for increased energy/power for fans. Then it became even clearer to us that increasing the number of fans to four would open the possibilities of increased energy usage, thus causing a more heated system which may impact the air pockets around the hovercraft, resulting in lower air intake for both the thrust and lift fans.

This discussion led us to another core concern of the design, which is limited by the amount of energy required by the hovercraft system. In this regard the choices are limited by the selection of batteries. This implies that we must choose a battery that will give the hovercraft enough power for enough length of time in order to complete the track. We must also make room for a scenario in which the hovercraft may need to readjust its course thus changing and increasing the energy requirements. Another factor we thought about was that we would need a battery that would not be forced to 'work too hard' to meet the minimum current/voltage requirements. We then gravitated towards the number of fans in total. We considered a hovercraft system with one fan, used for both lift and thrust. At first the single fan for the whole system leads to a higher score, but we reconsidered it and thought it would be not very practical. The reason is that the hovercraft would need to maintain a minimum height of three millimetres, while propelling forward. In any event where the height may be lowered or thrust may be affected, the hovercraft may not be able to regain the height. A single fan for the whole system would also include a difficult challenge of making it autonomous, and we would be forced to limit our design to a rudder based hovercraft. Because of this forced limit of a rudder based design only, we decided to abandon the idea of one fan for the hovercraft forever.

3.2 Research

Our research, lecture slides, watching YouTube videos, articles about hovercrafts in general etc., showed us a trend where we noticed that hovercraft with one lift fan, and two thrust fans seemed ideal for speed. Using two forward thrust fans meant that we would need two servos for the whole system, this would have increased the number of components unnecessarily. So we decided to not include servos and use two thrust fans as a steering mechanism by turning them off/on.

The shape of the hovercraft was actually the first factor we thought about. From researching real life hovercrafts, we noticed that a majority of the ones we saw were rectangular in shape with a rounded front edge. So we decided to opt for a design that is seen as operational in the real world. For our calculations, we kept the rectangular shape only without the front rounded edge for simplicity. We thought that we could build a simple rounded bumper for the front or carve it as a part of the whole depending on the stability of the actual prototype once we build it.

We thought of and immediately chose not to consider square shaped or circular shaped hovercrafts due to intuition. We felt that a square shaped hovercraft might not give us the area needed without jeopardising the space between the hovercraft itself and the maze walls/side rails. A circular shaped hovercraft leads us to believe that it might go out of control much easier and be caught in a spinning loop.

4.DESIGN SELECTION

4.1 The Hovercraft, preliminary designs

The hovercraft must function autonomously, and within two minutes, clear obstacles of three millimetres in height and complete a track of approximately 1090 cm in total length, including three sharp turns. From the initial starting point, traverse through x1-side track, make a sharp right turn, traverse through x2-side track and make a sharp left turn, traverse through x3-side track and make a sharp right turn, traverse through x4-side track and reach the end point.

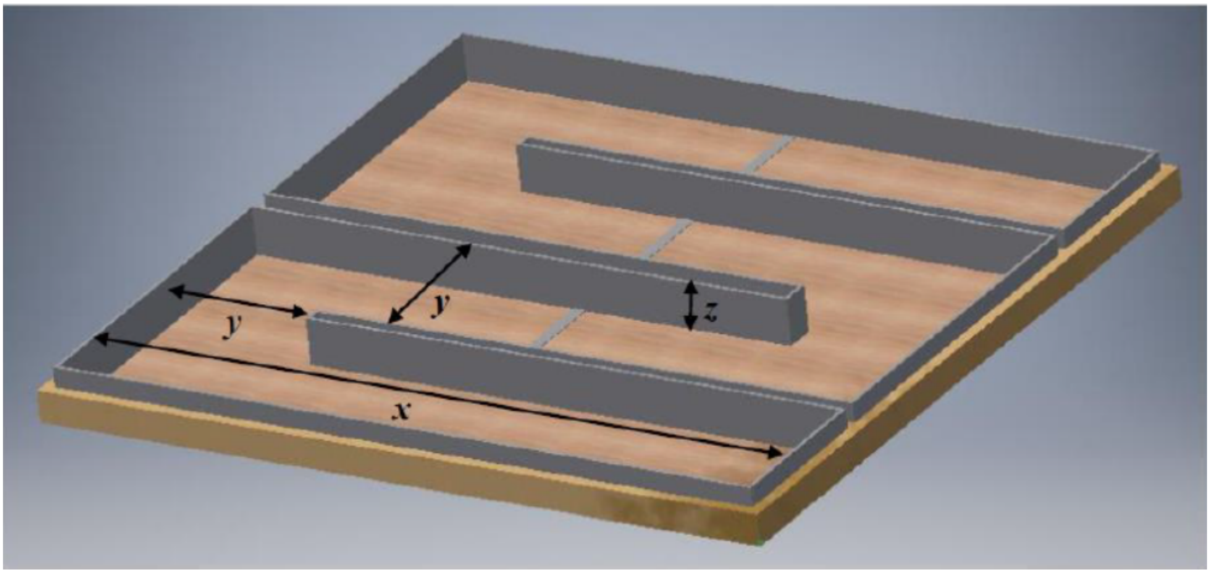


Figure 2: Schematic of the competition track

x: straightway segment length (wall-to-wall): 235 cm, (x1 = x2 = x3 = x4 = 235cm)

y: width of the track: 50-55 cm

z: height of the wall: 15 cm

A total of 235+235+235+235+50+50+50+50 = 1090cm length of track.

Achieve a high score based on the following formula where d is distance completed, Nc is the number of components and t is the elapsed time.

4.1.1 Functionality requirements

The hovercraft must have a vertical lift and the ability to move forward via propulsion fan/s and an autonomous control system. There are two types of fans available which can allow various types of designs depending on the number and types of selection, and installation locations on the hovercraft. For our project, we have decided to follow the idea of function over form, that is form follows function, and is subject to change depending on best and worst-case results of a functioning system.

4.1.2 Considerations

The main considerations for any design is its size, the manoeuvrability it provides, and the stability it has once the system is live (the system here being completely built hovercraft travelling autonomously through the maze). During the initial discussions, the group gravitated towards a rectangular design, proposing that a rectangular design would provide much needed space for all the components as well as a weight distribution system which will reduce instability. The main factor for the selection of a rectangular body is the nature of the centre of mass. The fans are heavy, and the designs need to be selected such that the weight is distributed evenly in such a way that the centre of mass is the centre of the hovercraft itself.

For the lift, the stronger, bigger fan is needed because it would need to provide enough power to support and lift the mass of the entire hovercraft. The smaller/lighter fan is then suitable enough for the thrust because once the hovercraft has lift, the power of thrust needed to move forward would be reduced due to reduced friction provided by the air cushion under the hovercraft body.

The whole system, the hovercraft, needs to be supplied with enough energy to complete the entire track, taking into consideration any needed course correction that may arise.

Following on from group discussions about system functionality, the selection was reduced to three designs in terms of lift and thrust, while taking into consideration pros and cons of front-wheel drive versus rear-wheel drive systems:

- Model 1: A rectangular Styrofoam body with rounded front, one 6.36W lift fan, one 5.5W thrust fan, one rudder mounted on and rotated by a servo, and with a skirt at the bottom of the hovercraft.
- Model 2: A rectangular Styrofoam body with round front, one 6.36W lift fan, two 5.5W thrust fans, no rudders, no servos, and with a skirt at the bottom of the hovercraft.
- Model 3: A rectangular Styrofoam body with a round front, one 6.36W lift fan, one 5.5W thrust fan mounted on and rotated by a servo for turns, and a skirt at the bottom of the craft.

The main consideration for all of these designs is the total area of the hovercraft. We have decided on a 0.40m by 0.30m rectangular design. This would give us a maximum of lifting force of:

(107.089N/m2) * (0.40m*0.30m) = 12.85068N of lifting force. Which would be enough for a lift even if we decide on the heaviest design with three fans, totalling in almost 825 grams of weight. The drawings are for a rectangular shaped hovercraft. This shape was kept to simplify preliminary calculations and ease of simulation. The final hovercraft design will have a rounded front end in order to ensure a smooth turn in the event that the hovercraft runs into the side walls/rails.

4.1.3 Fans

The MEC0251V1-000U-A99 (259-1470-ND) 5.5W, 162g, with a speed of 3100 RPM [1] will be used as the thrust/forward propulsion fan.

The AFB1212SH (603-1334-ND) 6.36W, 198g, with a speed of 3400 RPM [2] will be used as the lift fan. We decided to use this fan as the lift source because we foresee it installed right exactly on the centre of mass of the hovercraft. It made sense to us to use the heavier fan at the location of the centre of mass to increase overall system stability.

4.1.4 Servos:

Our initial online search showed that the HS-311 and HS-422 were highly favoured among the technicians, hobbying and prototyping community and other students. Also based on discussions with other students with experience with servos, we decided to narrow down our selection between HS-311 and HS-422. The WOT analysis for the servos shows that HS-422 would be a better choice for us..

4.2 Design 1

The first model is built using one 6.36W fan that weighs 162 grams, one 5.5W thrust fan, one servo upon which one rudder is installed, one IMU and two ultrasonic sensors, and one controller. This design features a rear-wheel drive hovercraft. We have decided that we shall be able to create a code that will give us accurate and precise readings, hence we shall have this hovercraft be able to make swift turns in order to prevent running into side-rails in case of a delayed turn. We have not yet built a prototype so we agreed that we shall assume that the code performance will outweigh the speed of turns. The diagram for this design is shown on the following pages, which was drawn using TinkerCad. This diagram is not to scale and does not show all of the components. The purpose of the drawing is to provide us with a general idea of what a hovercraft may look like.

For this design, the rudder is reinforced in the middle to prevent any chance of deformation in the middle area due to air pressure since the rudder is cut out of very light duty Styrofoam. This hovercraft will have a skirt installed at the bottom.

4.2.1 Components

Two qty of Gens 450mAh batteries (66g/0.6472N), one 6W fan(198g/1.9404N), one 5.5W fan (162g/1.5886N), one HS-422 servo(45g/0.441N), one controller including IMU/IR/ultrasonic sensors (40g/0.3922N), rudder (5g/0.04903N). Assuming the Styrofoam body will weigh around 5g/0.04903N.

Total Mass = 521g, Total Weight = 5.1092N.

As a rule of aerodynamics, if lift does not equal weight, the aircraft will climb or descend.

Lift force = air pressure * hovercraft body area = 107.089N/m2 * (0.40m*0.30m)= 12.85N

Force of Thrust T = 2*(ρ)*(A)*(V +v)*v

Thrust fan max air flow = 108.2CFM = 0.05106m^3/s [Link T1]

Thrust fan dimensions for flow: 120mm*120mm*25mm, in this case for airflow we use fan's area which is 120mm*120mm = 0.0144 m^2. Therefore air_velocity= volumeflow/area=(0.05106m^3/s)/(0.0144m^2) = 3.54583333 m/s.

Using the fluid mechanics equations:

F = 2*q*A*(Vinfinite+V)*V and F = air flow pressure * area

Mass_flow_rate = (ρ)*(A)*(V +v), where A is the propeller disk area [T2, Lecture 8].

At sea level and at 15 degrees C, the density of air is 1.225 kg/m3. This is the value of the ISA (International Standard Atmosphere, google.com)

So the Forward Thrust T: 2*Mass_flow_rate*velocity=2*(0.05106m^3/s)*(1.225kg/m^3)*(3.54583333 m/s) = 0.443573112N = 0.4436 N.

The hovercraft D1's acceleration is: F=ma => a=F/m = 0.4436/0.521=0.8514 m/s^2.

Air pressure = 0.28inchH2O = 7.111999mmH20=7.112mmH2O=69.7429N/m².

Rudder area expected to be: 13cm by 6cm. Maximum angle rudder should make is 45 degrees.

Torque_by_rudder_Design1 = air_pressure*rudder_area*sina*armlength*sinb=
69.7429*(0.13*0.06)*(sin45)*(0.40/2)(sin45)= 0.07877Nm.

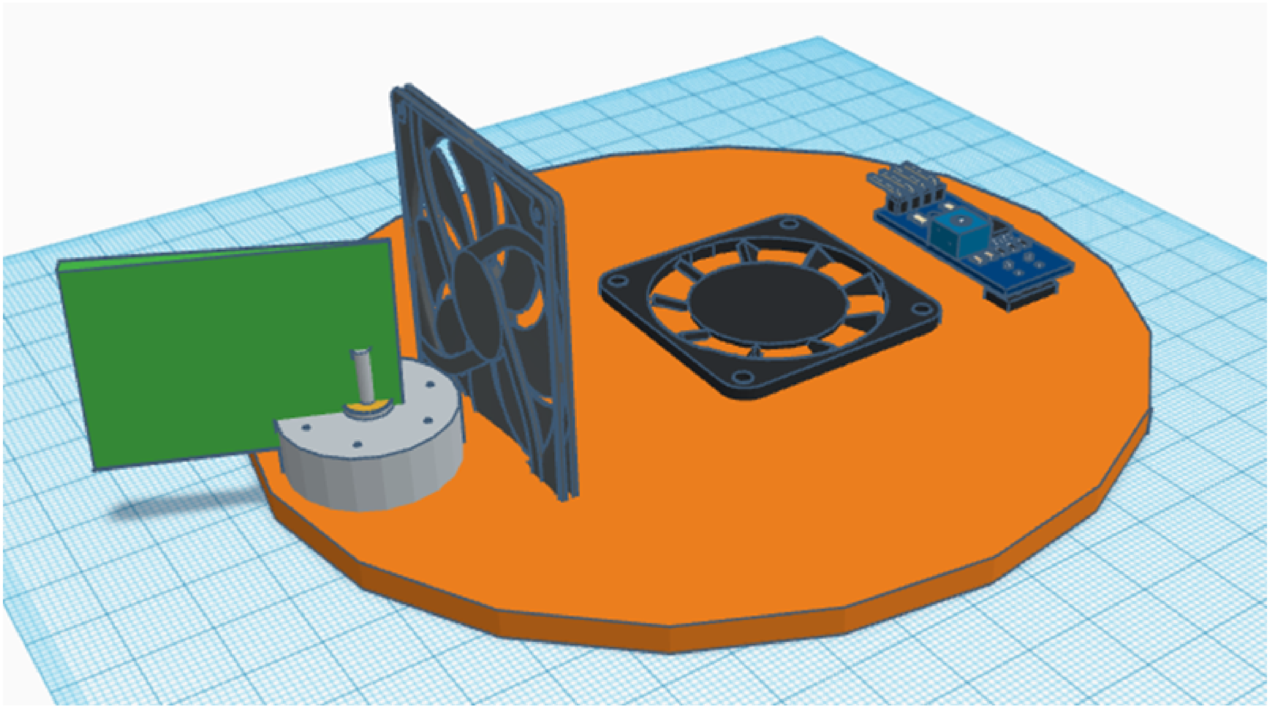


Figure 3: Design 1

As shown above, the total weight of the hovercraft would be 521 grams, and we would need a lift force of higher than 5.1092N in order to have the hovercraft lifted above the ground. We would need it to lift at least 3mm above the ground so that it would be able to overcome the highest obstacle. Once we have a working prototype, we plan on either increasing or decreasing the total area of the hovercraft in order to give us the maximum lift versus stability versus manoeuvrability value.

4.3 Design 2

The second model is built using one 6.36W lift fan, two 5.5W thrust fans, no rudders, no servos, with a skirt installed at the bottom. This design features two thrust fans that will be turned off one at a time in order to create turns. By taking inspiration from Assignment #1, and by using mental simulation and imagination, we have decided that this design will feature a middle-wheel drive as it were. That is to say, the thrust fans will be installed near the middle of the hovercraft on both sides. This, we hope, will give us an ideal balance between front-wheel and rear-wheel based turns. This design is the heaviest of all three and thus we hope it shall reach equilibrium after initial lift faster than the other two since the difference between the overall weight and the lift force is not that much.

4.3.1 Components

One 2200mAh Gravity 4S battery (258g/2.5284N), one 6W fan(198g/1.9404N), two qty of 5.5W (324g/3.1773N), one controller including IMU/IR/ultrasonic sensors (40g/0.3922N). Assuming the styrofoam body will weigh around 5g/0.04903N.

Total Mass = 825g, Total Weight = 8.090N.

Lift force = air pressure * hovercraft body area = 107.089N/m2 * (0.40m*0.30m)= 12.85N

Force of Thrust T = 2*(ρ)*(A)*(V +v)*v

Thrust fan max air flow = 108.2CFM = 0.05106m^3/s [Link T1]

Thrust fan dimensions for flow: 120mm*120mm*25mm, in this case for airflow we use fan's area which is 120mm*120mm = 0.0144 m^2. Therefore air_velocity= volumeflow/area=(0.05106m^3/s)/(0.0144m^2) = 3.54583333 m/s.

Using the fluid mechanics equations:

F = 2*q*A*(Vinfinite+V)*V and F = air flow pressure * area

Mass_flow_rate = (ρ)*(A)*(V +v), where A is the propeller disk area [T2, Lecture 8].

At sea level and at 15 degrees C, the density of air is 1.225 kg/m3. This is the value of the ISA (International Standard Atmosphere, google.com)

So the Forward Thrust T: 2*Mass_flow_rate*velocity=2*(0.05106m^3/s)*(1.225kg/m^3)*(3.54583333 m/s) = 0.443573112N = 0.4436 N.

Since this design has two thrust fans, the total thrust force is: 2 * Forward_Thrust_T = 2 * 0.4436= 0.8872N.

The hovercraft D2's acceleration is: F=ma => a=F/m = 0.8872/0.825=1.07239 m/s^2.

Air pressure = 0.28inchH2O = 7.111999mmH20=7.112mmH2O=69.7429N/m^2.

Torque_Design2 = Force * arm_length = 0.4436 * (0.15m) = 0.006654Nm since only one fan is on at the time of turning.

The total weight of this model is 825 grams, and therefore, we would need a total lift force larger than that of 8.090N. The lifting thrust shows that we would have 12.8506N which is larger than 8.090N, which means we will have a hovercraft able to lift above the ground.

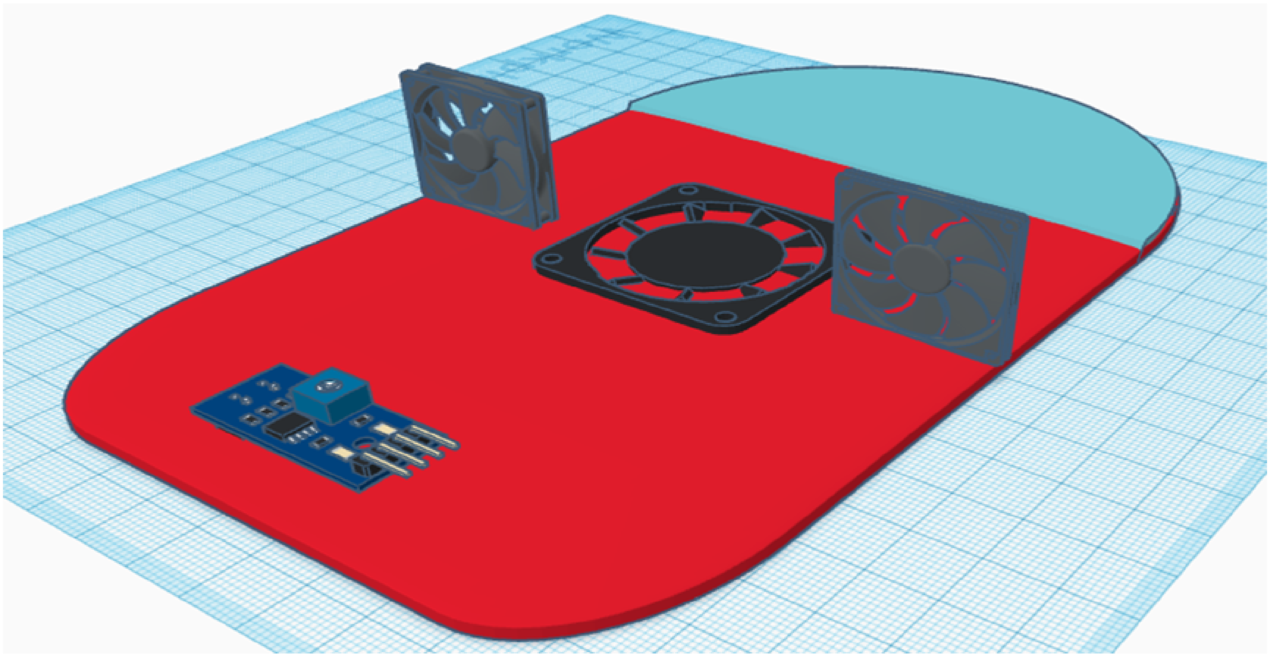


Figure 4: Design 2

4.4 Design 3

The third model is built using one 6.36W lift fan, one 5.5W thrust fan mounted on and rotated by a servo for turns. This model also features a rear-wheel drive. For this design, we opted to eliminate the need of a rudder by having the thrust fan turn in order to create turns. This is the lightest of all designs, but we feel that since the lift force is much greater than the overall weight of this design, the hovercraft may not remain stable while propulsion as well as life forces are acting on it. The following discussion gives a breakdown of some preliminary calculations.

4.4.1 Components

Two qty of Gens 450mAh (66g/6472N), one 6W fan(198g/1.9404N), one HS-422 servo(45g/0.441N), one controller including IMU/IR/ultrasonic sensors (40g/0.3922N). Assuming the styrofoam body will weigh around 5g/0.04903N.

Total Mass = 505g, Total Weight = 4.9523N.

Lift force = air pressure * hovercraft body area = 107.089N/m2 * (0.40m*0.30m)= 12.85N

Force of Thrust T = 2*(ρ)*(A)*(V +v)*v

Thrust fan max air flow = 108.2CFM = 0.05106m^3/s [Link T1]

Thrust fan dimensions for flow: 120mm*120mm*25mm, in this case for air flow we use fan's area which is 120mm*120mm = 0.0144 m^2. Therefore air_velocity= volumeflow/area=(0.05106m^3/s)/(0.0144m^2) = 3.54583333 m/s.

Using the fluid mechanics equations:

F = 2*q*A*(Vinfinite+V)*V and F = air flow pressure * area

Mass_flow_rate = (ρ)*(A)*(V +v), where A is the propeller disk area [T2, Lecture 8].

At sea level and at 15 degrees C, the density of air is 1.225 kg/m3. This is the value of the ISA (International Standard Atmosphere, google.com)

So the Forward Thrust T: 2*Mass_flow_rate*velocity=2*(0.05106m^3/s)*(1.225kg/m^3)*(3.54583333 m/s) = 0.443573112N = 0.4436 N.

The hovercraft D3's acceleration is: F=ma => a=F/m = 0.4436/0.505=0.878415 m/s^2.

Air pressure = 0.28inchH2O = 7.111999mmH20=7.112mmH2O=69.7429N/m^2.

Rudder area expected to be: 13cm by 6cm. Maximum angle rudder should make is 45 degrees.

Torque_by_rudder_Design3 = air_pressure*rudder_area*sina*armlength*sinb= 69.7429*(0.13*0.06)*(sin45)*(0.40/2)(sin45)= 0.07877Nm.

This design has a total weight of 505 grams and therefore we would need a force of higher than 4.9523N in order to have the hovercraft lift. Based on the area of the hovercraft selected, we get a total of 12.85068N of lifting force. This should be enough for the hovercraft to lift. As mentioned previously, the lift force is almost three times the total weight of the hovercraft so we predict there might be some stability issues.

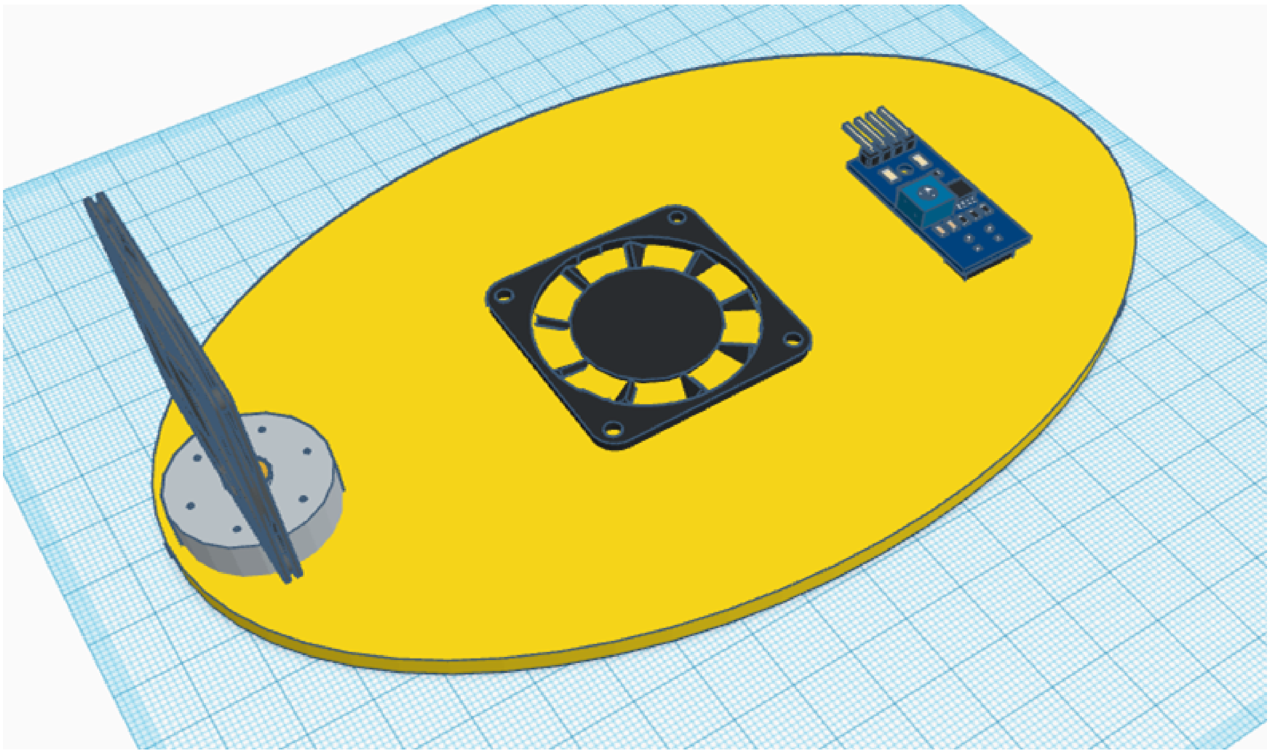


Figure 5. Design 3

4.5 Power estimation

4.5.1 Design 1

Power estimation: Two batteries source current = (460+460) = 920mAH

Lifting fan current = 530mA

Forward thrust fan current = 455mA

Servo current = 150mA

Controller and sensors estimated current = 70mA

Time =920/(530+455+150+70)*60=0.7734*60=45.80 minutes

Therefore, batteries should last for an operation of approximately 40 minutes on a full charge.

4.5.2 Design 2

Power estimation: One battery source current I = 2200mAH

Lifting fan current = 530mA

Forward thrust fan1 current = 455mA

Forward thrust fan2 current = 455mA

No servo, therefore current = 0mA

Controller and sensors estimated current = 70mA

Time =2200/(530+455+455+70)*60=0.75*60=87.4172 minutes

Therefore, the battery should last for an operation of approximately 60+ minutes on a full charge.

4.5.3 Design 3

Power estimation: Two batteries source current I = (450+450) = 900mAH

Lifting fan current = 530mA

Forward thrust fan current = 455mA

Servo current = 150mA

Controller and sensors estimated current = 70mA

Time =900/(530+455+150+70)*60=0.7468*60=44.8132 minutes

Therefore, batteries should last for an operation of approximately 40 minutes on a full charge.

	Weight	AFB1212SH	Weighted Score	MEC0251V1-0000-A99	Weighted Score
Mass	10	5	50	6	60
Pressure	5	8	40	5	25
Air flow	10	6	60	5	50
Power Consumption	5	5	25	6	30
Total	30		175		165

Table 1: WOT of Fans

	Weight	180 mAh (5)	WS	360 mAh (3)	WS	450 mAh (2)	WS	460 mAh (2)	WS	2200 mAh (1)	WS
Mass	12	5	60	6	72	7	84	7	84	2	24
Discharge Time	8	3	24	3	24	6	48	7	56	8	64
Total	20		84		99		132		140		88

Table 2: WOT of Batteries

	Weight	HS-311	Weighted Score	HS-422	Weighted Score
Mass	3	6	18	5	15
Stall Torque	10	6	60	5	50
Operating Speed	15	6	90	5	75
Running Current	2	5	10	6	12
Total	30		178		152

Table 3: WOT of Servo

4.6 SWOT Analysis

	Internal		External	
Designs	Strengths	Weaknesses	Opportunities	Threats
Design 1	● Has the best manoeuvrability and stability	● Largest number of components ● The back is heavier than the front, may increase friction	● Predetermined track ● Maximum of 3 attempts ● Technical resources are easily available on and off campus (Matlab,TA,etc)	● Autonomous movements ● Must hover at a height of 3mm ● Time given to build our Hovercraft ● Given 2 minute to complete the course
Design 2	● Lowest power consumption ● No servo motors ● Strongest forward thrust	● Difficult to manage two back fans simultaneously ● Largest mass	● Predetermined track ● Maximum of 3 attempts ● Technical resources are easily available on and off campus (Matlab,TA,etc)	● Autonomous movements ● Must hover at a height of 3mm ● Time given to build our Hovercraft ● Given 2 minute to complete the course
Design 3	● Smallest number of components ● Lightweight	● No rudder ● Slowest with a low forward thrust	● Predetermined track ● Maximum of 3 attempts ● Technical resources are easily available on and off campus (Matlab,TA,etc)	● Autonomous movements ● Must hover at a height of 3mm ● Time given to build our Hovercraft ● Given 2 minute to complete the course

Table 4: SWOT analysis for all 3 designs

For the SWOT analysis, we observe that design 2 has the most strengths but has one strong weakness (the difficulty to manage two tracks simultaneously) that can be problematic when it's time to build the hovercraft. But if managed correctly then only the heavy mass can't be fixed. Whereas Design 1 and 2 have technical weaknesses that can badly affect the completion of track. Otherwise the external factors are all the same since there are specific rules to the competition.

4.7 WOT Analysis

Criteria	Weight	Design 1		Design 2		Design 3	
		Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Number of components	20	5	100	9	180	7	140
Weight	15	7	105	4	60	8	120
Lift force	10	8	80	6	60	8	80
Linear Acceleration	15	6	90	8	120	5	75
Sum	60		375		420		415

Table 5: WOT analysis for all three designs

4.7.1 WOT Analysis explanation

The criteria chosen for the WOT analysis are directly linked to the requirements and equation for the competition. The equation is Score = $d_{completed}/(N_c \times t_{course})$ where $d_{completed}$ is the distance along the track that was successfully autonomously completed, N_c is the number of components used for the hovercraft and t_{course} is time in seconds taken to complete the track. If the course is complete from start to finish, N_c and t_{course} are the two factors that will mainly determine the score and differentiate the performance of the teams competing. Therefore, the number of components has the highest priority and can be quantified simply by counting which design has the lowest number of components. The time taken to complete the track can be obtained by dividing the distance by the average speed of the hovercraft. The weight and linear acceleration are the main factors used to determine the average speed. To complete the track, the lift and the weight are important to pass the track's obstacle. The lighter the hovercraft is, the easier it is to hover it.

Taking these criteria into consideration, we observe that design 2 won, followed very closely by design 3. Even though design 2 is way heavier than the other two, it has fewer components and has a greater linear acceleration. Those two criteria are linked to the score equation. Design 3, in contrast, is well-rounded on all criteria, which is why its score is very close to design 2.

4.8 Analytic Hierarchy Process

In the AHP analysis, we compared the 3 hovercraft designs based on the estimated weights of each of the criteria. The weights of each criteria were calculated using the comparative method specified in the AHP process. Table 5.a and 5.b gives us the results for the Pairwise Comparison Matrix and the Normalized Pairwise Comparison Matrix.

Criteria Pairwise Comparison Matrix					
	Number of Components	Lift	Propulsion (Linear Acceleration)	Power Consumption	Weight
Number of Components	1	1/3	1/3	2/1	1/4
Lift	3/1	1	2/1	4/1	4/1
Propulsion (Linear Acceleration)	3/1	1/2	1	3/1	3/1
Power Consumption	1/2	1/4	1/3	1	2/1
Weight	4/1	1/4	1/3	1/2	1
Sum	11.5	2.33	3.99	10.5	10.25

Table 6.a: Criteria Pairwise Comparison Matrix

Normalized Criteria Pairwise Comparison Matrix					
	Number of Components	Lift	Propulsion (Linear Acceleration)	Power Consumption	Weight
Number of Components	0.086956521	0.1416309	0.0827067669	0.19047619	0.02439024
Lift	0.260869565	0.4291845	0.5012531328	0.38095238	0.39024390
Propulsion (Linear Acceleration)	0.260869565	0.2145922	0.2506265664	0.28571428	0.29268292
Power Consumption	0.043478260	0.1072961	0.0827067669	0.09523809	0.19512195
Weight	0.347826086	0.1072961	0.0827067669	0.04761904	0.09756097
Previous Sum	11.5	2.33	3.99	10.5	10.25
New Sum	1	1	1	1	1

Table 6.b: Normalised Criteria Pairwise Comparison Matrix

By using the results obtained in Table 5.b, we were able to get the priority vector by taking the overall row averages. The values obtained correspond to the weights of the criteria. Table 5.c shows us the priority vector.

Priority Vector	
Number of Components	0.10523212487 ≅ 0.1052
Lift	0.39250070616 ≅ 0.3925
Propulsion (Linear Acceleration)	0.26089712377 ≅ 0.2609
Power Consumption	0.10476824232 ≅ 0.1048
Weight	0.13660180289 ≅ 0.1366

Table 6.c: Priority Vector

With the priority vector determined, we can determine the Consistency Ratio (CR). If the CR is less than 0.1, then we can conclude that the judgments we have made are acceptable. We first need to do the matrix multiplication (A * x) between the Criteria Pairwise Comparison Matrix(A) and the Priority Vector (x). With this new matrix, we can then determine the Consistency Vector. Table 5.d shows the results for (A * x) and the Consistency Vector.

A * x (matrix multiplication done on MATLAB)	Consistency Vector
0.5597	0.5597 / 0.1052 = <u>5.3203</u>
2.0735	2.0735/ 0.3925 = <u>5.2828</u>
1.367	1.367 / 0.2609 = <u>5.2396</u>
0.5027	0.5027 / 0.1048 = <u>4.7968</u>
0.8719	0.8719 / 0.1366 = <u>6.3829</u>

*Table 6.d: Results for (A * x) and the Consistency Vector*

With the consistency vector determined, we can now find l . l is equal to the average of the consistency vector. After finding l, we then use this information to determine the Consistency Index (CI). Finally, using the CI, we can determine the Consistency Ration (CR). Table 5.e shows the results for l, CI, and CR.

λ = (5.3203 + 5.2828 + 5.2396 + 4.7968 + 6.3829) / 5 = 5.4045

CI = (λ - n) / (n – 1) = (5.4045– 5) / (5-1) = 0.101125

CR = CI / RI = 0.101125 / 1.12 (from notes) = 0.09

λ	**CI**	**RI (from notes)**	**CR**
5.4045	0.101125	1.12	0.09

Table 6.e: Results for l, CI, and CR.

Since the value for CR (0.09) < 0.1, then we can conclude that the judgments we have made are acceptable. Now, we must do the same process of creating a Pairwise Comparison Matrix, a Normalized Pairwise Comparison Matrix, and a Priority Vector for each criteria with respect to our 3 designs. Tables 6-10 will show the results for the Pairwise Comparison Matrix, Normalized Pairwise Comparison Matrix and Priority Vector. Table 11 will show the final comparison table.

Number of Components:

# of Components Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	1	1/3	1/2
Design 2	3/1	1	2/1
Design 3	2/1	1/2	1
Sum	6	1.83	3.5

Table 7.a: # of Components Comparison Matrix

# of Components Normalized Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	0.1667	0.1803	0.1429
Design 2	0.5	0.5464	0.5714
Design 3	0.3333	0.2732	0.2857

Table 7.b: # of Components Normalised Comparison Matrix

	Priority Vector
Design 1	0.1633
Design 2	0.5393
Design 3	0.2974

Table 7.c: # of Components Priority Vector

Lift:

Lift Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	1	3/1	1/2
Design 2	1/3	1	1/4
Design 3	2/1	4/1	1
Sum	3.33	8	1.75

Table 8.a: Lift Comparison Matrix

Lift Normalized Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	0.3	0.375	0.2857
Design 2	0.0991	0.125	0.1429
Design 3	0.6	0.5	0.5714

Table 8.b: Lift Normalized Comparison Matrix

	Priority Vector
Design 1	0.3202
Design 2	0.1223
Design 3	0.5571

Table 8.c: Lift Priority Vector

Propulsion (Linear Acceleration):

Propulsion Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	1	1/3	1/2
Design 2	3/1	1	3/1
Design 3	2/1	1/3	1
Sum	6	1.66	4.5

Table 9.a: Propulsion Comparison Matrix

Propulsion Normalized Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	0.1667	0.1988	0.1111
Design 2	0.5	0.6024	0.6667
Design 3	0.3333	0.1988	0.2222

Table 9.b: Propulsion Normalised Comparison Matrix

	Priority Vector
Design 1	0.1589
Design 2	0.5897
Design 3	0.2514

Table 9.c: Propulsion Priority Vector

Power Consumption:

Power Consumption Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	1	1/4	2/1
Design 2	4/1	1	4/1
Design 3	1/2	1/4	1
Sum	5.5	1.5	7

Table 10.a: Power Consumption Comparison Matrix

Power Consumption Normalized Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	0.1818	0.1667	0.2857
Design 2	0.7273	0.6667	0.5714
Design 3	0.09091	0.2	0.1429

Table 10.b: Power Consumption Normalised Comparison Matrix

	Priority Vector
Design 1	0.2114
Design 2	0.6551
Design 3	0.1446

Table 10.c: Power Consumption Priority Vector

Weight:

Weight Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	1	5/1	2/1
Design 2	1/5	1	1/4
Design 3	1/2	4/1	1
Sum	1.7	10	3.25

Table 11.a: Weight Comparison Matrix

Weight Normalized Comparison Matrix			
	Design 1	Design 2	Design 3
Design 1	0.5882	0.5	0.6154
Design 2	0.1176	0.1	0.07692
Design 3	0.2941	0.4	0.3077

Table 11.b: Weight Normalised Comparison Matrix

	Priority Vector
Design 1	0.5679
Design 2	0.09817
Design 3	0.3339

Table 11.c: Weight Priority Vector

Final Design Comparison

Design	**Number of Components (0.1052)**	**Lift (0.3925)**	**Propulsion (Linear Acceleration) (0.2609)**	**Power Consumption (0.1048)**	**Weight (0.1366)**	**Total**
Design 1	0.1633	0.3202	0.1589	0.2114	0.5679	0.28404453
Design 2	0.5393	0.1223	0.5897	0.6551	0.09817	0.340654342
Design 3	0.2974	0.5571	0.2514	0.1446	0.3339	0.37630331

Table 12: Final Comparison Table

Based on the AHP Analysis that we did for all 3 designs; we can conclude that Design 3 has the highest score and thus is the better option. However, even though it had a higher score, Design 2 had a score which was very close to Design 3. From this, we can say that the AHP Analysis, by itself, might not be sufficient to make our decisions and that we would need to look at our SWOT Analysis, WOT Analysis and mathematical models for each design before selecting our final design.

4.9 Design changes and implementation

4.9.1 Changes made in the shape

Design 2 was originally equipped with one lift fan and two thrust fans, without rudders and servos and with a skirt installed at the bottom. This design features two thrust fans that will be turned off one at a time in order to create turns. But, once we had to build and program it for the competition, changes were made. First, the rectangular shape of the hovercraft was adjusted with rounded corners and an arch on the front to increase manoeuvrability. Also, pieces of Styrofoam were added along the edge of the hovercraft to accommodate the skirt (refer to figure 6 below).

Figure 6: Shape of the hovercraft

4.9.2 Changes made in the composition of the hovercraft

While the lift fan position didn't change position, we opted to use one thrust fan instead of two and we placed it in the rear. Since we only have one thrust fan, we needed to add a servo in order to rotate it for turns. Thus, mimicking in some parts our design 3. This design change made the build process less tedious and significantly lessened the weight of the hovercraft since we practically traded one thrust fan for a servo. But it also made the hovercraft a bit more challenging to code since we'll have to implement the servo with the sensors. These few changes also turned our design from a middle-wheel drive to a front-wheel drive. Thus, giving us the added benefit of a reduced turning arc, which offers a smaller and sharper angle of rotation compared to rear-wheel and middle-wheel drive. But we lose some balance given by a middle-wheel drive design.

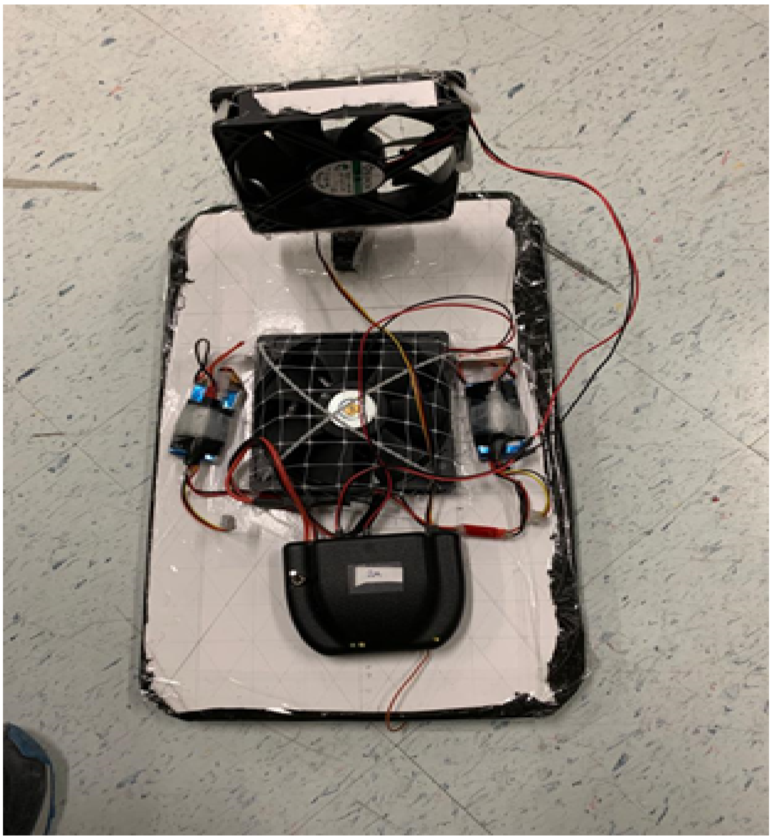


Figure 7: The structure of the hovercraft

4.9.3 Changes made for the sensors

Only two options were given for the selection of the sensors: the ultrasonic sensor (MB1030-000) and the Infrared range sensor (GP2Y0A02YK0F). Later on two more IR sensor modules came available which were GP2YOA21YK0F and GP2YOD21YK0F. The team decided to go with GP2YOA21YK0F IR sensor instead of the original model provided. For our design, at first, we decided to use two IR sensors placed on the left and right of the hovercraft. The IR sensors theoretically calculate the range of an obstacle (in our case the walls) from 10 to 80 cm. This would've allowed us in theory to make the hovercraft turn to the direction where one of the sensors detects a big distance change. But in practice, the IR sensors weren't very accurate and sometimes unreliable. It would frequently detect wrong distance changes even while on rest. However, the IR sensor performed better in closer range than the UltrasSonic sensor. Even though we would sometimes get inaccurate values, our testing showed that the IR sensor was the better choice. Therefore, we opted to use 2 IR sensors. We placed both the IR sensors on opposite sides and at a higher level.

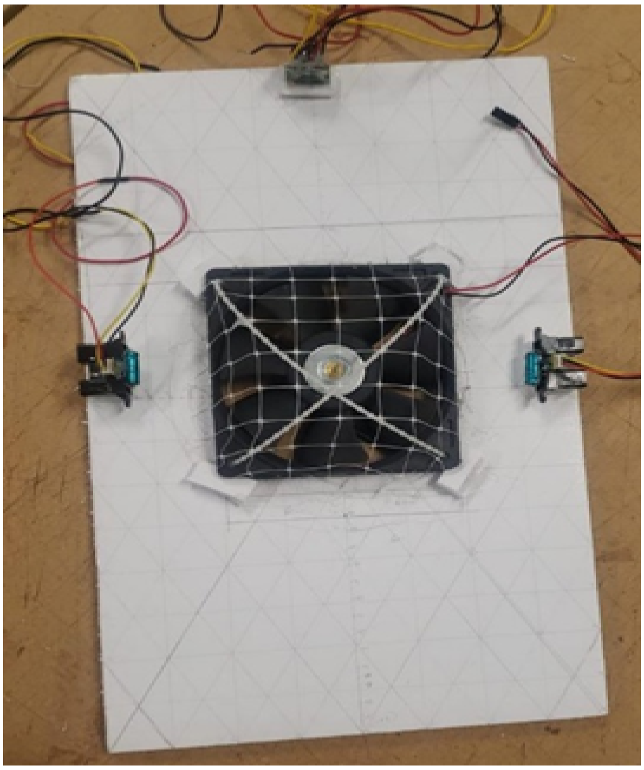


Figure 8: Sensors' position

4.9.4 Final skirt used for Hovercraft

Throughout our project design, we created multiple skirts to be used for the hovercraft. Every skirt created had its advantages and disadvantages. At the end, our first skirt prototype was the best design. Figure 9 shows the design of our skirt. We can see that for our skirt, we created many different shapes of holes on the skirt. This allows us to get the lift needed to hover over 3mm. For our final hovercraft, we used the skirt design seen in Figure 9 but we increased it in size to get maximum pressure.

Figure 9: Skirt Design

4.9.5 Conclusion

In conclusion, our final design is a mix of design 2 and design 3. We kept the rectangular shape of design 2 instead of the round shape of the other designs. And we change it to the configuration of design 3 by using only one thrusting fan instead of two and putting it in the rear and by adding a servo.

4.10 Code Description

Based on our final hovercraft design, we are using two fans, two ultrasonic sensors and one servo. For the fans, we used the pin number 7 and 10 on the controller to make them work. In the code, we used the analogwrite() function to set the speed to maximum and we leave it like that for the whole duration of the course. For the ultrasonic sensors, we had to first set a pin number for the trig pin and the echo pin. For the first sensor, the trig pin and echo pin are PC3 and PD3 respectively. For the second sensor, the trig pin and echo pin are PC4 and PD4 respectively. We created a function that would read the distance obtained from the sensor and save it in a variable. These values will be used to turn the hovercraft. In our void loop function, we have an if-else statement that uses the sensor distance to turn the hovercraft. If the distance of sensor 1 is greater than 30, the hovercraft will turn right. If the distance of sensor 2 is greater than 30, then the hovercraft will turn right. The turning of the hovercraft is thanks to the servo. On the servo, we use the 90 degree angle as reference. If we want to turn right, we tell the servo to turn at an angle greater than 90. If we want to turn left, we tell the servo to turn at an angle less than 90. Our code is present in the Appendix. From that, we can see that there isn't much code in the void loop function since we have created many functions to not clutter up the loop function. Our code doesn't use the IMU and solely relies on the information from the ultrasonic sensors.

4.11 MATLAB Simulation and Calculations

Acceleration:

Acceleration = force/mass

Velocity:

Velocity = Acceleration.* time

Linear Displacement:

Linear Displacement = (velocity/2).*t

Sample MATLAB code use for acceleration:

```
clear all;

close all;

clc;

%time set up

t=(0:30);

%Acceleration set up

%from calculations

a1 = 0.8514 * ones(size(t));

a2 = 1.07239 * ones(size(t));

a3 = 0.878415 * ones(size(t));

%graph / plotting

subplot(3,3,1);

plot(t,a1);

grid on;

title('Acceleration for Design 1');

xlabel('seconds');

ylabel('m/s^2');


subplot(3,3,2);
```

```
plot(t,a2);
grid on;
title('Acceleration for Design 2');
xlabel('seconds');
ylabel('m/s^2');
subplot(3,3,3);
plot(t,a3);
grid on;
title('Acceleration for Design 3');
xlabel('seconds');
ylabel('m/s^2');
```

Velocity sample code:

```
%plot for velocity
v1 = a1.*t;
v2 = a2.*t;
v3 = a3.*t;
subplot(3,3,4);
plot(t,v1);
grid on;
xlabel('Seconds');
ylabel('m/s');
title('Design 1 Velocity ');
subplot(3,3,5);
plot(t,v2);
grid on;
xlabel('Seconds');
ylabel('m/s');
```

```
title('Design 2 Velocity ');
subplot(3,3,6);
plot(t,v3);
grid on;
xlabel('Seconds');
ylabel('m/s');
title('Design 3 Velocity ');
```

Linear Displacement sample code:

```
%linear displacement
d1=(v1/2).*t;
d2=(v2/2).*t;
d3=(v3/2).*t;
subplot(3,3,7);
plot(t,d1);
grid on;
xlabel('Seconds');
ylabel('m');
title('Design 1 Linear Displacement');
subplot(3,3,8);
plot(t,d2);
grid on;
xlabel('Seconds');
ylabel('m');
title('Design 2 Linear Displacement');
subplot(3,3,9);
plot(t,d3);
grid on;
xlabel('Seconds');
ylabel('m');
```

title('Design 3 Linear Displacement');

Matlab Simulations

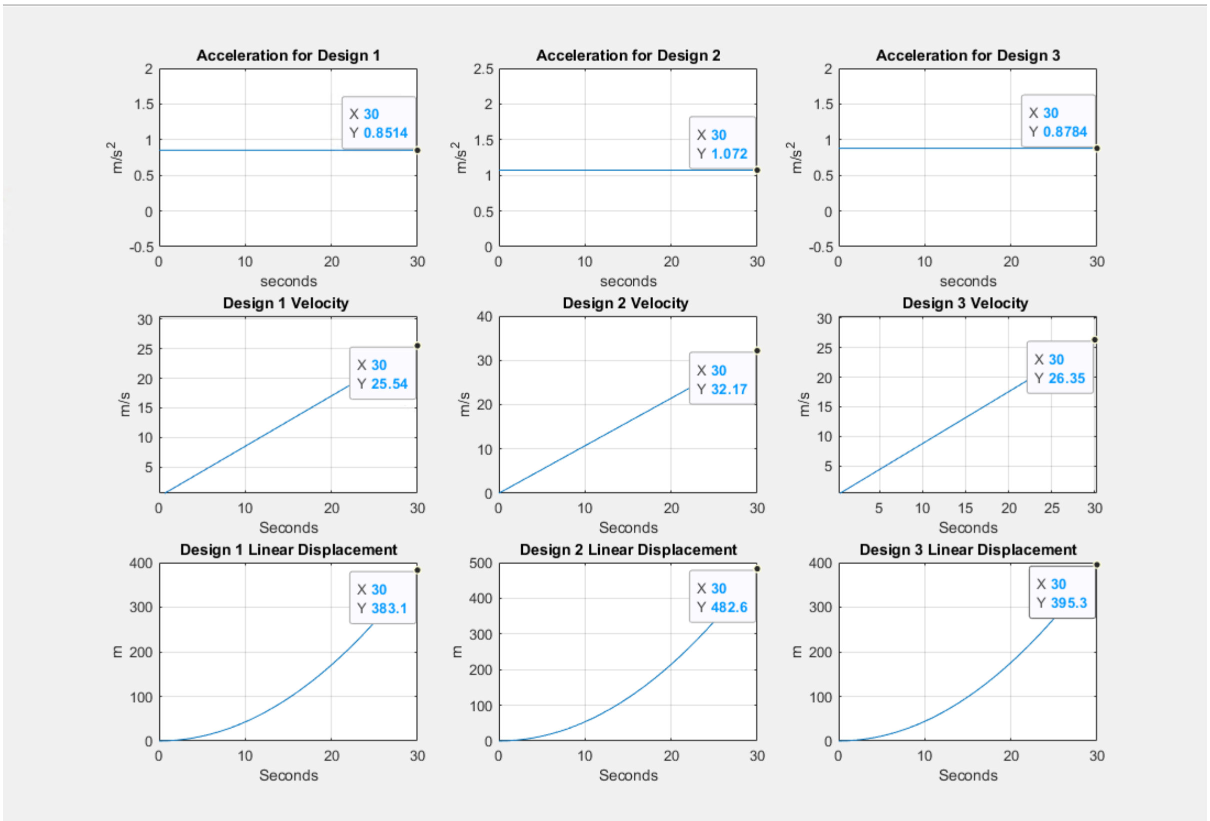


Figure 10: Matlab simulations

5. SCHEDULE

5.1 Meetings and Gantt Chart

Date of Meeting	Location	Time Allocated (h)	Members
Jan 12, 2022	Discord	2	all
Jan 17, 2022	Discord	1.5	all
Feb 4, 2022	Hall Building	3	all
Feb 9, 2022	Hall Building	3	all
Feb 11, 2022	Hall Building	2.5	all
Feb 16, 2022	Hall Building	2	all
Feb 18, 2022	Hall Building	5	all
Feb 22, 2022	Hall Building	2.5	all
March 3, 2022	Hall Building	4	all
March 4, 2022	Hall Building	4.5	all
March 6, 2022	Hall Building	1	all
March 11, 2022	Hall Building	2	all
March 16, 2022	Hall Building	2.5	all
March 18, 2022	Discord	1	all
March 23, 2022	Hall Building	1.5	all
March 25, 2022	Hall Building	3	all
April 6, 2022	Hall Building	2	all
April 7, 2022	Hall Building	2	all

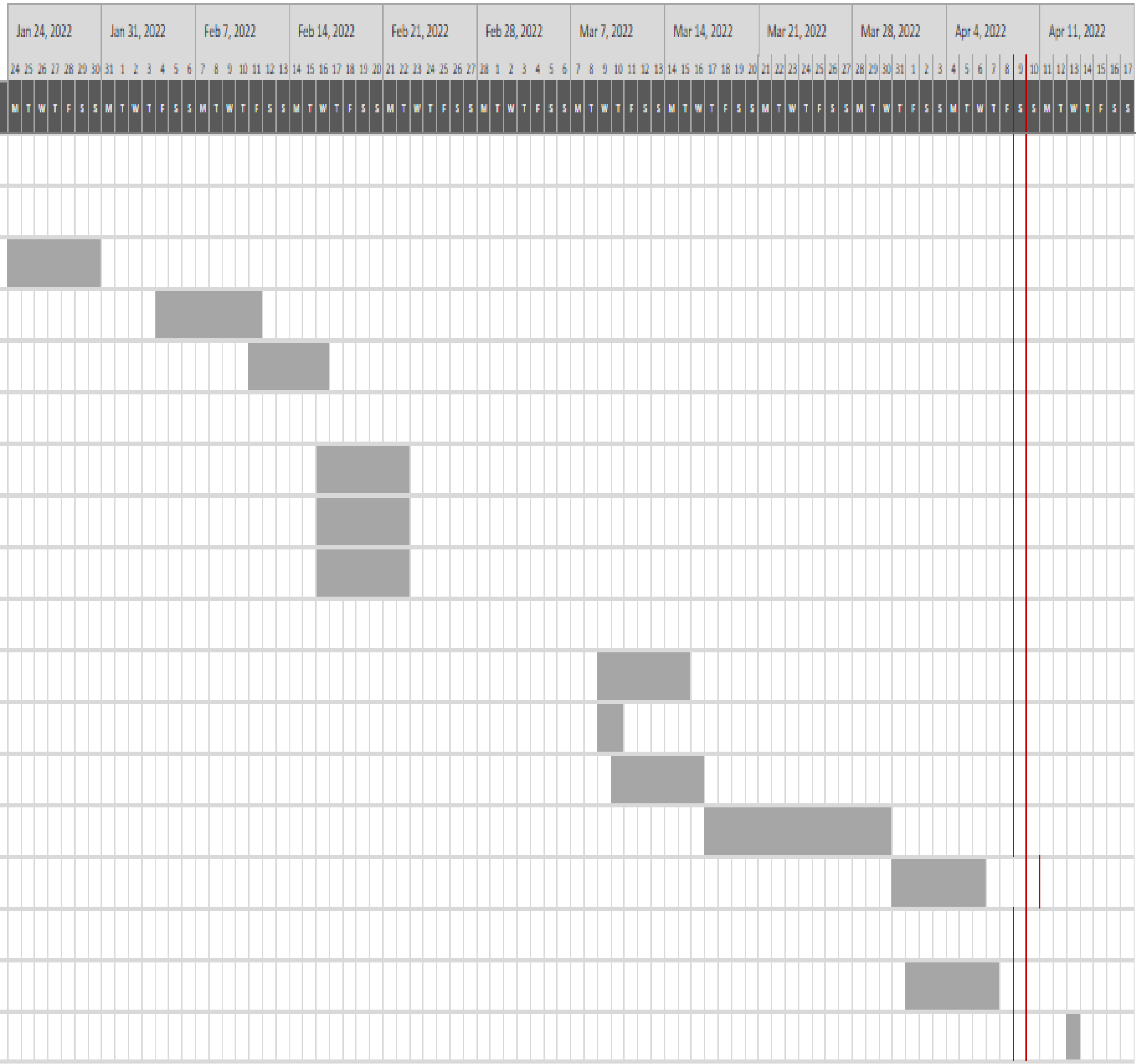
Table 13: Meeting and Event

Gantt Chart

Project Start: 1/12/2022

Display Week: 3

TASK	ASSIGNED TO	PROGRESS	START	END
PDR				
Group created		100%	1/12/22	1/13/22
Problem Description		100%	1/17/22	1/30/22
Research and brainstrom		100%	2/4/22	2/11/22
Design option discussed		100%	2/11/22	2/16/22
Design option analysis				
SWOT		100%	2/16/22	2/22/22
WOT		100%	2/16/22	2/22/22
AHP		100%	2/16/22	2/22/22
Testing and evaluation				
Prototyping		100%	3/9/22	3/15/22
Simulation environment setup		100%	3/9/22	3/10/22
Simulation Programming		100%	3/10/22	3/16/22
Test and evaluate		100%	3/17/22	3/30/22
Redefine		100%	3/30/22	4/5/22
Final Report				
Final report		100%	4/1/22	4/7/22
Competition		100%	4/13/22	4/13/22



6. SUMMARY

The goal of this report was to design and choose a hovercraft design that would be able to complete the course, hover off the ground and complete a course within 2min while being autonomously. The team started with 3 designs and chose 1 design after analysing all the autonomously. The team started with 3 designs and chose 1 design after analysing all the

data and results from the SWOT, AHP and WOT analysis. The team wanted to aim for a hovercraft that will be fast and stable that still provides the team with the best possible score in the competition.

From the SWOT analysis design 1 would be best for manoeuvrability and stability. However, it uses a lot of components which can affect the final score. For design 2 it seems like it would be in terms of speed and less complicated to build but may be more difficult in coding and controlling two fans at a time and has a big mass. Design 3 has the least amount of components and weight but has a slow forward thrust which can affect the speed of the hovercraft. It may not complete the course in time. Looking at the WOT analysis it seems that Design 2 was the winner in this analysis but not by much. Even though design 2 is heavier it seems to produce the best score in terms of the scoring systems of the competition. Looking at the AHP analysis it shows design 3 is better but not by a lot. Design 2 comes in a close second in this analysis.

When looking at all 3 analyses the team decided to go with design 2 as the final hovercraft design because it seems to produce the best score result for the competition in the WOT analysis and seems to have the best forward thrust force from the SWOT analysis. The design 2 of the hovercraft seems to meet the team requirement which were fast, best possible score in competition and stable.

Some design changes were made while building the hovercraft because the team realised that during testing having one less fan was better and having 2 sensors would be good.. A combination of design 2 and design 3 made the most practical sense given the equipment that was distributed and the feasibility of building the hovercraft and the coding for it. The rectangular shape of design 2 was kept and the configuration of the parts of design 3 was instead implemented.

7.REFERENCES

[1] https://media.digikey.com/pdf/Data%20Sheets/Sunon%20PDFs/MEC0251V1-0000-A99.pdf MEC0251V1-000U-A99 (259-1470-ND) data sheet.

[2] https://www.digikey.ca/en/products/detail/delta-electronics/AFB1212SH/2560458 AFB1212SH (603-1334-ND) data sheet.

Appendix:

[1] https://media.digikey.com/pdf/Data%20Sheets/Sunon%20PDFs/MEC0251V1-0000-A99.pdf MEC0251V1-000U-A99 (259-1470-ND) data sheet.

[2] https://www.digikey.ca/en/products/detail/delta-electronics/AFB1212SH/2560458 AFB1212SH (603-1334-ND) data sheet.

[3]https://www.discoverhover.org/infoinstructors/newguides/guide13-turning.html

[4]https://www.ls-france.com/en/power-assisted-hydraulic-steering-systems/torque-calculation-assist/

[5]https://estesrockets.com/wp-content/uploads/Educator/2845_Classic_Collection_TR-TN.pdf

[6]https://discovery.ucl.ac.uk/id/eprint/10103694/1/Determination_of_control_chara.pdf

[7]https://www.grc.nasa.gov/www/k-12/airplane/rud.html

[8]https://estesrockets.com/wp-content/uploads/Educator/Math_Curriculum.pdf

[Link T1] https://www.convertunits.com/from/cfm/to/m%5E3/s

[T2] Lecture8 Notes, slide 30.

8. APPENDIX

Final_hovercraftcode.ino

```
#include <Servo.h>
#include "SharpIR.h"

Pin Set Up
 +++++++++++++++++++++++++++++++++++++++++++++++++++++++

//fans
int lift = 7; //PD7 (ON/Off 0)  can change pin if need
int thrust = 6; //PB2 (PWM2) UP/Down power

//fan speed
int thrust_speed;
int start_speed;
int minimum = 0; //lowest speed of fan
int maximum = 255; //highest speed of fan
// May need to had inital fan speed for thrust

//____________________________________________________________________________

//servo
Servo myservo;
int pos = 88; //the starting position of motor (may not need this)

//____________________________________________________________________________

//sensor
// D4 =  PIN 5
// D5 = PIN 12

//IR Sensor
SharpIR SharpIR1(PC3, 1080); //RIGHT
SharpIR SharpIR2(PC4, 1080); // LEFT

int dis; // RIGHT
int dis1; // LEFT
//____________________________________________________________________________
```

```
//turning
bool turn = true;
//int turn_count = 0;

//start main program
bool On = true;

//+++++++++++++++++++++++++++++++ Void Set up
++++++++++++++++++++++++++++++++++++++++++++++++++++++
//run once:
void setup() {

Wire.begin(); //TWBR = 12; //400 kbit/sec I2C speed

Serial.begin(9600); //display speed in serial monitor can change
//while (!Serial) {};

//Servo set up
myservo.attach(9); // servo attched on pin 9 (PB1 -> PWM0)
myservo.write(pos);
delay(15); //to allow time for servo to reach position

// Set up the interrupt pin, its set as active high, push-pull
  pinMode(intPin, INPUT);
  digitalWrite(intPin, LOW);
  pinMode(myLed, OUTPUT);
  digitalWrite(myLed, HIGH);

// set up interrupt pin for sensors
  pinMode(5,OUTPUT);
  pinMode(12,OUTPUT);

  pinMode(PC3, OUTPUT);
  pinMode(PC4, OUTPUT);

analogReference(DEFAULT);
//the default analog reference of 5 volts (on 5V Arduino boards) or
//3.3 volts (on 3.3V Arduino boards)

  // set up interrupt pin for fans
  pinMode(thrust, OUTPUT);
  analogWrite(thrust, 255);
```

```
  pinMode(lift, OUTPUT);
  digitalWrite(lift, LOW);
}


//========================================================================================
=====================

//+++++++++++++++++++++++++++++++++ Void Loop
+++++++++++++++++++++++++++++++++++++++++++++++++
//run repeatedly
void loop() {
 //just add function order and small details

if (On){
 start();
}
  else{
  _end();
  }

//check distance
read_IR();

if(dis > 40){
    turn_right();
  }

  else if(dis1 > 40)
  {
    turn_left();
  }
  }

//++++++++++++++++++++++++++++++++ Functions +++++++++++++++++++++++++++++++++++++++++++

//================================ Fan =============================================

//Lift on
void turnOn(){
  digitalWrite(lift, HIGH);
}
```

```
//Lif off
void turnoff(){
  digitalWrite(lift,LOW);
}

//thrust off (may not need this
void thrustoff(){
  analogWrite(thrust,0);
}

//max and min values of the thrust fan
void maximum_minimum(){
  if (thrust_speed > maximum){
      thrust_speed = maximum;
    }
    else if (thrust_speed < minimum) {
      thrust_speed = minimum;
    }
}

//___________________________Hover craft on/off, moving ____________________

//Turning off hover craft  (END) both lif and thrust fan are off
void _end(){
  turnoff();
  thrustoff();
  myservo.write(90);  //changes the servo angle to be to 90 again
}

//starting of hover craft (starr)
void start(){
  turnOn();
  thrust_speed = 255; //change the starting speed
  forward();
}

//moving forward in straight line
void forward(){
  analogWrite(thrust, thrust_speed); //can adjust speed if needed
}
```

```
//______________________________Sensor and servo section____________________________________

//Sensors
void read_IR()
{
  dis=SharpIR1.distance();  // this returns the distance to the object you're measuring
  dis1=SharpIR2.distance();

  Serial.print("Dis: ");
  Serial.print(dis);
  Serial.print("Dis1: ");
  Serial.print(dis1);
}


//__________________________Turning of hovercraft_________________________________

void turn_left(){
analogWrite(6,240);
myservo.write(55);
delay (1500);
 myservo.write(35);
 delay(1000);
 myservo.write(88);
}

void turn_right(){
analogWrite(6,240);
myservo.write(105);
delay (1500);   //can change wait time to be slower or faster
 myservo.write(155);
 delay(1500);
  myservo.write(70);
  delay(500);
  myservo.write(88);
}
```