International Journal of the Physical Sciences Vol. 6(17), pp. 4185-4194, 2 September, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS10.311

Full Length Research Paper

Development of a hovercraft prototype with an aluminium hull base

A. K. Amiruddin[1], S. M. Sapuan[2]* and A. A. Jaafar[2]

[1]Automotive Focus Group, Faculty of Mechanical Engineering Universiti Malaysia Pahang, Locked Bag 12, 25000Kuantan, Pahang, Malaysia.
[2]Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

Accepted 23 July, 2011

A study was undertaken to construct an economical and robust hovercraft by using the aluminium Al 6061-T6 (marine). In this study, the stability and ultimate strength of the aluminium Al 6061-T6 was tested to find its stands as the material for the hovercraft hull base development. Structural analysis by using NASTRAN/PATRAN software was carried out to see the suitability and the reliability of the alloy. The construction of the hull base prototype was supported by the results from this analysis and simulations of establishing aluminium Al 6061-T6 as the material use in building up the hull base. After series of experimental testing, the propulsion and lifting systems were successfully demonstrated and the prototype capable of maneuvering nicely.

Key words: Hovercraft, hull base, aluminium, structural analysis.

INTRODUCTION

In 1956, Christopher Cockerell, a British engineer, has build a hovercraft; a vehicle that literally floats on a cushion of air; also referred to as an air-cushion vehicle (ACV). It was powered by a fan and supported by the air cushion, it moved effortlessly between land and sea (Spedding, 2001). In June of 1959, successfully experiment was crossing the English channel between the ports of Dover and Calais. However, the first hovercraft was actually launched in the Soviet union long before Cockerell's maiden voyage (Chernenko, 2002).

Hovercraft has paved its way for new opportunity in Malaysia manufacturing sector. Its major introduction in Malaysia is to assist fire and rescue department and was produced by AFE manufacturing company with Japanese technology collaboration (NST, 2003). In 2003, an event to launch the hovercraft has been held in Putrajaya. This is as a starter to another event in 2006 where Malaysia will host world hovercraft championship (NST, 2002).

New fuel technology in recent hovercraft designs has seen a shift away from the use of gas turbines towards air-cooled diesel engines. The weight of these diesel engines has led to RTK Marine (name of the leading company that supplied workboats and military boats for the UK and overseas markets) to incorporate aluminium extrusions into the design of its new Tiger 40, to reduce the overall weight of the craft. Constructed in Singapore, the Tiger 40 has an overall length of 17.25 m with a disposable load of 3.25 tonnes. Initially, models were developed as river patrol craft for use by police and the military in the Far East. Plans for a full cabin, 30-passenger version and a variation for hydrographic and seismographic surveying are currently being considered. The hull of the prototype Tiger 40 is constructed from marine grade alloy aluminium of 1.6 mm thickness. It is built mainly with standard extrusions (Anderton, 1972).

Materials selection and structures for hovercraft

In order to construct a hovercraft, the design requirements such as the lift-to-drag (L/D) ratio have to be meet in comparison to conventional vessels. Stated

*Corresponding author. E-mail: sapuan@eng.upm.edu.my.

differently, this means that major design and construction changes must be affected in order to reduce weight (Kennel et al., 1998).

Small aluminium boats are quite popular, because of their lighter weight, reasonable price, good durability, etc. Compared with FRP (fiber reinforced plastics) boats, aluminium boats have particular limitations in styling and design flexibility due to their basic structure and the conventional construction process using the developed surfaces of aluminium sheets or plates, and extrusions at the joints (Nakamura et al., 1997).

However, due to the aspect of recycling and pollution problems for marine environmental protection, aluminium alloys have a good potential as marine-use material. Therefore, the disadvantage of their poor design flexibility, which results in undesired performance and limited appearance, should be improved by new technologies. In order to cope with the problem of forming compound curved surfaces, several methods have been introduced, for example, the 'stretch forming' method is used for small and mass-produced aluminium boats such as canoes. The introduction of 'hydraulic counter pressure forming' and 'warm press forming' are also efforts to improve the formability of aluminium alloys (Tajiri, 1995).

As in the case of high temperatures, where residual stress formation begins, the cooling rates should be slow to minimize the thermal stresses. If the cooling rate has a significant impact on the mechanical properties of the alloy, as in the intermediate temperature, the cooling rate should be high to ensure a supersaturated solid solution is retained. As for the lower temperatures cases, the cooling rate can be reduced as it generally has little impact on the final mechanical properties of the alloy (Dolan and Robins, 2004).

Fatigue is a critical factor in the development of cost-effective, high-strength and yet lightweight structural details. Recent analyses of aluminium hull structures (Herrington and Latorre, 1998) and (Nobukawa, 1996) focused on the critical weld details between transverse and longitudinal stiffeners. Lightweight aluminium hulls are not the only marine structure susceptible to fatigue. Recently, Nobukawa (1996) discussed survey results of high-strength steel members used in tanker hull construction. They reported the damage surveys of 48 tankers. While these very large crude carrier (VLCC) tankers were only 3 to 4 years old without significant metal corrosion or wastage, each tanker was found to have 10 or more fatigue cracks.

Aluminium alloys has been the material of choice for building airplanes and sometimes for the construction of land-based structures due to high strength-to-weight characteristics. The aluminium characteristics such as high-strength, weldable and corrosion resistant, have proved it as the best material of choice for weight sensitive applications especially in marine applications (Paik et al., 2005).

Recently, the ultimate limit state design approach has also widely been adopted for steel marine structures (Paik and Thayamballi, 2003). [13]. It is recognized that the ultimate limit state design approach is useful for the design of aluminium structures for marine applications, and practical design formulae have been derived together with some relevant considerations in terms of mechanical properties (Paik and Duran, 2004).

METHODOLOGY

Aluminium base analysis

Aluminium hull base was chosen as it gives lighter weight (Dannecker et al., 1997). Aluminium is a cost effective material for this hovercraft prototype project and can be easily found in the hardware stores. Structure analysis was carried out to confirm the reliability of this aluminium usage on the construction of the hovercraft prototype hull base.

All the data gathered from the hull base design produced by CAD-CATIA modelling were processed with finite element analysis software, MSC NASTRAN /PATRAN. This software can be applied for 3 dimensional analyses of the modelling and provide detail information on the three: the reaction force, displacement and stress tensor. The computed data was used for comparison with the maximum permissible stress derived from the minimum guaranteed mechanical properties of the material used in the component.

Here, we briefly outline the pre-processing of the hovercraft hull in the NASTRAN/PATRAN. Firstly, the CAD modelling of the hull was drawn using computer added design software CATIA. It was written in *.igs file format and then transferred into FEA software PATRAN. The CAD model provided the facets of the hull which was then transformed into solid form before computational meshed can be generated.

Hovercraft prototype

The hovercraft prototype was constructed according to the aluminium hull base analysis. The characteristics of the hovercraft systems were based on the design chosen. Calculations were then made by the listing of these characteristics within the limitations of the materials and equipment available, location and the centre of gravity of the hull. The construction processes are as follows: hull base construction, load testing, seat and controller navigation installation, engine installation, blade and blade cover construction, preliminary testing, blower installation for lift system, skirt construction and testing.

Aluminium base hull analysis

The results from the FEA analysis by using linear static solver are described in the following.

Calculation of the loading forces

In determining the magnitude of forces acting on the hull, the mass to be considered were the engine, payload and the hull structure, with the gravitational acceleration = 9.81 m/s^2. The total forces (engine force, human force, structure force, lift force and trust force)

Table 1. Mathematical calculation base on mass of the hull components.

Description	Mass specification
Engine, m_{engine}	31 kg
Human , m_{human}	70 kg
Structures , $m_{structure}$	50 kg
Calculation of engine force, F_{engine}	F_{engine} = engine mass x gravity acceleration = (31 kg) (9.81 m/s^2) = 304.11 N take the F_{engine} = 310 N for the analysis
Calculation of human force, F_{human}	F_{human} = human mass x gravity acceleration = (70 kg) (9.81 m/s^2) = 686.7 N take the F_{human} = 690 N for the analysis
Calculation of structure force, $F_{structure}$	$F_{structure}$ = structure mass x gravity acceleration = (50 kg) (9.81 m/s^2) = 490.5 N take the $F_{structure}$ = 500 N for the analysis
Calculation of lifting force, $F_{lifting}$	$F_{lifting}$ = F_{engine} + F_{human} + $F_{structure}$ = 310 + 690 + 500 = 1500 N
Less force is needed to trust the hovering craft by assuming that the trust equal to half of the lifting force:	
Calculation of trust force, F_{trust}	F_{trust} = $F_{lifting}$ / 2 (assume) = 1500 / 2 = 750 N
Calculation of air pressure, P_{air}	P_{air} = $F_{lifting}$ / A = 1500 N / 3.22 m^2 = 465.84 N/m^2 take the P_{air} = 466 N/m^2 for the analysis

acting normal to the surface of the hull (area of 3.22 m^2) was balanced pressure which was calculated by using "P = F / A", that is, pressure = force / area (Hibbeler, 1997) equation. The magnitude of the mass used to calculate the force act on the hull is as shown in Table 1.

Specification of analysis

Initially, the length and width of the hull design were 2200 and 1500 mm with the thickness of 12.7 mm. As for the constraint of the analysis, 14 bolt holes were fixed with flat surface to be considered. Static movement condition was made as the first case analysis and second case analysed with hull moving condition applied. Details of material and computational grid properties are shown in Table 2. The tetra element shape was chosen to optimize the analysis on the boundary condition so as to generate the automation meshing where relative values were referred. This was for the purpose of studying the maximum deflection of the aluminium hull base usage in the construction of the hovercraft prototype.

There were seven trials on the hull design analysis to get the best combination analysis values of reaction displacements, force and stress for hull. These were done with improvement for each case/trial as shown in Table 3.

RESULTS AND DISCUSSION

The best combination analysis values of reaction displacements, force and stress for hull when the number of bolts was 8, the smallest value of the hull's thickness was 6 mm with 9 rectangular support bars attached to hull, were 0.698 mm, 360 N and 42.5 MPa, respectively as shown in Table 4. Maximum value of reaction force

Table 2. Specification for details of material and computational grid properties.

Description	Specification
Material	Al 6061-T6, E = 68.9 GPa, υ = 0.35, σ_y = 131 MPa (shear)
1. Hull	Stainless steel 304, σ_y = 207 MPa
2. Bolt and nut	(Hibbeler, 1997)
Element	
1. Mesh	Solid
2. Element shape	Tet
3. Masher	Tet mesh
4. Topology	Tet 10
5. Global edge length	Automatic calculation
Boundary condition	Fixed in x,y,z direction at bolt holes

Table 3. Improvement made for the hull design.

No. of case	No. of bolt	Hull thickness (mm)	No. of rectangular support bar
1	14	12.7	-
2	12	12.7	-
3	12	6.35	-
4	10	6.35	4
5	8	6.35	7
6	8	6	7
7	8	6	9

Table 4. Result for the analysis.

No. of case	Max constraint forces (N)	Max stress tensor (MPa)	Max displacements (mm)
1	128	1.99	0.0359
2	1840	28.0	0.88
3	5760	130.0	5.93
4	636	44.8	4.48
5	223	23.4	0.445
6	386	40.6	0.976
7	360	42.5	0.698

occurred only at the bolt holes located near the lifting hose fan hole at the centre of hull. The displacements of 0.698 mm were less than 1 mm.

From all cases, the maximum value result for the reaction forces was 5760 N as axial direction and for the safety purposes, purposes; this value was used as a reference to calculate the diameter of bolt. Equations used were F.S. = σ_{fail} / σ_{allow} (factor of safety = fail stress / allowable stress), "σ_{allow} = F / A" (allowable stress = force /area) and "A = $\pi D^2/4$" (area). Material used for bolt was stainless steel 304 with yield stress, σ_y = 207 MPa (which was considered as σ_{fail}) and the factor of safety was 1.5 (Hibbeler, 1997). After calculating all desirable factors for hull design, Table 5 shows all of the specifications.

According to the first three case of the analysis, reducing the number of bolt and thickness of hull caused the maximum value of reaction force and displacements to increase. However, the displacement of the hull was

Table 5. Related parameters in hull design.

Related calculation	
Allowable stress, $\sigma_{allow} = \sigma_{fail}$ / F.S	207 MPa / 1.5 = 138 MPa
Bolt diameter, D	7.29 x 10^{-3} m
Reaction force	5760 N
Displacements	0.698 mm
Bolt material	Stainless steel 304 with σ_y = 207 MPa
Bolt diameter	8 mm
No of bolt	8

lower when the hovercraft was static comparing to the displacement produced by a moving hovercraft due to the lifting force and pressurized air that occur at the bottom of the hull. In order to minimize the high reading (maximum) of the hull displacement, a rectangular support bar was placed at where the maximum displacement occurred starting from case four onwards.

Prototype of hovercraft

The prototype applied systems were described subsequently.

Lift system

In order to accelerate a hovercraft in a vertical direction, certain amount of air pressure was applied and distributed beneath the craft to support the weight. The lift and thrust performance were calculated and this performance changed with the motor speed. The volume of air supplied into the chamber must be sufficient to overcome the air lost underneath the skirt and the lower hull when the craft hovered. The calculations of lift power engine and actual hull design measurements is shown in Table 6.

Engine

A single sitter prototype hovercraft was built with 2 HP, two strokes Robin engine as in Figure 1b. One engine was used for thrust system (Figure 1b) and the air blower was for lift system (Figure 1a).

Blade

According to the aluminium base hull analysis, the best combination analysis values of reaction displacements, force and stress for hull when the number of bolts was 8, the smallest value of the hull's thickness was 6 mm with 9 rectangular support bars attached to hull and a propeller should be installed with 0.7 blade efficiency to lift the hovercraft. However, with only 0.3 efficiency blade available commercially, a blower was installed to complement the lifting system. Figure 2 shows the blade used in the experiment.

Center of gravity

The locations of the forces are as shown in Figure 3 with the center of gravity detail calculations as shown in Table 7 and are very important for the stability purposes especially after full assembly was carried out.

Description of construction

A rectangular hull shape was made out of 3 × 6 ft plywood and aluminium sheets clamped together by rivets. For the hovercraft navigation, the driver seat and stick controller were connected with rudder and the engine was installed with the blade cover fixed to the engine stand.

For safety reason and to increase the efficiency of the air flow, the blade was covered with aluminium sheets. However, during the preliminary testing, it was found that the aluminium sheets were prone to tear. Due to this, the covering and the rudder was changed to hard and lightweight 3 mm plywood. The size of the covering was around the edge of the blade to reduce the aerodynamic loose due to vortex formation. Eventually, this covering modification provided an increase in the speed of the vehicle.

For ergonomic assessment, L-bar aluminium was assembled as the leg rest. The angle of the leg rest was about 60 degree to the front and as an additional function, acting as a momentum absorber for the pilot and the hull.

Initially, the skirting was made of plastic, however, it

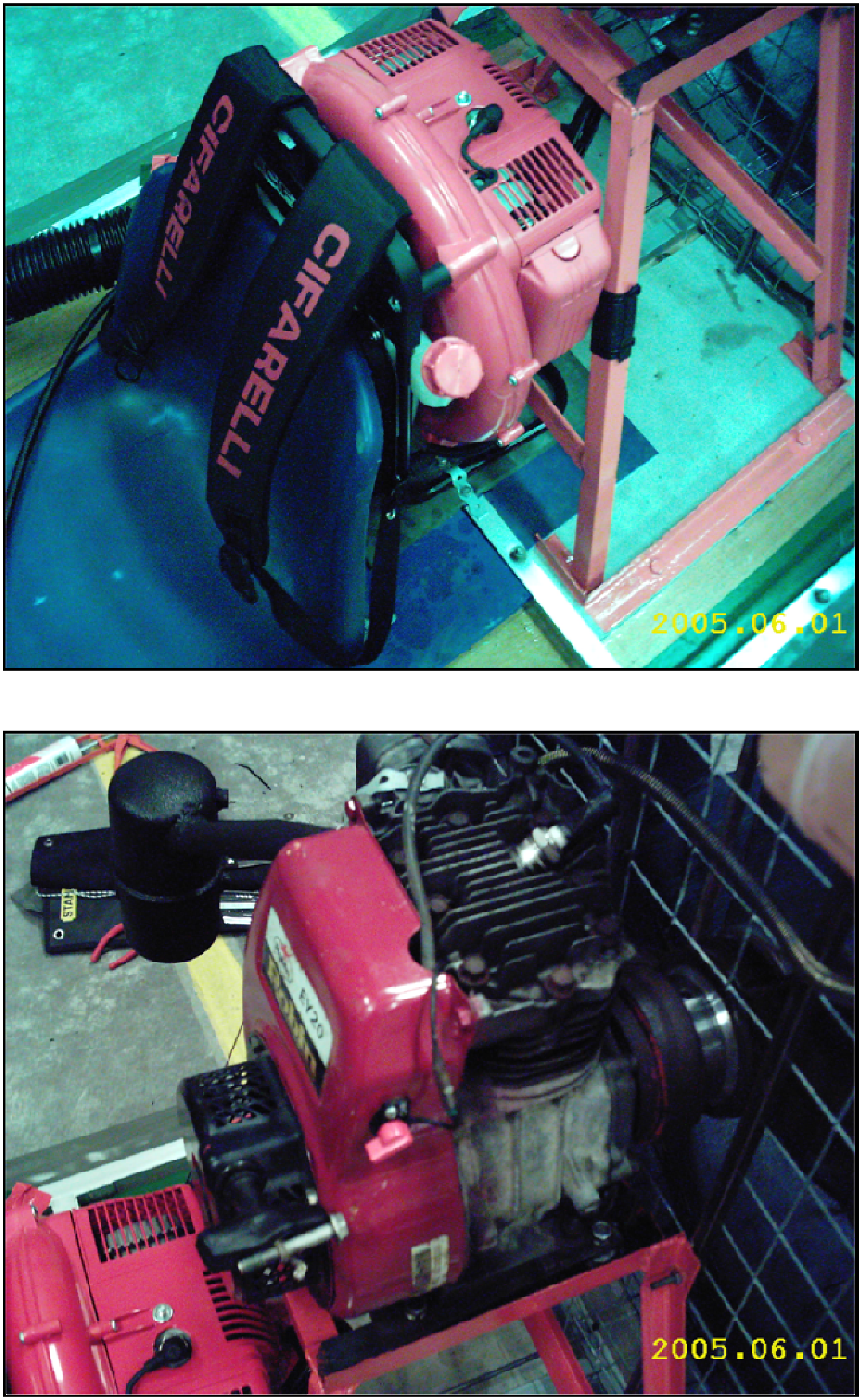
Table 6. Lift engine power and actual hull design calculation.

Estimate hovercraft length: 6 ft (1.8 m) Estimate hovercraft width: 3 ft (0.92 m) Estimate air gap, h_g: 0.75 in (0.02 m)	Estimate hull weight: 150 lb (68.04 kg) Estimate pilot weight: 200 lb (90.72 kg) Estimate engine weight: 80 lb (36.29 kg)
Area of air cushion, m^2	$18\ ft^2 = 1.67\ m^2$
Peripheral length, m	18 ft = 5.49 m
Total craft weight, W_t	430 lb = 1.913 kN
Air cushion pressure, $P_e = W_t / A_e$	0.166 psi = 1.144 kPa
Area of air gap, A_g	$162\ ins^2 = 0.105\ m^2$
Velocity of escaping air, $V_e = \sqrt{\frac{P_e}{0.5\rho}}$	141.73 ft/s = 43.2 m/s
Air flow rate at the gap, Q	$159.446\ ft^3/s = 4.52\ m^3/s$
Assuming propeller efficiency, η_f	0.7
Required engine power, HP = $\frac{Q \bullet P_e}{550 \bullet \eta_f}$	10 HP (The engine power required to lift the hovercraft is 10 HP)
Area of air cushion, $A_e = W_t / P_e$	$17.99\ ft^2 = 1.67\ m^2$
Width, W $= \sqrt{\frac{A_e}{2}}$	3 ft = 0.92 m
Length, L = 2W	6 ft = 1.84 m

collapsed during the testing due to the over stretchable limit point of the plastic. A more durable material, canvas was selected and the air flow system was modified to suit the material chosen. This prototype hovercraft integration was carried out for 9 weeks (Figure 4) with series of testing performed and assessed. The prototype model proved to be successfully developed for used on land and water as shown in Figure 5.

Conclusions

Series of attempts in coming up with Malaysian hovercraft have been made. However, as the hovercraft technologies are uncommon expertise in Malaysia thus making the information of the system difficult to be gathered. This prototype had been generated initially from the literature reviews made on the existing developmental technologies available outside of



a

b

Figure 1. Lifting and thrusting engines; (a) air blower (lifting) and (b) thrust engine (thrusting).

Figure 2. Propulsion blade.

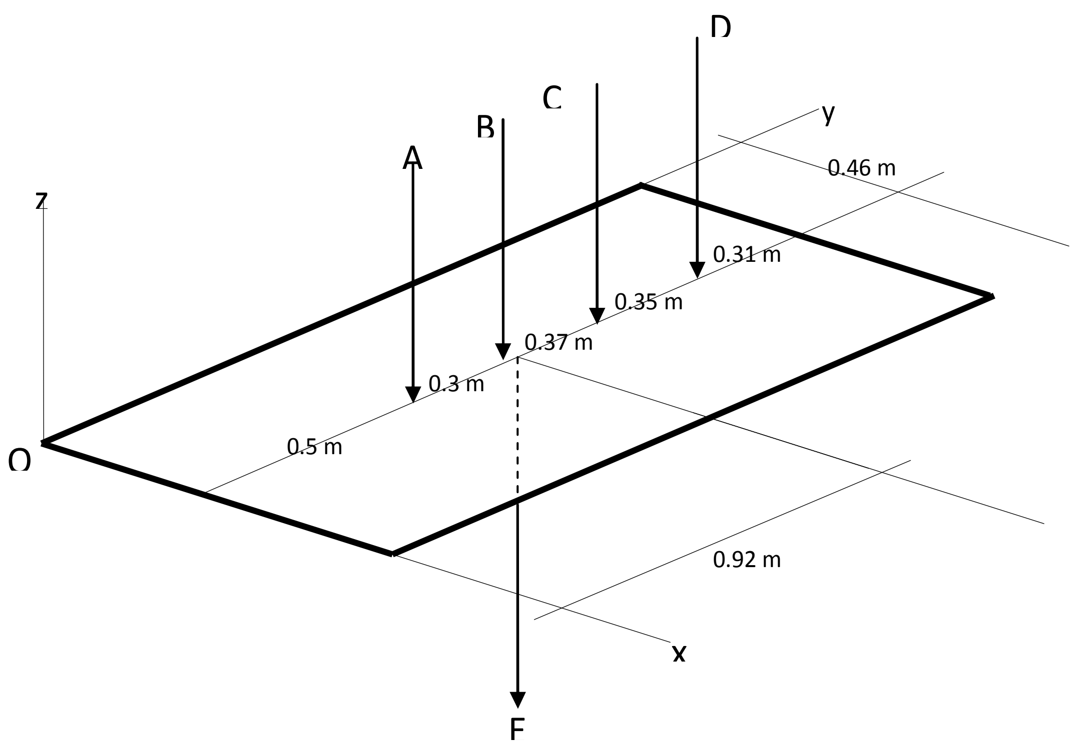


Figure 3. Hull weight distribution.

Table 7. Centers of gravity coordinate.

Parts	Weight, w(N)	x (m)	y (m)	xw (Nm)	yw (Nm)
Pilot (A)	735.75	0.46	0.50	338.45	367.88
Blower engine (B)	117.72	0.46	0.80	54.15	94.18
Thrust engine (C)	235.44	0.46	1.17	108.30	275.46
Propeller cover (D)	147.15	0.46	1.52	67.69	223.67
Hull (E)	667.08	0.46	0.92	306.86	613.71
Total	1913.39			875.45	1574.90

$$XW = \sum xw,\ X = \sum \frac{xw}{W},\ X = \frac{875.45(Nm)}{1913.39(N)},\ X = 0.46m.$$

$$YW = \sum yw,\ Y = \sum \frac{yw}{W},\ Y = \frac{1574.90(Nm)}{1913.39(N)},\ Y = 0.82m.$$

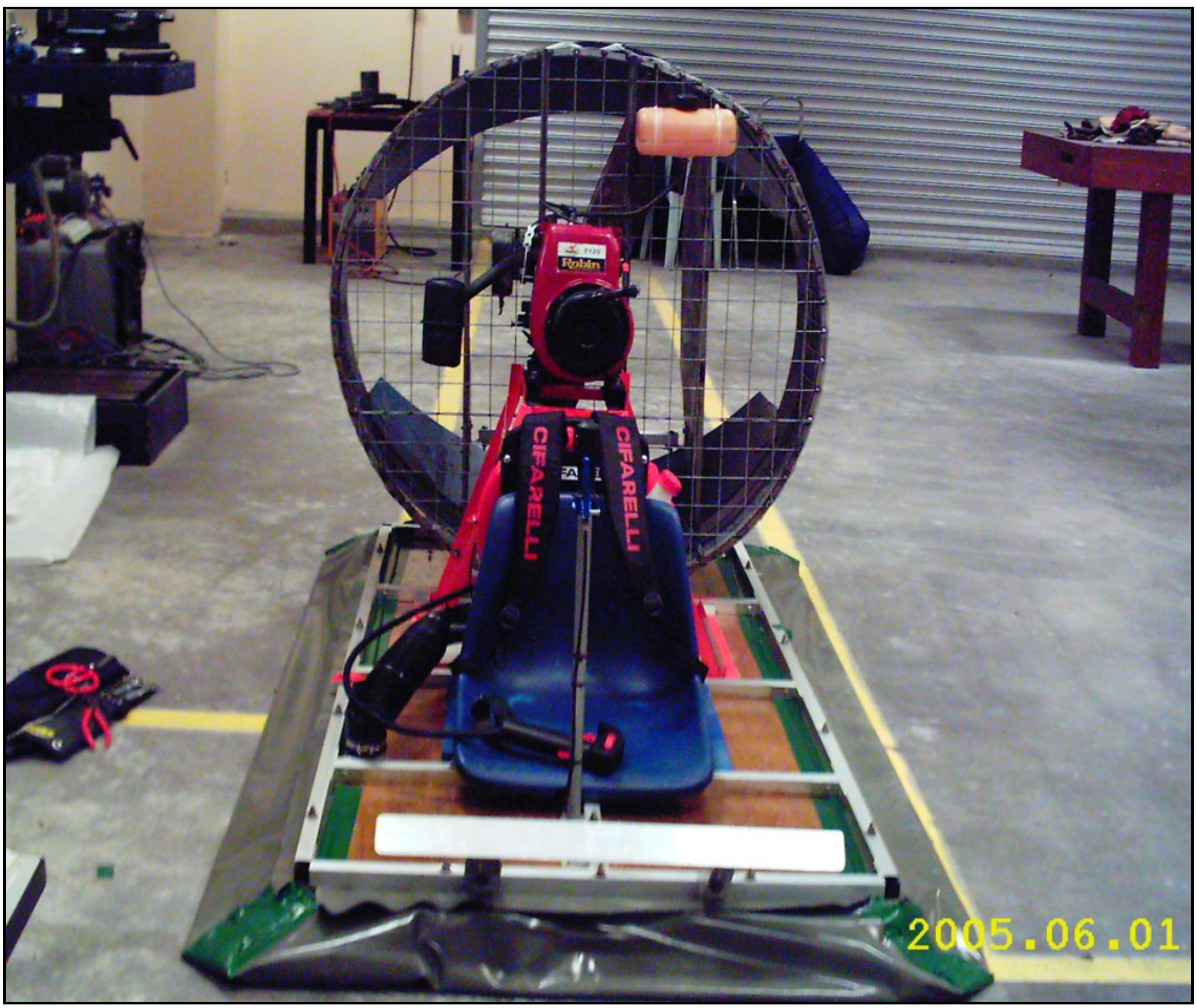


Figure 4. Complete hovercraft prototype.

Figure 5. Static testing and maneuvering on water surface.

Malaysia. This is the first prototype of hovercraft built up from used components and low cost material thus proved as a successful prototype capable to be use on land and water after series of experimental testing. The propulsion and lifting systems successfully demonstrated prototype capable of maneuvering nicely. The construction of the hull base prototype was supported by the results from analysis and simulations of establishing the right material suitable in building up the hull base.

ACKNOWLEDGEMENT

The authors wish to thank Universiti Industri, Selangor for providing facilities to carry out this research.

REFERENCES

Anderton D (1972). Internal Noise Reduction in Hovercraft. J. Sound Vib., 22(3): 343-359.

Chernenko G (2002). Historian:Levkov Hovercraft [Online]. Available from: http://www.ilparade.com [Accessed 20 June 2004].

Dannecker JD, McCue TP, Mayer RH (1997). “SOCV: A Sealift Option for Commercial Viability,” Paper I, SNAME Transportation, Operations, Management and Economic Symposium, New York, 1997.

Dolan GP, Robins JS (2004). Residual Stress Reduction in 7175-T73, 6061-T6 and 2017A-T4 Aluminium Alloys Using Quench Factor Analysis. J. Mater. Proc. Technol., 153-154: 346-351.

Herrington PD, Latorre RG (1998). Development of an Aluminum Hull Panel for High-Speed Craft. Mar. Struct., 11(1-2): 47-71.

Hibbeler RC (1997). Mechanics of Materials (4rd ed.), New Jersey.

Hibbeler RC (1997). Mechanics of Materials (4rd ed.),. New Jersey: Prentice Hall.

Nakamura H, Kayanuma H, Kimura S, Kosugi M (1997). A new process for small boat production based on aluminum hot-blow forming (ABF). J. Mater. Proc. Technol., 68: 196-205.

New Straits Times (NST, Malaysia) (2003). Mahathir: Better if less is said about polygamy.

New Straits Times (NST, Malaysia) (2002). Malaysia to host WorHovercraft meet in 2006.

Nobukawa H (1996). Discrete optimization of ship structures with genetic algorithms, J. Soc. Nav. Archit. Jpn., 179: 293-301.

Paik JK, Duran A (2004). Ultimate strength of aluminum plates and stiffened panels for marine applications. Mar. Technol., 41(3).

Paik JK, Thayamballi AK (2003). Ultimate limit state design of steel-plated structures. Chichester, UK: Wiley; 2003.

Paik JK, Veen SV, Collette ADM (2005). Ultimate compressive strength design methods of aluminum welded stiffened panel structures for aerospace, marine and land-based applications: A benchmark study. Thin-Walled Structures, 43: 1550-1566.

Spedding SG (2001). History of the Hovercraft. Available From: http://www.hovercraft.org.uk [Accessed 15 July 2004].

Tajiri A (1995). Aluminum thin plate forming. J. Jpn. Inst. Light Metals, 45(4): 226.