ENGR290

Group 11:
Preliminary Design Report

Submitted by

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Abstract

The goal of this technical paper is to provide the design and development techniques for a hovercraft, which is a vehicle that replaces physical touch with the ground with pressurized air contact to decrease friction. Team 11's goal for an upcoming hovercraft competition is to design, build, and test a hovercraft that can autonomously finish a track with three increasingly high track-wide obstacles in under 120 seconds, with a maximum of three tries. Team 11 began preparing for the mission in order to fulfill it successfully. Associated prerequisites were derived from the competition's regulations and photographs of the competition's course. Second, brainstorming sessions were held in order to meet the requirements. Experimenters came up with three separate hovercraft models, each with its own design and specs. Finally, AHP analysis, SWOT analysis, and WOT analysis were used to conduct a systematic examination of the three models. These evaluations enabled the team to identify which of the three models is most suited for the competition, while also taking into account the product requirements and design limits. Finally, a schedule was created, as well as a review of the work made thus far. The tasks were distributed evenly among the team members.

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1. INTRODUCTION

This report analyzes the design process: the thoughts, ideas, and decisions that went into designing and building a hovercraft that will compete in a race against hovercrafts built by colleagues. The goal of this project is to create a hovercraft that can move around a circuit on its own. It must hover high enough off the ground to avoid obstructions and turn without losing control or balance. Furthermore, the track must be finished in a specific length of time while utilizing the fewest available electrical components. The manner in which these final three factors are treated has a direct bearing on the final score awarded. As it moves, the hovercraft depends on a cushion of air formed by lift fans to reduce friction between a surface and itself. Because of this design choice, a hovercraft's peak speed can exceed that of a boat.

1.1 DOCUMENT PURPOSE

The technical goal of this PDR (Preliminary Design Report) is to detail the design methodologies used to create an autonomous hovercraft prototype while taking into consideration the many issues, limits, regulations, and requirements in the final hovercraft competition. This paper documents and organizes all of the criteria, objectives, and concepts needed to create a working hovercraft. A hovercraft is a vehicle that makes contact with the ground using a cushion of air as a point of contact. [1]

1.2 DOCUMENT SCOPE

The goal of the final competition is for hovercraft from various teams to traverse a predetermined course in the quickest time possible, up to 120 seconds. In other words, the major challenge in this competition was to design a hovercraft that struck the best balance between efficiency (time to complete a predetermined course) and the quantity of components employed on the hovercraft (fans, servo-motors and sensors). To create mission objectives and global design goals, the requirements were first examined. Team 11 has built three prospective hovercraft models after multiple brainstorming sessions. Team 11 used AHP (Analytic Hierarchy Process) analysis and SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis on all three models to undertake a systematic examination of the early designs [2]. The analysis findings will be used to compare one hovercraft model to another and to choose the ultimate hovercraft model based on quantitative and qualitative data presented in this document.

A visual representation of the work to date was created to emphasize the tasks that needed to be addressed and to make the execution of future targets more manageable.

2. REQUIREMENTS

In general, all initiatives aimed at solving a problem must fulfill certain criteria in order for the end result to be usable.

The following are the requirements. The hovercraft should be able to:

I. Complete the course in the shortest period of time possible.
II. Be able to re-adjust its path to avoid colliding with walls.
III. Hover higher than 3mm above the ground to avoid obstructions.
IV. Use as few components as possible and rotate at least 180 degrees.
V. Function autonomously.
VI. Finish the track in under 120 seconds.

Furthermore, the width of the hovercraft must not exceed 45cm while still following the competition's regulations, with an aim to maximize the score yield if all of the conditions are met.

3. IDEAS AND RESEARCH

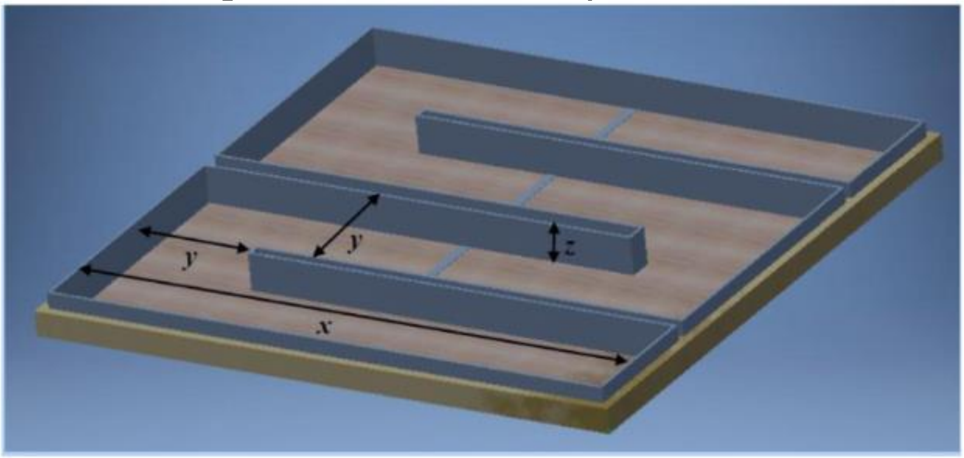
Through literature and internet research on hovercrafts, ideas that have come up are as follows:

- The hovercraft could have a rounded shape. The rounded part could aid in the hovercraft not getting stuck in between the walls of the track when turning.
- The overall shape could be a circle or a square to allow larger surface area for all the components that need to be included on the hovercraft.
- One of the fans could be placed on top of the body of the hovercraft and be the one turning instead of the entire body itself, which would allow for more fluid movement through the track when turning. This would allow less chances of the hovercraft getting stuck between the walls.
- The hovercraft could be surrounded by a soft layer to avoid collision and damage to the vehicle when coming in contact with the walls of the track.

4. MISSION OBJECTIVES

The basic goal of the task is to create a hovercraft that can finish the course in figure 1 on its own. At certain points throughout the track, there will be obstacles that take up the whole width of the track and have increasing heights. The equation presented in section 1.0 may be used to define the hovercraft's score. The tournament is won by the team with the highest score. Each team gets three attempts to complete the course. To compute the score, the three best efforts will be picked.

Figure 1: The Hovercraft Competition Track



X = 235, Y = 50-55, and Z = 15 (dimensions in cm)

5. DESIGN SPECIFICATIONS AND CRITERIA

List of specifications:

- Linear acceleration: The hovercraft should go straight forward not too slow to finish the track in time and not too fast to avoid bumping on the walls
- Angular acceleration: The craft should be programmed in a way to turn autonomously and avoid being stuck
- Lift fan: The hovercraft should hover at a certain height to pass the ground obstacle
- Thruster fan: The thruster should steer and propel at the same time the craft during the competition.
- Process: The craft should be able to receive data from the sensors and use them.
- Sensors: Detects data from the physical environment and responds with appropriate movement

General list of criteria that are assessed in each design:

- Turning Capability
- Linear Acceleration
- Weight
- Stability
- Number of Components in Hovercraft
- Energy Efficiency
- Simplicity

6. DESIGNS' CALCULATIONS

6.1 DESIGN 1

A circular design was considered desirable, as the associated physics of rotation and distance finding would be simplified. This example uses a single lift fan at the geometric center to minimize wobble (i.e. undesired pitch and roll). Two thrust fans are placed equidistant from the lift fan at the rear of the craft, and occupying the same horizontal (see Figure 2-A). Servos connected to these fans enable the craft to steer. All other components are positioned so that their weight is symmetrically distributed about the diametric whose endpoints face forward and backwards. This decision is to minimize weight imbalance, and to therefore minimize perturbations in the main forward thrust vector.

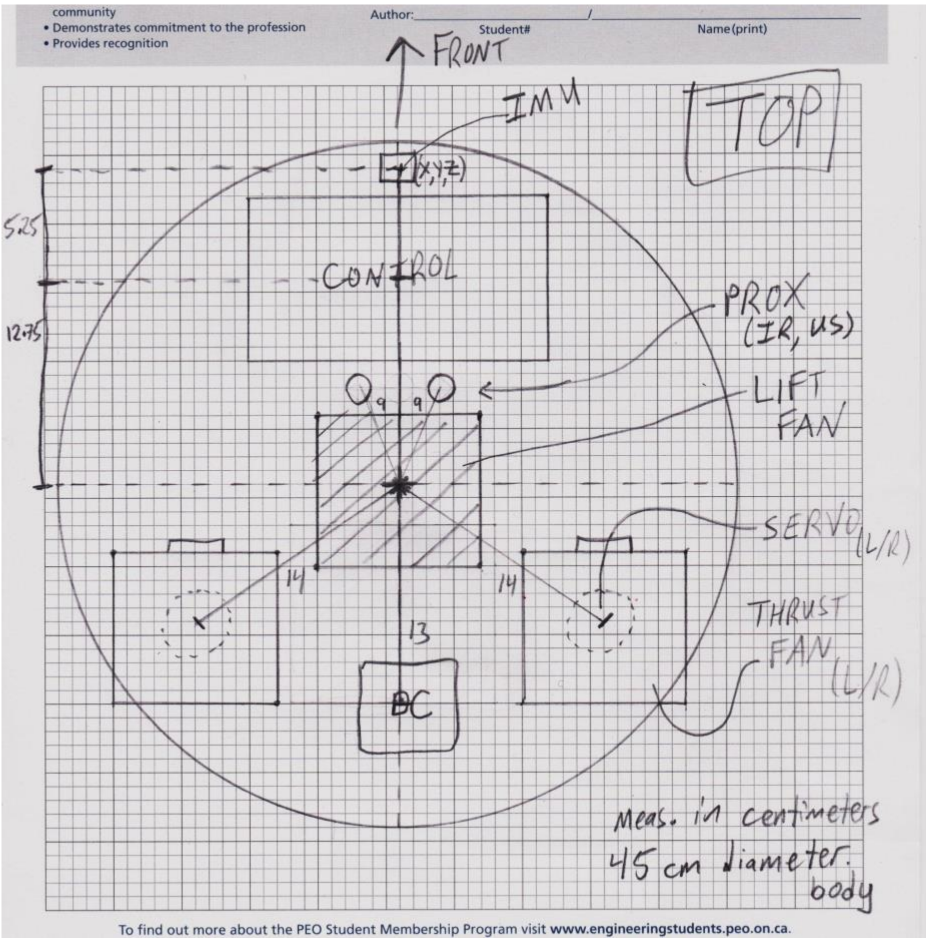


Figure 2-A: Circular Design, Top View

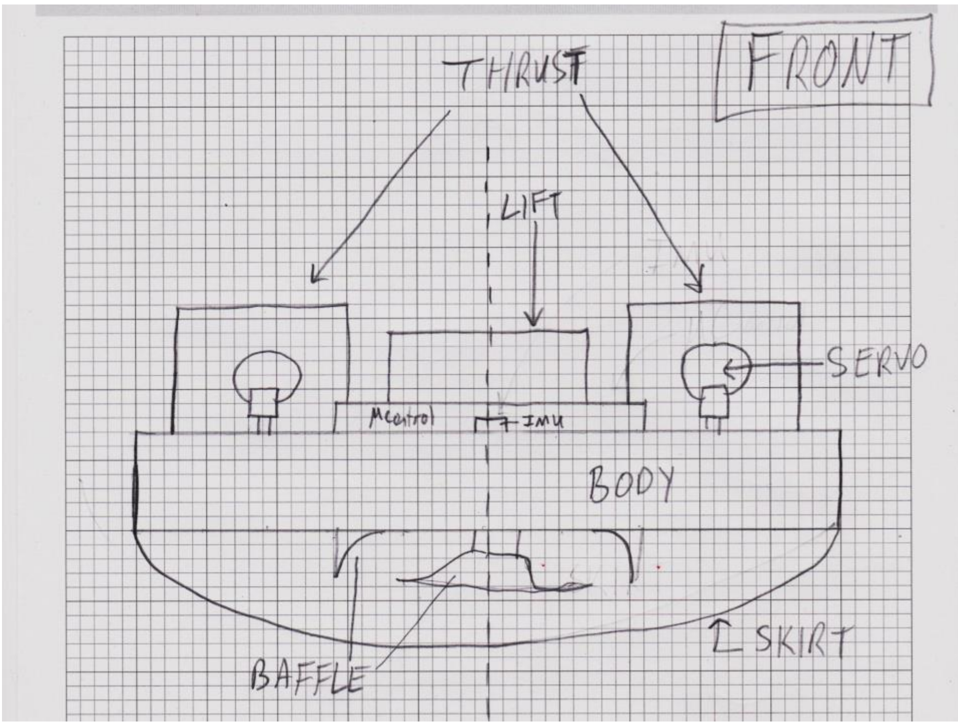


Figure 2-B: Circular Design, Front View

Mechanical considerations for the craft can be approximated from the design schematics: AFB-1212SH's, Servo HS-311's, MEC-0251V1's, IR sensor's, US Sensor's, microcontroller's, Rhino 11.1V's, and Rhino 7.4V's mass, VDC, and dimensions from [3], [4], [5], [6], [7], [9], [10], [11].

<u>Table 1</u>: Circular Design Component

Circular Design	**Bolded entries**		are criterion values			
				Rad. dist from		
Component	Qty	VDC in	Mass (kg)	center (m)	Mom. inertia	
Lift Fan AFB-1212SH	1	12	0.198	--	4.75E-04	, for I (Square plate) =
Servo HS-311	2	5	0.043	0.14	1.69E-03	1/6 * m * L * L
Thrust Fan MEC-0251V1	2	12	0.162	0.14	6.35E-03	
IR Sensor GP2Y0A02YK0F	1	5	0.0048	0.09	3.89E-05	
US Sensor MB1030-000	1	5	0.0043	0.09	3.48E-05	
Microcontroller	1	5	0.15	0.1275	2.44E-03	
IMU/Regulator/Board	1	5	0.05	0.18	1.62E-03	
DC Sources	**Expending 1840 mAh total**					
Rhino 11.1V 460 mAh	3	--	0.0414	0.13	2.10E-03	

Rhino 7.4V 460 mAh	1	--	0.0285	0.13	4.82E-04	
TOTALS	**13**		**0.9698**		**0.01522**	
	# Components		**Total mass**		**Total moment**	
everything included					**of inertia (Stability)**	

Manufacturer's data for the two choices of fans allows thrust force per unit to be calculated, alongside other data that will be useful for every design consideration:

Table 2: Fan Thrust Parameters

FAN THRUST & RELATED PARAMETERS								
	radius, sweep (m)		Swept Area		volume flow rate (approx, m^3 min^-1)			
AFB		0.06	0.01131			3.018		
MEC		0.06	0.01131			3.018		
Since the swept areas and volume flow rates are approximately equal, subsequent calculations								
will also be approximately equal (exact calculations will be used in simulations and final build).								
		A				B		C
volume flow rate, per second	exit velocity (m/s)			density of air at STP		mass flow rate		Thrust Force
0.0503		4.4475		1.2754		0.0642		0.2853
A: Exit velocity = volume flow rate / swept area								
B: Mass flow rate = volume flow rate * density of fluid								
C: Thrust force = exit velocity * mass flow rate								

Table 3: Fan Lift, Circular Design

FAN LIFT, CIRCULAR DESIGN					
Static Pressure, avg, AFB		96.939	Pa		
Radius of skirt		0.225	m		
Area of skirt		0.1590	m^2		
Lift Force		15.417	N		
Lift > Normal?	TRUE				
Normal Force		9.514	N		
If Lift > Normal, we can assume Normal ~= 0, so friction ~= 0					
Maximum Thrust, Fwd		2 *	calculated =	0.57064	N
Maximum Linear Accel				**0.58841**	**m s^-2**
Max rotation occurs if both fans apply thrust 90 degrees from the center					
This will apply 2 * F(thrust) at a distance defined by joining the midpoint					
of the line connecting the fans, with the center of the craft					

Max thrust, fwd		2 *	calculated =	0.57064	N
Radial arm length				0.13	m
Torque	rxF	perpendicular		0.07418	N m
Max angular accel	**= torque/mom of Inertia**			**= 4.8728**	**rad s^-2**

Table 4: Criteria Screen, Design 1

Criterion	Expected Performance
Turning Capability	WIth a top angular acceleration of almost 5 rad s^{-2} , this craft is capable of making reasonably fast rotations.
Linear Acceleration	Under ideal conditions (e.g. assuming absolutely no friction), the craft could complete one long straight section of the track from rest ($v_i = 0$) in less than three seconds. Unfortunately, it has no way to stop.
Weight	Neglecting the foam core body and the wires, the craft's total weight is under a kilogram, which was somewhat lower than expected.
Stability	While the single lift fan is an asset, there is concern that concentrating the weight along a single diametric may encourage unanticipated and undesired roll.
Number of Components/Simplicity	The craft contains three fans, three sensors, and four batteries. This seems to be a typical number of components: indeed, the craft has not necessarily been optimized for this parameter.
Energy Efficiency	4 x 460 mAh batteries were chosen, although a sufficiently efficient craft (discoverable under iteration and testing) could probably lower this metric. As it stands, this design is intended to be failsafe, and complete the objective comfortably (see Number of Components).

Table 5: SWOT Analysis, Design 1

Strengths	Weakness	Opportunities	Threats
- Simple build - Lightweight - Quick rotation and significant linear acceleration	- C.O.M. is concentrated along a single diametric - Single (intended) forward thrust vector with no redundancy - No option for reverse	- Very strong traversal of straight ideal paths - Body shape may minimize any disruptions caused by	- Round body is susceptible to unexpected yaw movement (especially when colliding with ground obstacles) that

	thrust - Design is focused on completion of the task, and does not optimize	wall collisions	may be difficult to correct in software - High angular acceleration with unstable C.O.M. and no brakes is a disaster waiting to happen

6.2 DESIGN 2

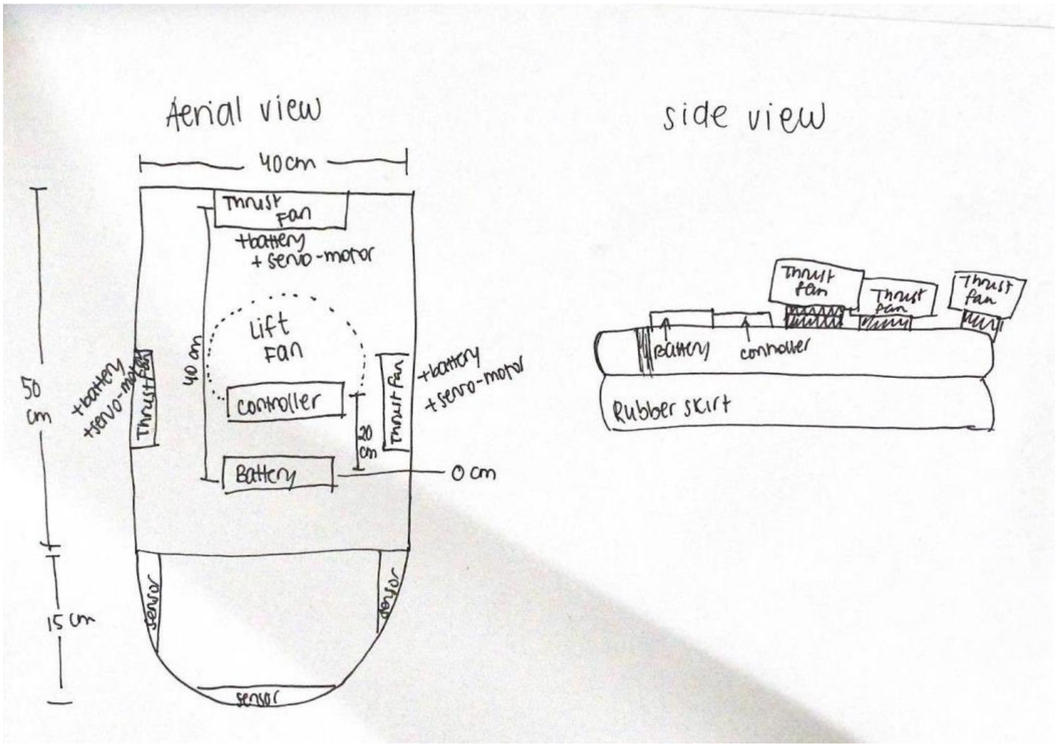


Figure 3-A: Triple Thrust Fan Design

Overview of the design:

This second design was chosen firstly because the shape is a common choice among teams. We wanted a small platform so it would be easier for the craft to turn in the corner. We added three sensors to make sure there wouldn't be any blind sport and the craft would be able to see every wall. Then we added the first thrust fan on the back to make it propel straight forward. The two thrust fans on the side were added as a way to steer. We wanted to implement in a way that if one of the sensors on the side would detect a wall, the thrust fan on this side would give more power to make it turn or move away from the wall.

In this design, there are a total of 17 components. Amongst those components, there are three thrust fans that are going to be allowing the hovercraft to move, and one lift fan that is going to lift the machine from the ground. The chosen thrust fan is the MEC-0251V1, since it is lighter in weight than the other options (0.162kg).

There is going to be a servo-motor, a component that allows the hovercraft to perform linear and angular displacement, connected to each of the thrust fans. The chosen servo-motor is the HS-311, which has a maximum rotation of 202°. The lift fan is going to be located in the middle of the hovercraft to ensure equal distribution of air within the skirt of the hovercraft. However, according to the design, the center of mass is going to be situated near the battery of the front.

Looking at the geometry of the design, the hovercraft could be split into two components; the semi-circle and the rectangular portions. In the semi-circle, there are three IR GP2Y0A02YK0F sensors, one in the front and one on each side. The reason why we have chosen to place a semi-circle in front is because, compared to a design with corners, a semi-circle is going to have a laminar friction distribution, while a design with corners is going to have an equal distribution of friction.

The battery that has been chosen to propel the hovercraft is the Gravity 2200 mAh. There is one for each of the four fans. The current requirement for each of the thrust fans is 0.455A.

Current requirement for the hoverboard;

$$0.455 + 0.455 + 0.455 + 0.455 = 1.82A$$

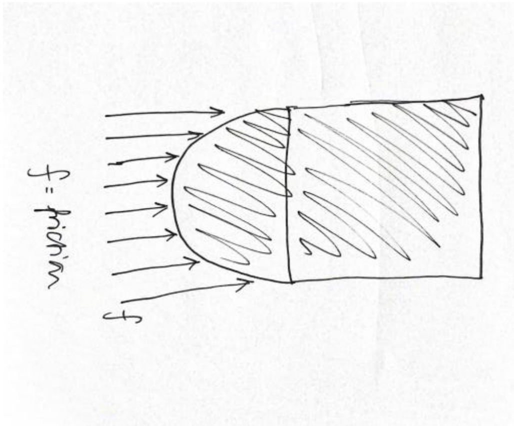


Figure 3-B: Triple Thrust Fan Design - Frictional Force Considerations

AFB-1212SH's, Servo HS-311's, MEC-0251V1's, IR sensor's, microcontroller's and Gravity 2200 mAh's mass, VDC, and dimensions from [5], [3], [4], [6], [11], [8].

Table 6: Total mass of the hovercraft

Component	Quantity	Mass (kg/component)	Mass (total kg)
Lift Fan AFB-1212SH	1	0.198	0.198
Servo HS-311	3	0.043	0.129
Thrust Fan MEC-0251V1	3	0.162	0.486
IR Sensor GP2Y0A02YK0F	3	0.0048	0.0144
Microcontroller	1	0.15	0.15
IMU/Regulator/Board	1	0.05	0.05
DC Sources			
Gravity 2200 mAh	4	0.228	0.912
TOTALS	**17**	**1.4968**	**1.9394**

Criteria to Choose:

Criterion to choose	
Turning Capability	This design can't turn on itself but is small enough to make the turns in the track
Stability	Due to the three fan thrusters, the craft will be too heavy and will struggle to hover correctly. There is too many

	components
Simplicity	Three directional thrusters are not simple to implement, if it goes on one side, the thruster on this side will overpower the other and will destabilize the craft.
Linear Acceleration	Thanks to the several thrust fans, the craft should go at a higher speed. But the velocity is also compromised when there is a lack of stability and added weight.
Energy efficiency	The designed hovercraft will not be energy efficient because of the many thrusters present, it will need a lot of energy but it won't have enough space to store evry batteries as it will be too heavy

Explanation of the criteria:

1. Turning Capability

This design is advantageous in the sense that it is small and compact enough to get the body of the hovercraft to rotate. However, we may encounter issues when rotating the body on itself, due to the fact that the force of the thrust fans are going to be canceling each other. In fact, if we take a look at the thrust fans in the front, located in parallel with one another, we see that if both of these fans are active, the forces generated by the thrust fans are going to cancel each other out. The only one that is going to be propelling the hovercraft is going to be the one that is situated in the back. Considering that this fan is located in the back, there is a possibility that the force generated by the fan in the back might not be enough to make the hovercraft move. If one of the side fans and the one in the back are active, the force generated by the thrust fan on the side of the hovercraft may not be enough to make the hovercraft move as a whole.

2. Stability

The design 2 has many components to it, such as 3 thrust fans, a lift fan, 4 servo motors, etc., to drive the hovercraft. As known, when there are too many components to a hovercraft, the weight adds up. When adding up the weight of each of the components, it is seen that it totals to 1.9824kg. From all of the designs in this report, this is the heaviest one. This could be an issue to lift the hovercraft as a whole, as well as its velocity. Furthermore, most of the weight of the hovercraft is concentrated within the first 20cm from the center of mass in the x- and y-axis. Thus, it could be concluded that there is unequal distribution of weight within the hovercraft, leading to potential issues while maneuvering the hovercraft.

3. Simplicity

At first glance, it could be said that this design is not simple, as there are too many components on the hovercraft. In fact, there are a total of 17 components, stipulating that there is extra weight added to the hovercraft, compared to the other designs. Also, if we look at the current requirement, we see that it is not met.

<u>Table 7:</u> Calculation on the current output by the battery in the 120s.

Time in hours	- the hovercraft is going to be traveling the maze in 120s in hours; 120s/3600s = 0.0333h
Current given by the Gravity 2200mAh	- in amperes => 2200mAh = 2.2A
Current in 120s	$0.0333h * 2.2A = 0.07326A \; in \; 120s$
Conclusion	From the calculations above, we see that the current requirement of the hovercraft is not met.

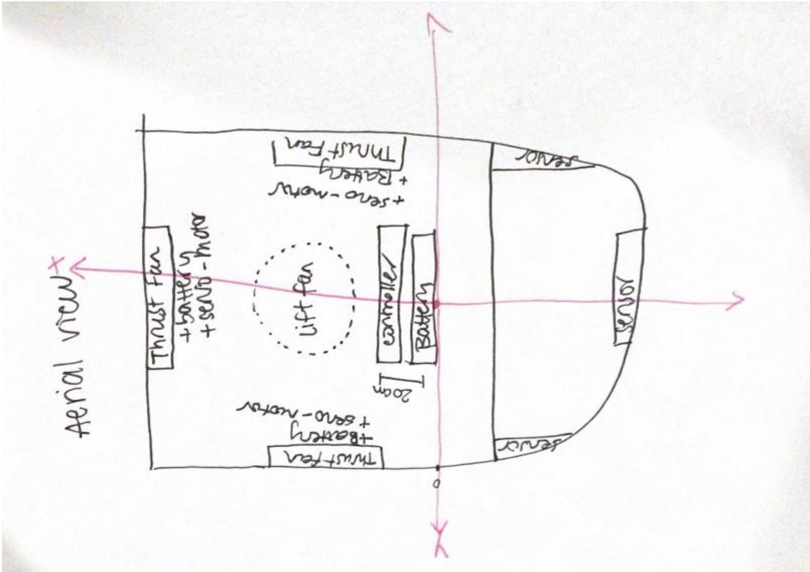


Figure 4: Triple Thrust Fan Design - C.O.M. Detail

4. Linear Acceleration

Having three thrust fans is going to allow this design to have a relatively fast velocity and linear acceleration. However, this velocity could be compromised, considering that there is the added weight of 17 components.. The moment of inertia is also an important criteria to look at when talking about velocity since we want to see how resistant to angular acceleration the hovercraft is going to be. In the case of design #2, the net moment of inertia is estimated to be 0.0936912 kg/m^2, which is higher than the other two designs. This means this design is going to need additional force to displace and rotate the body. With that being said, this fact could also be translated into linear and angular acceleration. The linear acceleration is calculated to **0.3242232258 m/s^2** , while the angular acceleration is approximated to **1.71504934 rad/s**. Both of these values are smaller than design #1, meaning that the hovercraft is not going to be rotating and moving optimally.

Data for the linear acceleration:

Maximum Thrust, Fwd	0.6427401228N
Maximum Linear Accel	**0.3314118402m s^-2**

Data for the angular acceleration

Max thrust, fwd	0.6427401228N
Radial arm length	0.25m

Torque	0.1606850307N m
Max angular accel	**1.747123346 rad s^-1**

Table 8: Calculation of the moment of inertia.

Component	**Mass (total kg)**	**Radial distance from center (m)**	**Moment of inertia**
Lift Fan AFB-1212SH	0.198	--	0.0004752
Servo HS-311	0.129	0.2	0.00516
Thrust Fan MEC-0251V1	0.486	0.4	0.07776
IR Sensor GP2Y0A02YK0F	0.0144	0.2	0.000576
Microcontroller	0.15	0.2	0.006
IMU/Regulator/Board	0.05	0.2	0.002
DC Sources			
Gravity 2200 mAh	0.912	0	0.0002047
TOTALS	**1.9824**		**0.0919712**

Table 9: Data for the lift fan:

Lift Fan		Value	Units
	Static Pressure, avg, AFB	96.939	Pa
	Radius of skirt	0.2523	m
	Area of skirt	0.1999789914	m^2
	Lift Force	19.38576345	
			Lift > Normal?
	Normal Force	19.025514	**TRUE**

<u>Table 10:</u> SWOT Analysis Design 2

Design 2			
Strengths	Weakness	Opportunities	Threats
- more speed - easier to avoid walls with all the sensors - smaller so easier to move	- too heavy - less energy efficiency - less stable - harder to implement	- make use of the maneuverability to complete the track faster -	- Clipping corners will happen because of the fan thrust - obstacles can be difficult to pass

6.3 DESIGN 3

This design goes with a more simple approach with a smaller number of components compared to the other designs, with a total of 12 components. This will prevent the hovercraft from being weighed down and makes it more convenient for hovering throughout the track. The hovering will be accomplished by two lift fans that are placed on two sides of the craft, which allow for stability and a more equal proportion of air being pushed into the skirt. There is a single thrust fan that will allow for the movement of the hovercraft by pivoting on a platform controlled by the motor. This can prevent the hovercraft from getting caught when turning since the body will simply move in a linear manner the entire course.

Figure 5-A displays the dimensions of the base styrofoam platform that will be used for this design:

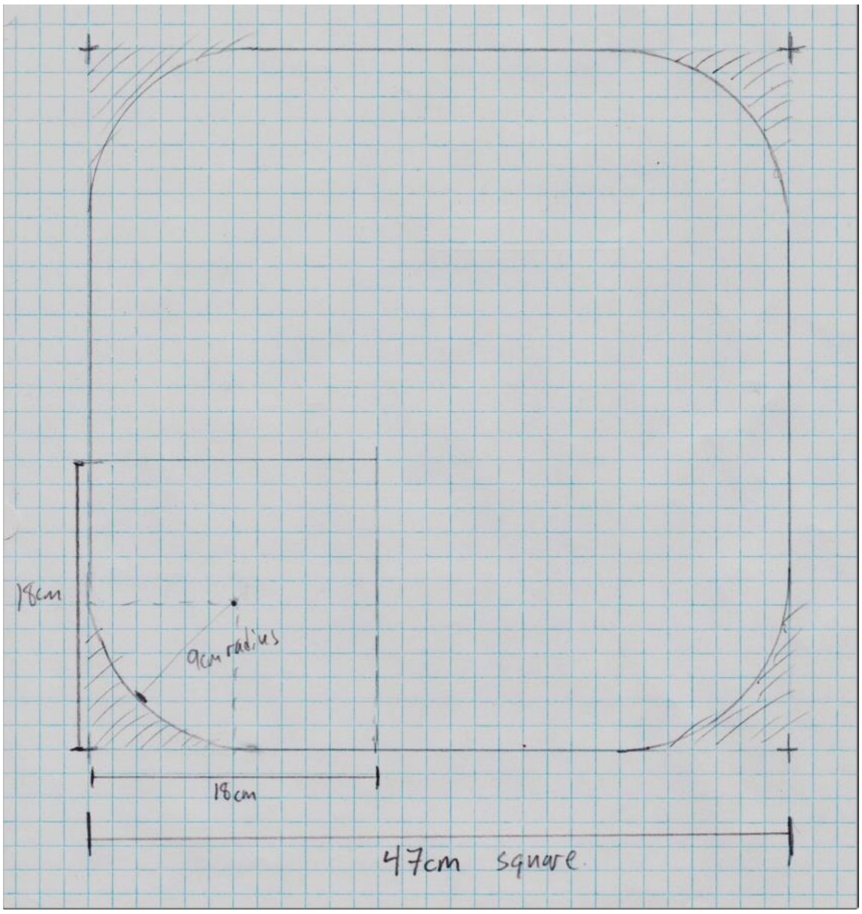


Figure 5-A: Final Design - Dimensions Detail

The figure below shows the placement of all the components on the styrofoam base platform, including the skirt that will cover the perimeter of the platform:

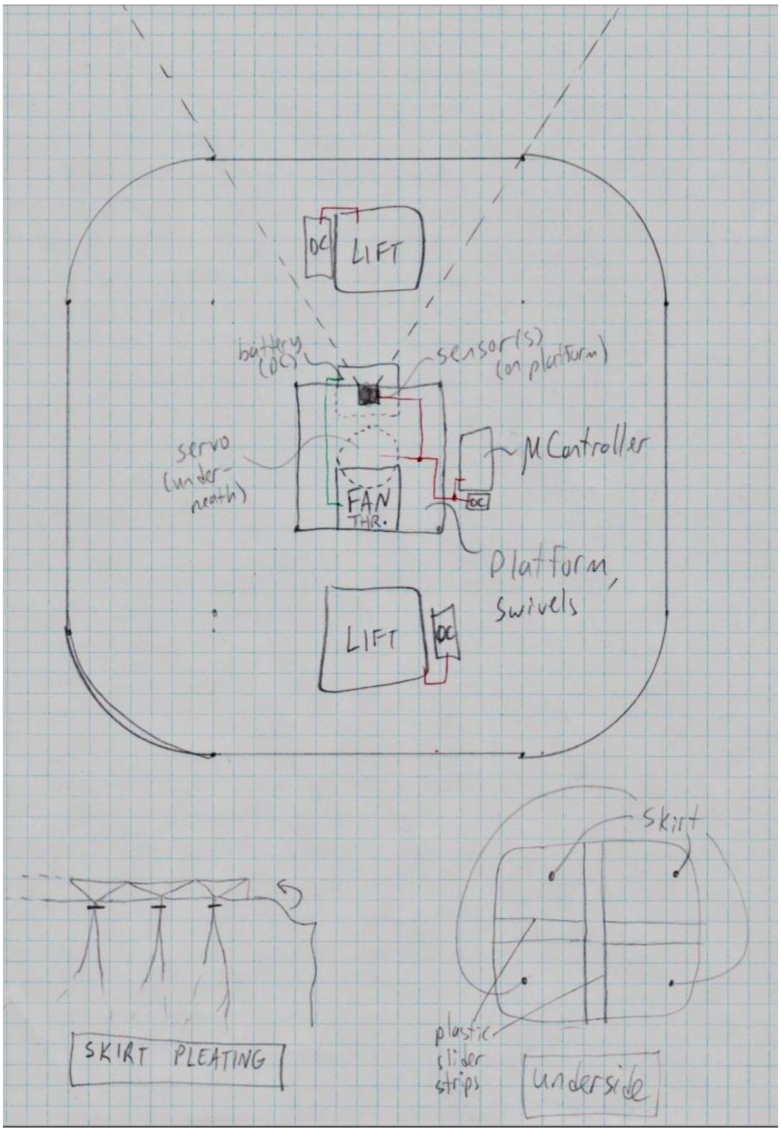


Figure 6: Final Design - Components Detail

(Figure 8 contains the exact placements/measurements of the components seen on the base platform in Figure 6 according to the center point of the hovercraft with the radial distance.)

Note the placement of the batteries in Figure 6 with respect to their load components: dedicated sources are located next to each lift fan, as well as next to the thrust fan, with the small potential DC near the microcontroller powering the remaining components.

See below the components that will be required to construct this design and their details: AFB-1212SH’s, Servo HS-311’s, IR sensor’s, US Sensor’s, microcontroller’s, and Gravity 2200 mAh’s mass, VDC, and dimensions from [5], [3], [6], [7], [11], [8] .

Table 11: Component Details

Component	Quantity	Mass (kg)	Total Mass (kg)
Lift Fan AFB-1212SH	2	0.198	0.396
Servo HS-311	1	0.043	0.043
Thrust Fan AFB-1212SH	1	0.198	0.198
IR Sensor GP2Y0A02YK0F	1	0.0048	0.0048
US Sensor MB1030-000	1	0.0043	0.0043
Microcontroller	1	0.15	0.15
IMU/Regulator/Board	1	0.05	0.05
DC Sources			
Gravity 2200 mAh	2	0.228	0.456
Gravity 2200 mAh	2	0.228	0.456
TOTALS	**12**		1.7581

All calculation equations are specified in design 1.

The following figure displays important measurements and calculations performed as a basis for further understanding the rotational aspect of the hovercraft. It includes information on the exact placement of the components on the base styrofoam platform according to the center point of the platform:

Table 12: Rotational Data of Hovercraft

Component	Radial distance from center (m)	Moment of inertia			
Lift Fan AFB-1212SH	--	0.0004752			
Servo HS-311	0	0			
Thrust Fan AFB-1212SH	0	0			
IR Sensor GP2Y0A02YK0F	0	0			
US Sensor MB1030-000	0	0			
Microcontroller	0.115	0.00198375			
IMU/Regulator/Board	0.07	0.000245			
DC Sources					
Gravity 2200 mAh	0.07	0.0022344		**Expending 8800 mAh total**	
Gravity 2200 mAh	0.2	0.01824			
TOTALS		**0.04412795**			

Table 13 below shows data for the two lift fans that are used in this design:

<u>Table 13:</u> Lift Fans' Data

Static Pressure, avg, AFB		96.939		Pa			
Perimeter of skirt		1.7255		m			
				m			
Area of skirt		0.2139469		m^2			
Lift Force		20.73979854			The lift force of each fan (2 lift fans in total)		
				Lift > Normal?	TRUE		
Normal Force		17.246961					

Since the lift force is higher than the normal force, the frictional force can be considered to be zero, allowing the craft to hover over a certain distance.

Table 14 shows the calculation process for obtaining the linear acceleration of the hovercraft depending on characteristics that will be further explained:

<u>Table 14:</u> Calculations for Linear Acceleration

Maximum Thrust, Fwd	1	*	calculated =		0.2853185507	N
Maximum Linear Accel					**0.1622880102**	**m s^-2**

In this design, the linear acceleration is lower due to the presence of a single thrust fan. Due to this, there is less thrust force than if there were multiple thrust fans since only one device is now going to be pushing the air in order to move the hovercraft forward. However, considering the low component count on the craft, and its stability, the movement of the hovercraft can be done smoothly, compensating for the slower acceleration.

Table 15: Calculating Angular Acceleration

Max thrust, fwd	1	*	calculated =		0.2853185507	N		
Radial arm length					0.0139	m	from datasheet of servo	
Torque		rxF	perpendicular		0.003965927855	N m		
Max angular accel		**torque/mom of Inertia**			**0.08987337627**	**rad s^-1**		

In Table 15 there is again mention of the thrust force that is applied because this will help determine the torque of all components on top of the servo motor used since those are the parts of the craft that will allow the turn of the vehicle. The radial arm length considered is from the circular component on the servo on which the small platform will be placed in order to cause the fan's rotation. This is where the force will be applied to initiate the rotational movement. This allows for a smaller torque to be needed at every turn in the track since the force does not need to be applied on the larger body of the hovercraft. Knowing the moment of inertia of the hovercraft, the maximal angular acceleration that would occur is calculated to be fairly small, similar to the linear acceleration. However, going back to the smaller area on which force is applied, the rotation can be performed with more ease.

Table 16 explores important criteria that should be considered to get optimal performance and the way this design respects each criterion:

Table 16: Important Criteria and Performance According to Design #3

Criteria	Performance
Turning Capability	Since the entire body is not required to rotate, it is rather the platform holding the fan that will perform rotation, there will be more freedom in rotation. This will also require less area around the craft to perform the turns, thus preventing it from getting stuck. The torque necessary will also be smaller considering the smaller surface where the force needs to be applied (0.003965927855 N*m), allowing for an easier turn.
Linear Acceleration	Due to a single thrust fan, the linear acceleration will not be high (0.1622880102 m*s^2), but should be able to complete the track in the given time. Linear acceleration will however still be very important considering the body of the craft keeps

	moving in a linear manner even through turns, therefore it can be picked up more rapidly.
Energy Efficiency	All four batteries used are of the highest capacity (2200 mAh), therefore there is high energy usage, however all components will be given the power necessary to function with fewer issues in the long run. The test runs that will need to be done prior to the final competition were also considered in the decision of these batteries.
Weight	The addition of all the components causes the weight to be large, which can cause lower velocity, however the elements are placed in a manner that will prevent instability.
Stability	There are two lift fans placed on two equal distances from the center point of the craft, which will allow it to hover in a stable manner by dispersing the air more evenly through the skirt.
Number of Components/ Simplicity	There is a fairly low number of components, which allows for a simpler design and better placement of the components on the body of the hovercraft.

<u>Table 17:</u> SWOT Analysis Table

Design #3			
STRENGTH	WEAKNESS	OPPORTUNITY	THREAT
Less components Less likely to get caught between walls (because the body does not turn) Torque only needed on small surface Large surface area for proper dispersal of components -> more stability	Slightly heavier than other designs Smaller thrust force Smaller linear acceleration	120 seconds is given to complete the track There are fairly long distances in the track that are straight, therefore less angular acceleration needed The lower the number of components and time to complete the track, the higher the overall score	There are multiple turns There are three obstacles to hover over

7. SELECTION OF DESIGN

In this section, we select the hovercraft design using AHP and WOT analyses.

7.1 AHP ANALYSIS

The Analytic Hierarchy Process is a comparison method to help choose which design will be the best based on the criteria chosen and their priorities. This process helps to have an objective view on which design is better depending on the criterias chosen. We first did the paired comparison matrix to choose the importance of each criterias. Then we did an analysis of each criteria on the three designs to see which designs was superior.

<u>Table 18:</u> Paired comparison matrix

Criteria	Turning capability	Linear acceleration	Stability	Simplicity	Priority vector (in %)
Turning Capability	1	1/5	1/6	1/8	4.33
Linear acceleration	5	1	1/3	1/3	19.37
Stability	6	3	1	1/4	29.7
Simplicity	8	3	4	1	46.51
Total	20	7.2	5.5	1.70	100

Ax (result of multiplication of matrix between A and x)	Consistency vector
18.94795	18.94795 / 4.33 = 4.375
66.1693	66.1693 / 19.37 = 3.416
125.4175	125.4175 / 29.7 = 4.22
258.06	258.06 / 46.51 = 5.54

$\lambda max = (4.33 + 3.416 + 4.22 + 5.54) / 4 = 4.20$
CI = $(\lambda - n) / (n-1) = 0.0126$
CR = $0.0126 / 0.90 = 0.014 < 0.1$

Table 19: Paired comparison matrix level 2 with respect to the rotation factor

Choice of design	Design 1	Design 2	Design 3	Priority vector (in %)
Design 1	1	1/5	1/9	6.34
Design 2	5	1	1/3	30.6
Design 3	9	3	1	62.98
Total	15	4.2	1.44	100

Table 20: Paired comparison matrix level 2 with respect to the Velocity factor

Choice of design	Design 1	Design 2	Design 3	Priority vector (in %)
Design 1	1	1/3	1/7	8.33
Design 2	3	1	1/4	23.98
Design 3	7	4	1	67.72
Total	11	5.33	1.39	100

Table 21: Paired comparison matrix level 2 with respect to the Stability factor

Choice of design	Design 1	Design 2	Design 3	Priority vector (in %)
Design 1	1	2	1/6	12.24
Design 2	1/2	1	1/5	6.57
Design 3	6	5	1	46.40
Total	16.5	8	1.36	100

Table 22: Paired comparison matrix level 2 with respect to the Simplicity factor

Choice of design	Design 1	Design 2	Design 3	Priority vector (in %)
Design 1	1	5	1/6	34.80
Design 2	1/5	1	1/5	7.90
Design 3	6	5	1	67.72
Total	11	5.33	1.39	100

Table 23: Overall composite weight of each alternative choice based on the priority of each criteria

Criteria	Turning capability	Linear acceleration	Stability	Simplicity	Priority vector (in %)
Priority vector (in %)	4.33	19.37	29.7	46.51	100
Design 1	6.34	8.33	12.24	34.80	21.42
Design 2	30.6	23.98	6.57	7.90	17.26
Design 3	62.98	67.72	46.40	67.72	61.205

7.2 WOT ANALYSIS

To know which hovercraft is better between all our designs, we used different methods such as the WOT analysis. It is a way to see which design is better and why. To do that, we had to choose the most important criteria which are: rotation, velocity, stability, and simplicity of implementing this design. We then gave a "grade" for each design on each criterion, normalized to a value of 1. To calculate the weighted evaluation, we multiplied the importance weight by the "grade" given for each criterion. Then we did the average and found the design with the higher score was Design 3.

Table 24: WOT Analysis

		Design 1		Design 2		Design 3	
Factor	Importance (weight)	Grade	Weighted evaluation	Grade	Weighted evaluation	Grade	Weighted evaluation
Turning capability	0.35	0.6	0.21	0.4	0.14	0.9	0.315
Linear acceleration	0.15	0.6	0.09	0.7	0.105	0.4	0.06
Stability	0.3	0.4	0.12	0.3	0.09	0.7	0.21
Simplicity	0.2	0.7	0.14	0.5	0.1	0.6	0.12
Total	1	0.575	0.56	0.475	0.435	0.65	0.705

7.3 CHOSEN DESIGN

Given the previous calculations and analyses, Hovercraft Design 3 was chosen. Since in the analyses, it had the highest scores and respect more of the criteria that were specified previously.

8. MATLAB SIMULATION OF CHOSEN DESIGN

Below is the Matlab Simulation Code used to prove that our chosen design can in fact complete and finish the track within a maximum of 120s.

Editor - G:\My Documents\MATLAB\PDRHOVERCRAFT.m

PDRHOVERCRAFT.m

```
%%Getting the Hovercraft's linear Acceleration, linear velocity,and linear displacement
volumeFlowRate=0.0503;
radiusSweepOfFan=0.06;
densityOfAirSTP=1.2754;
MassTotalHovercraft=1.7581;
t = 0:120; %total time to finish track

%Getting the swept area of fan
sweptAreaofFan=pi*radiusSweepOfFan*radiusSweepOfFan;
%Getting the Exit Velocity of fan
ExitVelocityFan=volumeFlowRate/sweptAreaofFan;
%Getting the mass flow rate of air
massFlowRateAir=volumeFlowRate*densityOfAirSTP;
%Getting the thrust force
thrustForce= massFlowRateAir*ExitVelocityFan;

%Getting the hovercraft's linear acceleration
hovercraft_linear_acceleration= thrustForce/MassTotalHovercraft;

%Getting the hovercraft's linear velocity
%vf=vi+at where vf=final velocity and vi=initial velocity=0
hovercraft_linear_velocity= hovercraft_linear_acceleration*t;

%Getting the hovercraft's linear displacement
%x=1/2at^2+vi(t)+xi
%where vi=0, xi=0
hovercraft_linear_displacement=1/2.*hovercraft_linear_acceleration.*t.^2;

%plotting the hovercraft's linear acceleration, velocity, displacement
```

Figure 12-A: MATLAB Simulation Code, Part 1

```
subplot(3,1,1)
yline(hovercraft_linear_acceleration)
%since linear acceleration is a constant so graph is horizontal line
title('Hovercraft Linear Acceleration vs. Time')
xlabel('Time(s)')
ylabel('Linear Acceleration (m/s^2)')

subplot(3,1,2)
plot(t,hovercraft_linear_velocity)
title('Hovercraft Linear Velocity vs. Time')
xlabel('Time(s)')
ylabel('Linear Velocity (m/s)')

subplot(3,1,3)
plot(t,hovercraft_linear_displacement)
title('Hovercraft Linear Displacement vs. Time')
xlabel('Time(s)')
ylabel('Linear Displacement (m)')

%%Getting the hovercraft's angular acceleration, angular velocity, angular displacement
totalMomentsOfInertia= 0.0714573475;
distance_torque=0.0139;

%Getting the torque
torque=thrustForce*distance_torque;

%Getting the angular acceleration
hovercraft_angular_acceleration=torque/totalMomentsOfInertia;
```

Figure 12-B: MATLAB Simulation Code, Part 2

```
%Getting the angular velocity
hovercraft_angular_velocity=hovercraft_angular_acceleration*t;

%Getting the angular displacement
hovercraft_angular_displacement=1/2 .*hovercraft_angular_acceleration.*t.^2;

%Plotting the hovercraft's angular acceleration, velocity, displacement
figure

subplot(3,1,1)
yline(hovercraft_angular_acceleration)
title('Hovercraft Angular Acceleration vs. Time')
xlabel('Time(s)')
ylabel('Angular Acceleration (rad/s^2)')

subplot(3,1,2)
plot(t,hovercraft_angular_velocity)
title('Hovercraft Angular Velocity vs. Time')
xlabel('Time(s)')
ylabel('Angular Velocity (rad/s)')

subplot(3,1,3)
plot(t,hovercraft_angular_displacement)
title('Hovercraft Angular Displacement vs. Time')
xlabel('Time(s)')
ylabel('Angular Displacement (rad)')
```

Figure 12-C: MATLAB Simulation Code, Part 3

The codes in Figure 12-A, 12-B, 12-C generate the two subplots found in Figure 13 below.

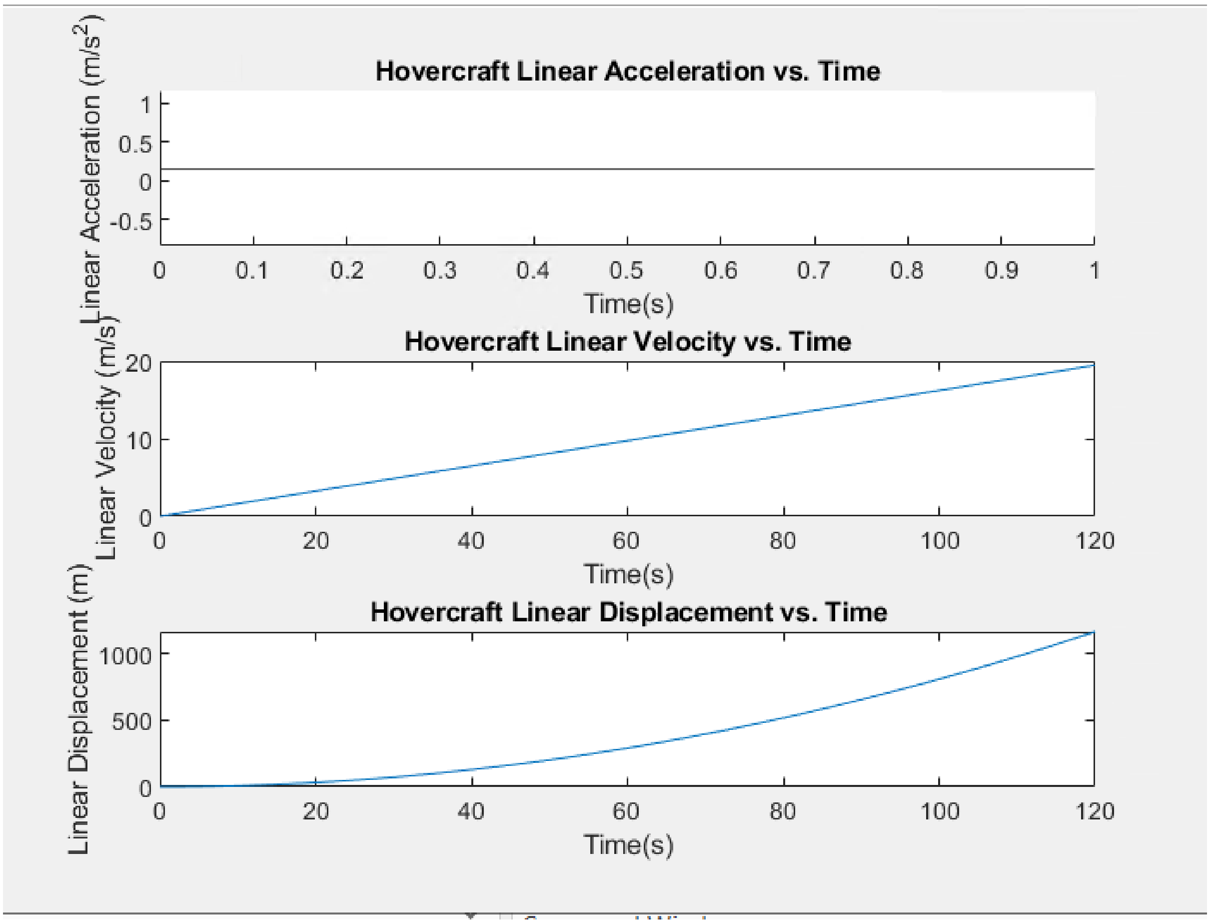


Figure 13-A: Linear Acceleration, Linear Velocity and Linear Displacement vs. Time

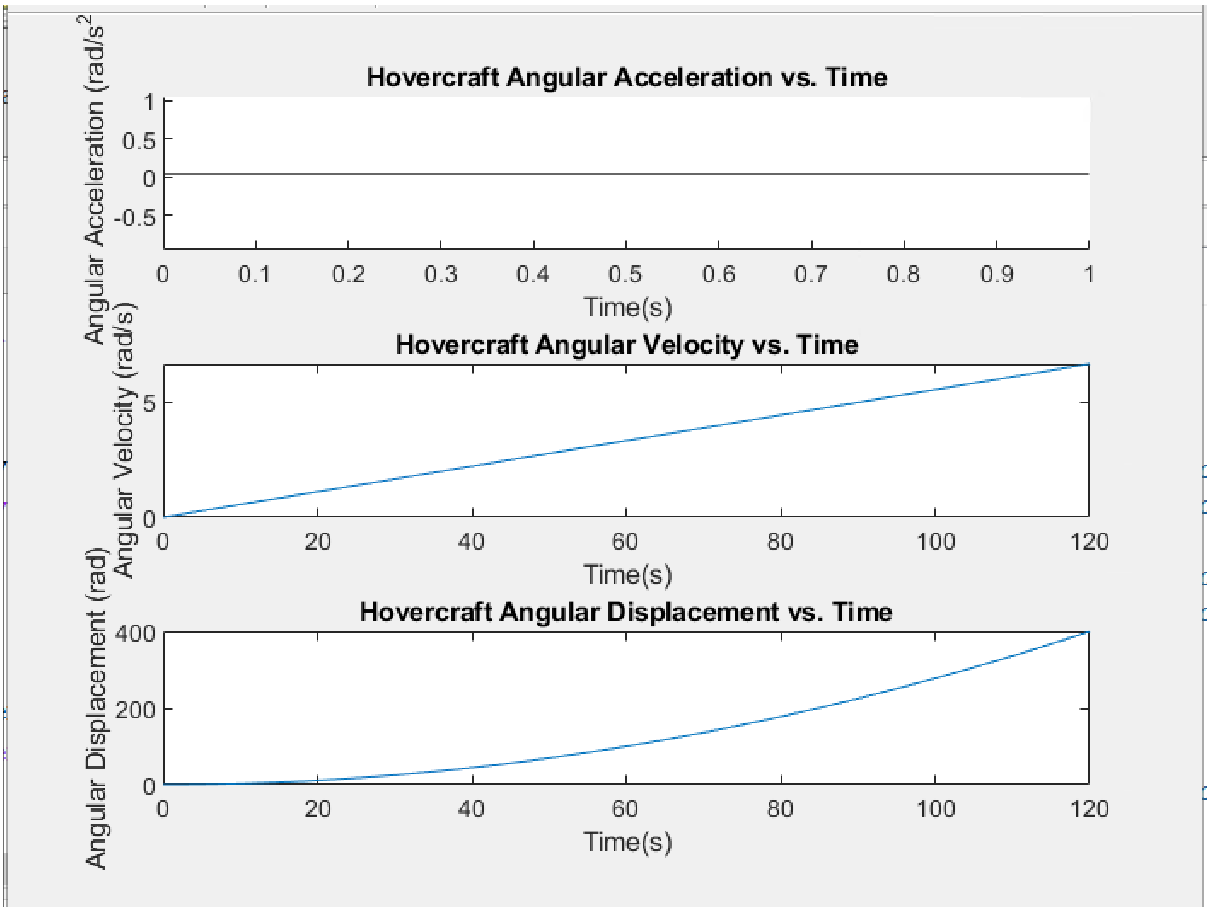


Figure 13-B: Angular Acceleration, Angular Velocity, and Angular Displacement vs. Time

The figures 13-A and 13-B above prove the fact that the hovercraft will be able to complete and finish the track within a maximum of 120s.

9. SUMMARY

The competition's purpose is to design and build a hovercraft. The hovercraft, as the name implies, is a device/vehicle that hovers over the ground (depending on the proportion). The hovercraft in our case is a little gadget that should hover 3-5mm above the ground. However, there are several needs and limits in the construction of this device: first and foremost, the hovercraft must be autonomous, meaning it must complete the circuit without the assistance of the competitors. Second, the device has a 120-second time limit each try, with a total of three attempts. Finally, the hovercraft must conquer 3 obstacles. The team obtains a score of 0 if any of these standards are not satisfied.

To win the tournament, the teams must construct their hovercrafts in such a way that they would score the maximum points. These points are awarded based on a simple calculation that essentially translates to: in order to get the maximum points, you must complete the track as quickly as possible while utilizing the fewest possible major components.

It was vital for the team to brainstorm several ideas utilizing available resources. Many meetings were spent deliberating, sketching, revising, debating, and choosing which ideas were most suited to gaining the most points. The best of three distinct designs was picked for the next competition using several sorts of assessments, such as SWOT, WOT, and AHP.

After spending many hours on a new design iteration for the new model, it was evident how much effort goes into an engineering project and how it affects the engineers. Projects like this might be delayed by days or weeks if effective cooperation and communication are not in place. During the course of this assignment, it is reasonable to state that an important lesson was learned.

10. PROGRESS SCHEDULE

Below is the progress schedule to date. It was last updated on March 7.

ENGR 290 - Autonomous Hovercraft Project

Progress as of March 7

Group 11

Project Start : Sat, 1-22-2022

Display Week (1 is beginning) : 1

Jan 17, 2022 — Jan 24, 2022 — Jan 31, 2022

TASKS	MEMBERS RESPONSIBLE	PROGRESS	START	END
Phase 1: Groundwork				
First Meeting	Everyone	100%	23-01-22	23-01-22
Rough Designs	Jamie, Eddy, Aminata	100%	23-01-22	30-01-22
Code/Controller Review	Asha, Pavithra, Kamar	100%	23-01-22	30-01-22
Group Meeting	Everyone	100%	30-01-22	30-01-22
Performance Critera	Everyone	100%	01-02-22	05-02-22

Display Week (1 is beginning) : 4

Feb 7, 2022 — Feb 14, 2022 — Feb 21, 2022 — Feb 28, 2022 — Mar 7, 2

TASKS	MEMBERS RESPONSIBLE	PROGRESS	START	END
Phase Two: Initial Builds				
SUPERTASK: P.D.R.	Everyone (see Phase 2B)	100%	06-02-22	09-03-22
Retrieve Kit 1	Jamie, Kamar, Pavithra	100%	21-02-22	21-02-22
Code - Controller	Kamar	100%	01-03-22	05-03-22
Code - Sensors	Jamie	100%	01-03-22	05-03-22
Safety Tests	All - TBA			

Display Week (1 is beginning) : 6

Feb 21, 2022 | Feb 28, 2022 | Mar

21 22 23 24 25 26 27 28 1 2 3 4 5 6 7 8

TASKS	MEMBERS RESPONSIBLE	PROGRESS	START	END
Phase 2B: Preliminary Design Report				
Report Framework	Eddy	100%	25-02-22	05-03-22
Intro, Requirements	Eddy	100%	28-02-22	02-03-22
Ideas/Research	Pavithra	100%	01-03-22	06-03-22
Indiv. Design Analysis	Jamie; Asha/Aminata; Kamar/Pavithra	100%	02-03-22	06-03-22
Progress Report	Jamie	100%	02-03-22	07-03-22
Summary	Asha	100%	05-03-22	08-03-22
References	Kamar	100%	05-03-22	08-03-22
Final Format	Everyone	100%	07-03-22	08-03-22
Presentation	Everyone	100%	04-03-22	08-03-22

10.1 SOFT PROGRESS SCHEDULE

This is a list of subtasks that do not currently have a fixed schedule, and are slated to be integrated into the Gantt chart as the project progresses.

<u>MARCH</u>

- Approach Dmitry re: controller operation
- Safety tests; obtain kit 2
- Create craft body and servo/fan platform
- Craft skirt and pleat to body
- Weight and balance testing
- Final wiring plan re: power supply weight and capacity

· Continue building and testing code (milestones to be defined and set after Tech Asst. 2)
- Physical testing - find suitable testing ground

<u>APRIL</u>

- Finalize design; screen for final features and balance
- Attempt full dry run with track (or reasonable facsimile)
- Troubleshooting: schedule well-defined time slots for final testing and debugging

11. REFERENCES

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