IOP Conf. Series: Materials Science and Engineering **114** (2016) 012150 doi:10.1088/1757-899X/114/1/012150

Development of a working Hovercraft model

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Abstract. This paper presents the development process to fabricate a working hovercraft model. The purpose of this study is to design and investigate of a fully functional hovercraft, based on the studies that had been done. The different designs of hovercraft model had been made and tested but only one of the models is presented in this paper. In this thesis, the weight, the thrust, the lift and the drag force of the model had been measured and the electrical and mechanical parts are also presented. The processing unit of this model is Arduino Uno by using the PSP2 (Playstation 2) as the controller. Since our prototype should be functioning on all kind of earth surface, our model also had been tested in different floor condition. They include water, grass, cement and tile. The Speed of the model is measured in every case as the respond variable, Current (I) as the manipulated variable and Voltage (V) as the constant variable.

1.Introduction

At the beginning of the history hovercraft was created for military marine vehicle. In this era of globalization, hovercraft is also used in the public transportation, travelling, agricultural, forestry, sport activities, recreational and others. The other term of hovercraft is called as "Air Cushion Vehicle" (ACV). Hovercraft can provide a better speed compared with the other marine vehicles and also an excellent performance on the rough surface as well.

In the hovercraft design, the vehicle is equipped with one or two engines to create the air cushion (Lift force) and to create the thrust to move to any direction. However the design that will be presented in this paper used two engines; the first is located at the back of hovercraft for the thrust to move forward or reverse motion, while the second is located at the centre of the model to create the "Lift". The lifting or hovering of hovercraft pushes the air into the ground and thus creates pressure. The chosen pressure will strengthen the cushion and lift the weight. The air escapes from the bottom part of hovercraft produces the hovering effect.

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2.Background

A hovercraft is a vehicle that is hovering just above the ground or over snow or water by a cushion of air [1]. In a hovercraft a similar cushion of air is maintained by pumping in a steady air supply, to keep pace with the linkage round the sides. There is always some leakage because the craft has to be free to move, but the designers use various methods to keep leakage as small as possible so that only minimum power is required to keep up the air supply [2]. There are various ways of creating of air cushion and reducing leakage. When the fan rotates, the air pressure is pushed inside the skirt to create lifting and the hovercraft hovers with almost no friction. A well designed hovercraft has much better performance than the normal boat because it has less drag and requires less horsepower to move. This condition results higher speed and less fuel consumption. The hovercraft gets above twice the fuel mileage of a boat with similar size or capacity [3]. The medium scaled hovercraft also works very well in water where the standing waves up to a meter high [4]. By using the concept and equation of Bernoulli, the volumetric flow rate of the hovercraft fan can be obtained.

The first hovercraft is produced ever in Malaysia was by AFE manufacturing company with Japanese technology collaboration [5]. The launching of the hovercraft in Putrajaya in 2003 has paved way for new opportunity in manufacturing sector. This event was a prelude for the event in 2006 where Malaysia will host World Hovercraft Championship [6]. The hovercraft has been made in variety of shapes, sizes and types based on its characteristics and purpose. There are three main types or categories of hovercraft which are amphibious hovercraft, non-amphibious and the semi-amphibious hovercraft. The weight of the hovercraft is one of the considerations important in the design. Light-weight materials are used for the construction. Moreover, the pressure must be created inside the plenum chamber in order to create the sufficient lift force to the hovercraft. In the model, the Peripheral Jet system is applied.

2.1 Calculation of Lift Force

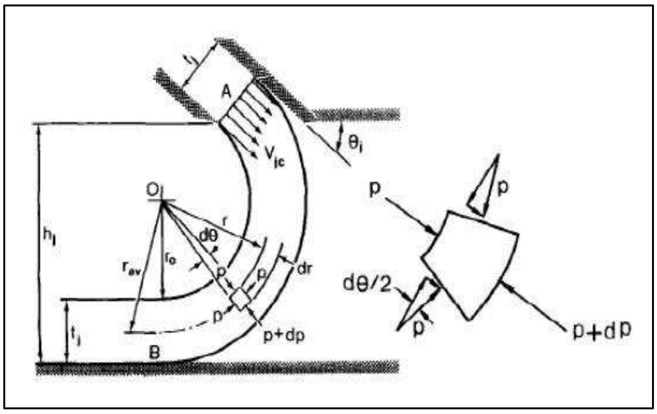

Figure 1. Geometry of Peripheral Jet System. [1]

2.1.1 General equation:

$$Fc = W = Pc\,Ac + Jj\,Lj\,Sin\,\theta j \quad (1)$$

(Okafor B E 2013)

- Fc = Lift force (N)
- W = Weight of the model (N)
- Ac = Area of cushion (m^2)
- Jj = Momentum flux of air jet per unit length of the nozzle (Kg/s^2)
- Lj = Nozzle perimeter (m)
- θj = Angle of the nozzle from the horizontal (°)

$$Jj = Pc\,r \quad (2)$$

(Okafor B E 2013)

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- r = The average radius of the curvature of the length (m)
- *Pc* = Cushion pressure (Pa)
- *hj* = The lift height (m)

From the calculation, we get:

- *Ac* = Length x Width = 0.025 m²
- *W* = Mass x Gravity = 0.8 x 9.81 = 7.848 N
- r = hj / (1 + cos θj)
- *hj* = 6.2 cm = 0.062 m (measured)
- $\theta = 45^o$
- r = 0.062 / (1 + 0.7071) = 3.5147 m
- *Jj* = 3.5147 Pc
- *Lj* = π x tj
- *tj* = orifice diameter (m) = 0.06 m
- *Lj* = 0.1885 m

Finally:

- $W = Pc\ Ac + Jj\ Lj\ sin\theta j$
- *W* = *Pc Ac* + 3.5147 *Pc* (0.1885) sin 45º = Pc (Ac + (3.5147 * 0.1885 * sin 45º))
- *Pc* = *W* / (*Ac* + 0.4685) = 7.848 / (0.025 + 0.4685) = 15.9027 Pa = 15.9027 N/m²

$$Pc/Pj = 1 - e^{-2tj/rav} \tag{3}$$

(Okafor B E 2013)

- *Pc/Pj* = 1 – 0.9664339552976728 = 0.0335660447023272 ≈ 0.03357
- *Pj* = 15.9027 / 0.03357 = 473.7176 Pa = 473.7176 N/m²

Total volume flow per second into the skirt is:

$$Qj = \frac{Ljhj}{1+cos\theta j}\left(\frac{2Pj}{\rho}\right)^{\frac{1}{2}}\left(1-\left(1-\frac{Pc}{Pj}\right)^{\frac{1}{2}}\right) \tag{4}$$

(Okafor B E 2013)

$$Qj = \frac{0.1885 \text{ x } 0.062}{1+\cos 45}\left(\frac{2(695)}{1.184}\right)^{1/2}\left(1-\left(1-\frac{15.9027}{473.7176}\right)^{1/2}\right)$$

$$Qj = 3.9709 \text{ x } 10^{-3} \text{ m}^3/\text{s}$$

Power required is given by:

$$Paj = Pj\ Qj = 473.7176 \text{ x } 3.9709 \text{ x } 10^{-3} = 1.881 \text{ W}$$

3.Design

A computer aided drawing (CAD) software CATIA V5 is used in this study to design the hovercraft in the test section as shown in Figure 1 before the fabrication process is started.

Table 1. Properties and values.

Properties	Value
Length	50 cm
Width	5 cm
Height	8 cm
Lift and Thrust Power	Battery
Lift Method	Propeller
Thrust Method	Ducted Propeller
Thrust Line Control	Servo Controlled
Body Material	Polystyrene
Model Weight	0.8kg

For the electrical part, the model fully operates by Arduino Uno. Two brushless motor (AXN-2208-2150), one PS2 controller and servo motor that needs the pulse Width modulation (PWM) from Aiduino are used. The PWM needs to activate all of the motor, and Arduino sends the PWM by the signal. All of the signals must be declared in the coding of Arduino.

Table 2. Pin number connection in Arduino Uno.

Arduino connection			
LIFT MOTOR (AXN-2208-2150)		PLAY STATION 2 CONTROLLER	
Pin	Description	**6**	Attention
9	Pulse Width Modulation(PWM)	**11**	Command
GND	Ground	**12**	Controller
THRUST MOTOR (AXN-2208-2150)		**13**	Clock
10	Pulse Width Modulation(PWM)	**Vcc**	3.3 V
GND	Ground	**GND**	Ground
SERVO MOTOR			
5	Pulse Width Modulation(PWM)		
Vcc	5 V		
GND	Ground		

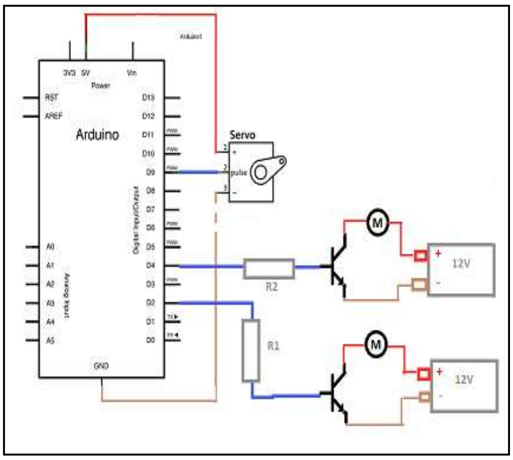

Figure 2. Circuit Diagram of Arduino.

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The PS2 controller is used to control the hovercraft model. There are six cables which are connected to the Arduino Uno: Clock, Ground, 3.3V, Attention, Controller and Command.

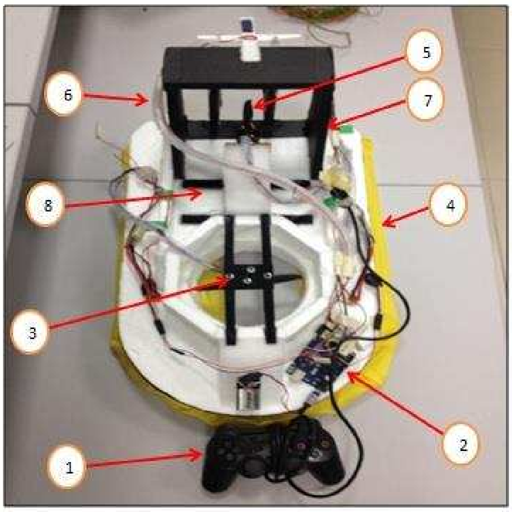
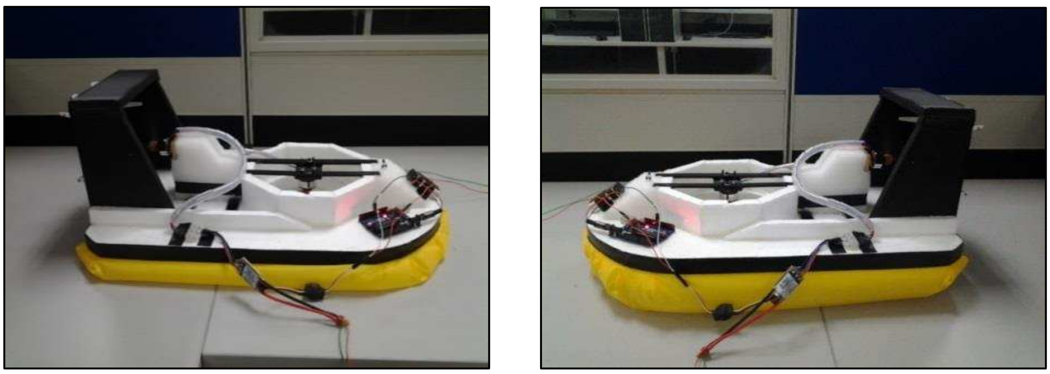


Figure 3. The Hovercraft Model Indication

Table 3. The Label and description

Label	Description
1	Playstation 2 Controller
2	Arduino Uno (Processing Unit)
3	Brushless Motor for lifting
4	Skirt/Air cushion
5	Brushless Motor for Propulsion
6	Rudder
7	Thrust Duct
8	Hull Base



a) Free condition **b) Hovering condition**

Figure 4. Free and Hovering Condition of the Hovercraft Model

Table 4. Dimension of Model Hovercraft

No	Items	Amount
1	Hull length	0.5m
2	Hull width	0.05m
3	Air gap	1mm
4	Max gross weight	0.8kg

Table 5. Hovercraft Model Measurement

Items	Unit	Amount
Approximate lift Perimeter	(m)	0.062
Total hover gap area	(m)	0.001
Total cushion area	(m^2)	0.025
Cushion pressure	(Pa)	15.9027
Expected actual air Velocity	(m/s)	14.26464
Lift air volume	(m^3)	0.00155
Estimated lift engine Power	(W)	1.881
Fan diameter	(m)	0.12

4.Testing

Hovercraft data log indicates the performance of hovercraft that has been tested in multi type of floor condition. There are four types of floor conditions: Tile floor, Cement floor, Grass and Water. For of all these floor test, the constant variable is the Voltage (V), the manipulated variable is the Current (I) and the respond variable is the Speed (S).

4.1 Hovercraft Performance Result on Tile Floor

- Floor conditions: Tile floor
- Motors: Brushless Motor (AXN-2208-2150)
- Constant variable: Voltage 11.5 Volts
- Manipulated variable: Current (Ampere)
- Respond variable: Speed of hovercraft (Hovercraft Performance)

Table 6. Hovercraft Performance Result with Tile Floor

No	Voltage (V)	Current (A)	Average time to travel 3 meter (s)	Speed (m/s)
1	11.5	0.0	–	–
2	11.5	0.5	–	–
3	11.5	1.0	–	–
4	11.5	1.5	15.8667	0.1891
5	11.5	2.0	4.9233	0.6093
6	11.5	2.5	3.3333	0.9000
7	11.5	3.0	3.1767	0.9444

4.2 Hovercraft Performance Result on Water

- Floor conditions: Water
- Motors: Brushless Motor (AXN-2208-2150)

- Constant variable: Voltage 11.5 Volts
- Manipulated variable: Current (Ampere)
- Respond variable: Speed of hovercraft (Hovercraft Performance)

Table 7. Hovercraft Performance Result on Water

No	Voltage (V)	Current (A)	Average time to travel 3 meter (s)	Speed (m/s)
1	11.5	0.0	–	–
2	11.5	0.5	–	–
3	11.5	1.0	–	–
4	11.5	1.5	9.8872	0.3034
5	11.5	2.0	6.6742	0.4495
6	11.5	2.5	5.0092	0.5989
7	11.5	3.0	4.4479	0.6745

4.3 Hovercraft Performance Result with Cement Surface

Floor conditions: Cement

- Motors: Brushless Motor (AXN-2208-2150)
- Constant variable: Voltage 11.5 Volts
- Manipulated variable: Current (Ampere)
- Respond variable: Speed of hovercraft (Hovercraft Performance)

Table 8. Hovercraft Performance Result with Cement Surface

No	Voltage (V)	Current (A)	Average time to travel 3 meter (s)	Speed (m/s)
1	11.5	0.0	–	–
2	11.5	0.5	–	–
3	11.5	1.0	–	–
4	11.5	1.5	25.4892	0.1177
5	11.5	2.0	23.6784	0.1267
6	11.5	2.5	22.2456	0.1349
7	11.5	3.0	19.0972	0.1571

4.4 Hovercraft Performance Result with Grass

- Floor conditions: Grass
- Motors: Brushless Motor (AXN-2208-2150)
- Constant variable: Voltage 11.5 Volts
- Manipulated variable: Current (Ampere)
- Respond variable: Speed of hovercraft (Hovercraft Performance)

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Table 9. Hovercraft Performance Result with Grass

No	Voltage (V)	Current (A)	Average time to travel 3 meter (s)	Speed (m/s)
1	11.5	0.0	–	–
2	11.5	0.5	–	–
3	11.5	1.0	–	–
4	11.5	1.5	32.2465	0.0930
5	11.5	2.0	30.4490	0.0985
6	11.5	2.5	29.5668	0.1015
7	11.5	3.0	28.3313	0.1059

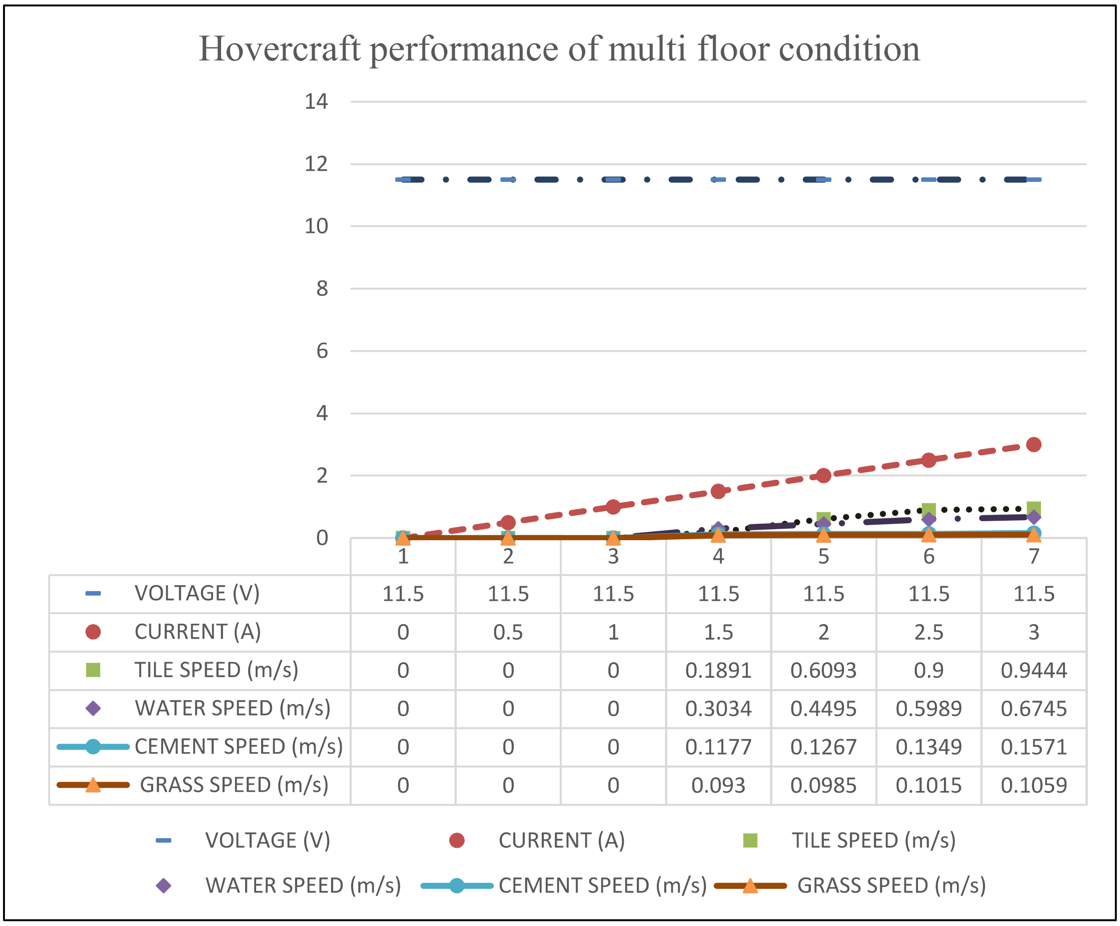

Figure 5. Hovercraft Model Performance of Multi Floor Conditions

5. Conclusion

The mechanical part is the most challenging issue; especially this is the model to the Hovercraft prototype in fabrication in the Faculty of Manufacturing Engineering. The hull of the model was made from the polystyrene due to light, low cost and easy to shape. The loss of the energy due to the air friction should be revised by fabricating a better thrust duct using different materials and method, a study that does not presented here in this paper. For the skirt, the soft rain coat is used. The location of the weights relative to the centre of gravity is very important. Since this is only a small model of 1/4 scale of the Hovercraft prototype, the stability problem seems not very serious. But in the prototype, every position of the weight of the parts is measured precisely so that the prototype will have a reliable stability whether on the road, on the grass or in the water. For the electrical part, the model uses Arduino Uno to activate the ESC (Electronic Speed Controller) because both of these motor drivers

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need supply by the pulse width modulation signal (PWM) that supported 25 Ampere. Two brushless motors AXN-2208-2150 are used for the purpose of lifting and propulsion. The fabrication of the Hovercraft model has been successful and the data of speed, air cushion pressure and power have been recorded for the use in the fabrication of the Hovercraft prototype in process.

6. References

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