Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

SMALL-SCALE AEROSTATIC CRAFT- DESIGN AND FABRICATION

NUR FARAIHAN ZULKEFLI, MUHAMMAD NUR IQMAL MARIMAN and NURHAYATI MOHD NUR

Aerospace Department, Universiti Kuala Lumpur- Malaysian Institute of Aviation Technology,
Lot 2891 Jalan Jenderam Hulu, 43800 Dengkil, Selangor.
Email: nurfaraihan@unikl.edu.my

ABSTRACT

The purpose of this study is to design and fabricate a lightweight small scale Aerostatic craft by using lightweight material. A lightweight material such as plastic or Styrofoam might be able to reduce the weight of the craft. It also can reduce the tendency for the accident occurred and reduced the power used to operate the Aerostatic Craft. The motor, battery, propeller diameter, ESC (Electronic Speed Controller), servo, transmitter and receiver were selected for this purpose. The weight of the small Aerostatic Craft was set at 1 kg maximum. The revolutions-per-minute (RPM), power, torque and efficiency were determined accordingly.

Keywords: Aerostatic craft, air cushion vehicle, RPM, efficiency

INTRODUCTION

An aerostatic craft also referred to as hovercraft is a vehicle that can be used to travel overland, water, mud and ice at alternative speed and one stationary. Unlike a boat that floats on the water, the aerostatic craft is suspended between above the water on a cushion of air. It allowed an aerostatic craft to move over land and float over small depression such as a ditch or waves. A powerful fan designed especially for aerostatic craft created an air cushion that is part of the hovercraft. For this reason, the aerostatic craft is also called an air-cushion vehicle or ACV [1]. Hovercraft refers to gentle terrain although it capable of climbing slopes up to 20% depending on surface characteristics. Modern aerostatic craft is used for many applications where people and equipment need to travel at speed over water but also able to load and unload on land. It also can be used as passenger or freight carriers, as recreational machines and even warships [2]. Aerostatic craft is very exacting to fly and effortlessly traveling from land to water and back again. The aerostatic craft uses a blower to produce a large volume of air below the hull or planform that is slightly higher than atmospheric pressure. The pressure between the upper-pressure air below the hull and lower pressure ambient air above it produces lift that causes the hull to float above the operating surface. The air is usually blown through slots or holes around the outside of a disk or oval planform due to stability reasons and giving moist aerostatic craft characteristics rounded-rectangular shape [3]. A flexible curtain of the material located at the edge of aerostatic craft allows the vehicle to travel over small obstruction without damage knows as a skirt. It helps to prevent the escape of air from the plenum chamber to

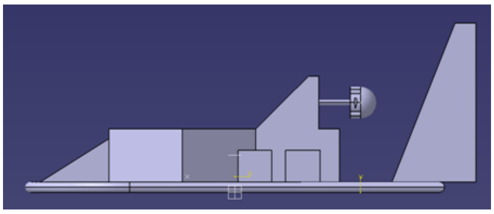
Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

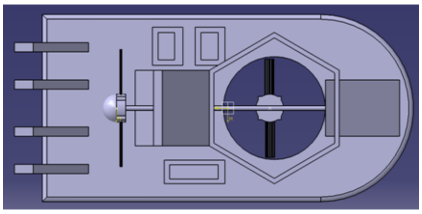
lessen the energy needed to generate the suspending airflow. The skirt must be a single piece of material made from rubber and light. If the skirt is worn out, the entire skirt has to be replaced [4]. Several vehicles supported in various ways, especially aerostatic craft designed with wing shape lifted just off the surface when it reached a sufficient horizontal speed of the ground effects [5]. The fan is usually used to support the aerostatic craft that forces air down under the vehicle to create lift and forward movement. Difference types of standard propeller used on aerostatic craft. The propeller blades generate back-pressure as it rotates, and the backpressure would decrease the efficiency of the air cushion for aerostatic craft [6]. In the current situation, aerostatic craft design and materials used are mostly heavy, a lot of power usage, fuel cost and maintenance cost increase due to heavy weight craft [7]. By creating a small and lightweight craft, the fuel cost and maintenance can be decreased. In this study, the development of small-scale aerostatic craft is identifying how the aerostatic craft operates and maintenance of the aerostatic craft. The aerostatic craft is fabricated using lightweight materials such as plastic and composite to create a small craft that gains lift and thrust force.

METHODOLOGY

Aerostatic craft design

CATIA V5R19 is used to design aerostatic craft components and parts. Figure 1 shows the side view, top view and isometric view of the aerostatic craft.


(a)


(b)

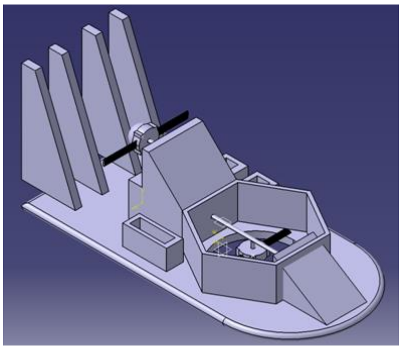

(c)

Figure 1: (a) Side view of Aerostatic craft; (b) top view of aerostatic craft; (c) isometric view of Aerostatic craft in CATIA V5R19 design

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

Block diagram of Aerostatic Craft

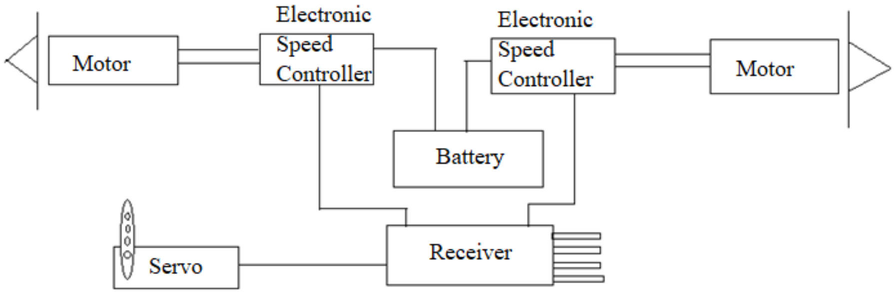


Figure 2: Block diagram of an aerostatic craft

Figure 2 shows the electronic component used in this project. Before selected the Brushless motor and ESC (Electronic Speed Controller), the weight of the aerostatic craft needs to be determined to calculate the lift, thrust and the total power needed from the motor and diameter of the propeller blade. The motor and propeller need to generate enough lift and thrust to hover the craft. The ESC for the motor speed controller depends on the maximum current output from the motor and the amount of ampere that the ESC can handle. Lipo (lithium-ion polymer) battery used depends on the current due to its flexibility and comes in different sizes and weights. Servos will be used to control the flight control surfaces and the ground steering. The servo motor must be small and light in weight but provide a great power torque so that it can move the two rudders mounted behind the thrust propeller. The Fly Sky FST6 controller was selected due to the simplest, cheapest and sufficient in this project. Fly Sky FST6 came with both 6 channels 2.4 GHz transmission radio control transmitter and receiver. The remote will provide 6 channels but only 3 channels will be used for this project. The usage of the 3 channel will be able to control thrust motor, lift motor and rudder. The receiver plays important roles that control and communicate with all the electronic components. Additional attention is needed when it comes to the receiver due to it’s only able to receive 5V while the battery usually supplies at least 7V – 11V. Therefore, any ESC that has a built-in BEC (Battery Elimination Circuit) will be the best option to overcome this issue.

Product specification

Brushless motor

The brushless motor provides lift and thrust for lifting and forward motion for the aerostatic craft. A Brushless motor has higher power to weight ratio compared to a brush motor. The overall weight of the prototype is estimated maximum at 1000g. It is better to overestimate the weight to provide extra thrust and more power. The lifting motor and thrust motor was shown in Figure 3.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

(a) (b)

Figure 3: (a) Gartt 3300KV Brushless Motor for lifting; (b) KDS-WS2217 1400KV Brushless Motor for thrust

To select two different motors, the values of the KV on the motor were identified. The KV value is the constant velocity of a motor (not kilovolt). It is measured by the number of revolutions per minute (RPM) that a motor turns when 1V (one volt) is applied with no load attached to that motor [8]. The rate of KV available for the motor is between the ranges of 1000KV to 4000KV shown in Table 1.

Table 1: Speed characteristic depends on the KV [8]

KV Value	Characteristic
1000	High Thrust (3.5 to 4.5 g/W approx) Low Air Speed
2000	Medium Thrust (2.5 to 3.5 g/W approx.) Medium to High Air Speed
3000	Low Thrust (1.8 to 2.5 g/W approx.) Higher Air Speed(Propeller and Ducted Fan)
4000	Lower Thrust (1.5 to 2.5 g/W approx.) Higher Air Speed (Ducted Fan)

For the thrust motor, the KV is the range between 1000 to 1500 KV due to its high thrust and low airspeed. KDS-WS2217 1400KV brushless motor was chosen to fulfill this requirement. Meanwhile, the range for the lifting motor between 3000KV to 4000KV brushless motor, Gartt 3300KV was selected due to lower thrust and higher airspeed.

Propeller diameter

Table 2 shows the propeller diameter that depends on the motor KV. For the lifting motor, there are limited clearances and only a small propeller can be used due to its width are only 10 in or 25.4 cm. Therefore 4 in propeller diameter were selected due

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

to a higher speed motor in KV. For the thrust motor, a low KV motor is used because it is easier to control at its operation. However, a low KV value will have to use a bigger propeller. Therefore, the 8 in propeller diameter was selected.

Table 2: Propeller diameter depending on motor KV [9]

Kv	Diameter (inches)
500	17
600	15
700	13
800	12
900	11
1000	10
1100	9.5
1200	9

Kv	Diameter (inches)
1300	8.5
1400	8
1500	7.5
1600	7
1700	7
1800	7
1900	6.5 -7
2000	6.5
2100	6
2200	6
2300	5.5
2400	5.5
2500	
2600	5
2700	

Kv	Diameter (inches)
2800	5
2900	
3000	4.5
3100	
3200	4
3300	
3400	4
3500	
3600	3
3700	
3800	3
3900	
4000	2 -2.5

Electronic Speed Controller (ESC)

ESC is used to control or vary the speed of the motor, direction and also as a dynamic brake. ESC is widely used in electric powered radio controlled models which often paired up with a brushless motor. The maximum output motor is 22A for thrust and 30A for lifting and it wisely to choose above 30A ESC; and 50A and 60A Hobbywing are selected so that ECS will be able to handle the maximum current output from the motor (refer Figure 4). ESC also able to handle 4S Lipo batteries and has a built-in BEC (Battery Elimination Circuit) which required receiver of 5V input.

(a) (b)

Figure 4: (a) 50A ESC (Electronic Speed Controller), (b) 60A ESC (Electronic Speed Controller)

Lipo battery

Figure 5 shows Lipo battery or lithium-ion polymer battery is a rechargeable battery of lithium-ion technology. Unlike other batteries, the Lipo battery used polymer electrolyte instead of a common liquid electrolyte. For this project, Gartt YPG 4S LiPo Battery 11.1V 1500MAH is chosen due to its compatibility with the both motor used.

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

Figure 5: Gartt YPG 1500MAH LiPo battery pack

Transmitter and Receiver

To control and communicate with all the electronic components at a distance, a remote controller is essential as shown in Figure 6. It has been decided to use a transmitter that has 6 channels on the receiver which also means that it can control 6 different components under one transmitter. But only 3 channels will be used for this project. The Fly Sky FST6 model of the transmitter has been choose and came together with a receiver; and it is programmable which allows the user to change the configuration of the controller.

(a) (b)

Figure 6: (a) Fly Sky FS T6 Transmitter; (b) Receiver

Servo

The purpose of the servo is to control the rudder located after the thrust propeller. The servo has to be small and light in weight and a 9g servo was choose to be used in this project. Tower Pro SG 90 micro servo was chosen because it is small in size and light in weight but has enough torque power to move the control system as shown in Figure 7.

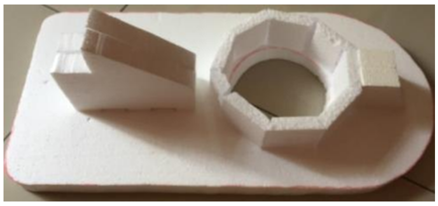
Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

Figure 7: Tower Pro SG 90 micro servo

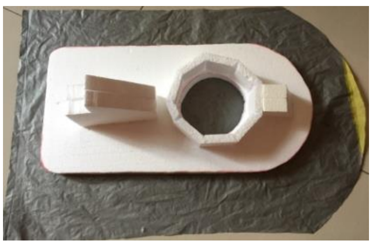
Project Construction

The project construction begins by selecting materials for the planform or base. The lightweight, strong and high-density foam was used to construct the craft. The hot wire used to cut according to design. The hole is necessary for the airflow and is based on the size of the propeller for lifting force (refer Figure 8(a)). Then, the foam was cut to form a motor tower for lifting and thrust. The tower height depends on the length of the propeller as shown in Figure 8(b). Next, the canvas was used as a skirt of the craft. The canvas is very durable for the craft (refer to Figure 8(c)). The glue was used to attach the canvas and the planform. Figure 8(d) shows the motor for lifting was attach to the craft using a hot glue gun. Then, the motor for lifting was connected to the ECS and battery as shown in Figure 8(e). The ESC was connected from the transmitter to 6 Channel receiver of the controller as shown in Figure 8(f). But, only 3 Channel was utilized. Channel 1 is used to control the rudder movement. Channel 2 was used for lifting and Channel 3 for thrust performances. Figure 8(g) shows the attachment of the rudder using thin and lightweight Depron. Then, the servo was glued at the base of the craft. The servo was connected using push rode or wire to control the rudder as shown in Figure 8(h). Finally, Figure 8(i) shows the final result of the aerostatic craft construction and the performance of the aerostatic craft motor was tested.

(a)



(b)

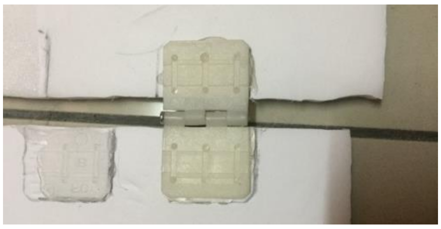


ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

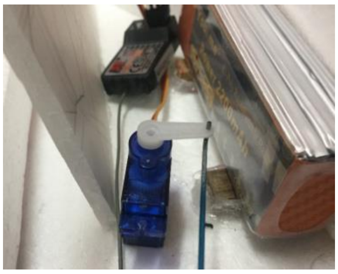
(c)

(d)

(e)

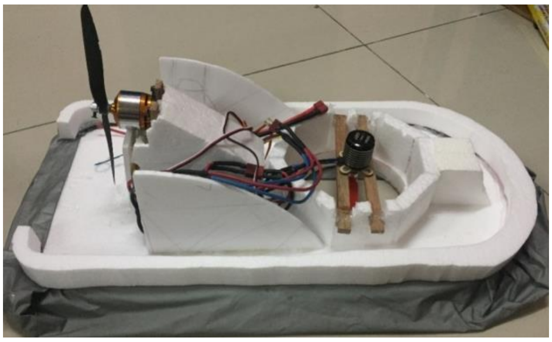


(f)



(g)

(h)



(i) The final product of Aerostatic Craft

Figure 8: Development of small aerostatic craft steps

RESULT AND DISCUSSION

The performance of the lifting motor and thrust motor RPM, power, speed, torque, efficiency need to be calculated.

Radius-per-minute (RPM) calculates as below

$$N_{(RPM)} = Motor\ KV \times Battery\ Voltage(V)$$

Electrical Power Input

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

$$Power\ Input\ (Watts) = Amphere(A) \times Voltage(V)$$

The angular speed of the propeller

$$\omega_{(\frac{rad}{s})} = N_{(RPM)} \times \frac{2\pi}{60}$$

The linear speed of the propeller is the angular speed(ω) multiplied by the radius of the propeller(r)

$$v_{(\frac{m}{s})} = \omega \times r$$

Speed of the propeller in km/h

$$V_{(\frac{km}{h})} = v \times \frac{3600}{1000} = \frac{3}{25}\pi r N_{(RPM)}$$

Torque motor

$$\tau_{(Nm)} = \frac{Power(Watts)}{\omega_{(\frac{rad}{s})}}$$

Mechanical Power Output

$$Power\ Output(Watts) = \tau_{(Nm)} \times Speed(\frac{rad}{s})$$

Motor efficiency

$$Motor\ Efficiency(\%) = \frac{Power\ Output}{Power\ Input}$$

Performance of lifting motor

For the lifting motor, Gartt 3300KV Brushless Motor was selected with Lipo battery 11.1 V with 30A electronic speed controller (ESC).

Radius-per-minute (RPM) calculates as below

$$N_{(RPM)} = 3300\ KV \times 11.1V = 36630$$

Electrical Power Input

$$Power\ Input\ (Watts) = 30A \times 11.1V = 333$$

The angular speed of the propeller

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

$$\omega_{(\frac{rad}{s})} = 36630 \times \frac{2\pi}{60} = 3835.88$$

The radius propeller for the lifting motor is 4 in diameter equal to 2 in or 0.05m radius

$$v_{(\frac{m}{s})} = 3835.88 \times 0.05 = 191.78$$

Speed of the propeller in km/h

$$V_{\left(\frac{km}{h}\right)} = \frac{3}{25}\pi \times 0.05 \times 36630 = 690$$

Torque motor

$\tau_{(Nm)} = \frac{Power(Watts)}{\omega_{(\frac{rad}{s})}}$=0.868

Mechanical Power Output

$$Power\ Output(Watts) = 0.868 \times 3835.88 = 3329.07$$

Motor efficiency

$$Motor\ Efficiency(\%) = \frac{3329.07}{333} = 9.99\% \approx 10\%$$

The RPM of the craft is 36630 with a battery voltage is 11.1V. The rpm may change when used with a different type of battery. The max current for the motor is 30A. The RPM for the lifting motor is 36630, the speed of the propeller is 690km/h, the torque is 0.868Nm and the efficiency is almost 10%

Performance of thrust motor

For the thrust motor, KDS-WS2217 1400kv Brushless Motor was selected with Lipo battery 11.1 V with 22A electronic speed controller (ESC).

Radius-per-minute (RPM) calculates as below

$N_{(RPM)} = 1400\ KV \times 11.1V =$ 15540

Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)
ISSN：1671-5497
E-Publication：Online Open Access
Vol: 40 Issue: 12-2021
DOI 10.17605/OSF.IO/TM2QC

Electrical Power Input

$$Power\ Input\ (Watts) = 22A \times 11.1V = 242.2$$

The angular speed of the propeller

$$\omega_{(\frac{rad}{s})} = 15540 \times \frac{2\pi}{60} = 1627.34$$

The linear speed of the propeller is the angular speed(ω) multiplied by the radius of the propeller(r). The radius propeller for thrust motor is 8 in diameter equal to 4 in or 0.1m radius

$$v_{(\frac{m}{s})} = 1627.34 \times 0.1 = 162.73$$

Speed of the propeller in km/h

$$V_{(\frac{km}{h})} = \frac{3}{25}\pi \times 0.1 \times 15540 = 585.84$$

Torque motor

$\tau_{(Nm)} = \frac{Power(Watts)}{\omega_{(\frac{rad}{s})}}$=0.15

Mechanical Power Output

$$Power\ Output(Watts) = 0.15 \times 1627.34 = 244.1$$

Motor efficiency

$$Motor\ Efficiency(\%) = \frac{244.1}{242.2} = 1.0\%$$

The RPM of the craft is 15540 with a battery voltage is 11.1v. The rpm may change when used with a different type of battery. The max current for the motor is 22A. The speed of the motor is 585.84km/h, the torque is 0.15Nm and the efficiency is 1%.

CONCLUSION

The working model of aerostatic craft has similar properties with hovercraft and air cushion vehicle (ACV). The high-density foam and lightweight together with a durable skirt was used to support the lifting of the craft. The motor for thrust and lifting was selected based on the specification in the need of the project. The estimation of RPM (revolution-per-minute), power, speed, torque and efficiency were calculated by the formula for both lifting and thrust motor. The next investigation was focus on the performance of the motor for lifting and thrust based on the weight provided.

REFERENCES

[1] A. Tiwari, “To study and fabrication of air cushion vehicle,” *Int. J. Res.*, vol. 3, no. 3, pp. 70–84, 2015.

[2] G. Miskolczy, J. Burchfield, M. Ales, and H. Rochow, “Design and fabrication of a A.C.V.-A Review,” *Int. J. Sci. Res. Dev.*, vol. 4, no. 04, pp. 48–51, 2016.

[3] D. Ajay Anil, R. Shubhan Sanjay, S. Akash Laxman, and P. Suraj Pradeep, “Design and Fabrication of Hovercraft,” *Int. Eng. Res. J.*, no. 9, pp. 597–601, 2015.

[4] Sciencedirect, *Hovercraft Technology, Economics and Applications*, 1st ed. 1989.

[5] V. K. Rajamani, “Design and Analysis of Winged Hovercraft,” *J. Appl. Mech. Eng.*, vol. 04, no. 05, 2015.

[6] S.V. Uma Maheswara Rao and V. S. S. Prakash, “Development of an Integrated Air Cushioned Vehicle (Hovercraft),” *Int. J. Modern Eng. Res.*, vol. 4, no. 5, pp. 21–28, 2014.

[7] A. V. Kale, A. . Ghogare, R. N. Yerrawar, and P. . Birader, “Design & Air Flow Simulation of Small Scale Working Model Of Hovercraft,” *IOSR J. Mech. Civ. Eng.*, vol. 17, no. 01, pp. 23–28, 2017.

[8] “Understanding Kv Ratings,” *Rotor Drone Pro*, 2020. [Online]. Available: https://www.rotordronepro.com/understanding-kv-ratings/. [Accessed: 08-Sep-2020].

[9] B. Hulbert, “Motor kv prop size.” .