Conceptual Design of Low Altitude Unmanned Small Hybrid Airship

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***Abstract*— In the last two decades, popularity of Unmanned Air Systems (UAS) are at their peaks. Their capacities and abilities are advancing day by day in parallel with development of science and technology. They are doing almost everything what conventional aircrafts are doing except passenger transfer, for now. Despite an UAS can be controlled from thousands of miles away, they are still limited in range and endurance because of their energy storage capacities. Most of the energy sources of an aircraft is used against to gravitational force. However, Lighter Than Air(LTA) gases like helium, hydrogen etc. provides an option to aircrafts using lifting capacity of these gases and combination of lifting capacity of LTA gases and mechanical forces produced by engines allows engineers to create hybrid airships. Hybrid Airships gains flight altitude by using static lifting force of lighter than air gases in addition of the mechanical force which is produced by the propulsion system of the vehicle. Engines makes necessary maneuver with direction units to control the airship in all directions. Static lift from the LTA gases provide additional payload capacity to vehicle without consuming energy. Therefore, unlike the conventional aircrafts, hybrid airship has more flight duration than the others and more payload capacity. Aim of this work is, developing a low-cost small hybrid airship by using static lift force of the lighter than air gases and present to advantages of hybrid aircrafts.**

***Keywords*—Unmanned Air Vehicle (UAV), Lighter Than Air (LTA), Hybrid, Helium, Airship**

I. Introduction

Unmanned Air Vehicles(UAV) have been used since the beginning of the aircraft history [1]. Rapid advance of the technology in all fields allows engineers to develop the most advanced UAV like conventional aircrafts. Initially, UAVs operation range was limited by the line of sight of the operators. Nowadays, with the development of navigation and satellite systems, operator can give orders to UAV from thousands of kilometers away [2]. Even the most advanced type of UAVs has the ability of autonomous flight. Like the other technology fields, the very first examples of the UAVs were developed for the military purposes. Still military applications are pioneer of development of the UAV technologies. In the last decades, these vehicles become one of popular product of civilian consumers [3]. Respectively they have small and limited capacity but all necessary materials are available in the market to produce more advanced types.

Whether it is used for military or civilian purposes, they have some critical limitations especially range, endurance, and payload capacity. The UAVs with fuel powered engine have longer range than the UAVs with an electric motor but it still is limited. In addition, production, operation, and maintenance costs are quite high. Also, they need more maintenance time after flight [4].

The simplest description of the UAV is an aircraft operated by a computer system or radio link without any crew occupied the aircraft. UAVS is a combination of aircraft and sub systems like control system, communication system etc. Almost all subsystems have their equivalent with conventional aircraft except aircraft crew. When describing to UAV, it should be avoided to confuse with radio-controlled (RC) model aircrafts and drones. RC aircrafts are mostly used for hobby and they have limited abilities. They must stay at sight of the operators. Drones should have ability to fly out of sight but also, they have limited ability and no autonomy or intelligence. On the other side, UAV have different degree of intelligence and autonomy. They are able to communicate the controller and able to send collected data and flight data like orientation, altitude, position etc. Also, they are able to give decisions based on conditions and pre-defined tasks. Even if connection is lost with the ground control, they still are able to be complete the task or return home based on their design [5]

Lighter than air (LTA) gases provide an excellent opportunity to increase endurance and range of the unmanned vehicles. LTA gases has lifting capacity in the air. A blimp or balloon with enough size and capacity is able to neutralize total weight of the aircraft. In this way, aircraft don't have to consume its energy against the gravity. Therefore, energy resources could be used at maximum efficiency. Combination of motor force and lifting capacity of the LTA gases, hybrid aircraft are gain ability of even unlimited flight.

The very first known example of Lighter Than Air (LTA) unmanned aerial vehicle used by famous Chinese General Zhuge Lhuge (180 - 234). He used paper balloons with an oil-burning lambs then flew them over the enemies at night. He tried to make enemy think there were something supernatural power over them [6]. With the development of unmanned aerial

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systems, engineers get benefit also from LTA gases to design long-endurance and low-power consuming systems. Modern LTA-UAS are mainly classified as tethered and hybrid air vehicles [7]. Tethered air vehicles use only lifting power of the LTA gases and they are tied to ground station with a rope and communication cables. They are used to observe around specific areas like borders, critical buildings, check points etc. with on-board radar and surveillance system.

Unlike tethered systems, hybrid LTA UAS use motors as thrust sources to get ability of flying in addition to lifting power of the LTA gases. LTA-UAS's have several advantages against conventional UAS. LTA gases provide lifting power without consuming any energy resource. Therefore, LTA-UAS's have better energy efficiency performance. This energy performance also allows longer operation time and further operation range. By adding additional energy generator systems, these systems gain unlimited flight range and time. Other important specification is the payload. By adding bigger envelope, payload capacity can be increased without changing any mechanical parts. When considering all these advantages, LTA-UAS's production, maintenance and modification costs are lower than conventional UAS. LTA-UAS have mainly two disadvantages. Their envelope size is bigger and because of the envelope size, their speed is lower than conventional UAS [8].

II. AIRSHIP MODEL DESIGN

Design of Low Altitude Hybrid Surveillance blimp can be divided into mainly 2 sections:

- Envelope Design
- Propulsion System Design

Envelope is a LTA gases carrier and it will be filled with an LTA gas, preferably helium because of the non-flammable specification of the helium. Envelope size to be defined to satisfy payload capacity of the vehicle. The higher volume of envelope, the more payload capacity it means. Material selection also effects the payload capacity. To increase payload capacity, lighter material should be used. In addition to the envelope size, envelope shape is also important as a design criterion. Aerodynamic structure of the envelope is important against air resistance. It directly effects power consumptions and air speed of the vehicle. Envelope to be designed based on all these considerations. Envelope design will be detailed in following sections.

LTA aircrafts are mainly classified as tethered and non-tethered. Non-tethered are also called as hybrid airship. Hybrid airships use motors to get ability to fly. Also, motors provide additional payload capacity to the vehicle. Motors and motor control units form propulsion system. Conventional air crafts and hybrid airships use wings, flaps, and tails to orient the vehicle. In this work, servo motors will be used to direct the vehicle by creating a tilt-rotor mechanism.



Fig. 1. Tethered airship [9]



Fig. 2. Hybrid airship [10]

A. Envelope Design

Airship envelope design one of the most complex step in the airship design. Material selection, envelope shape and envelope volume is the key parameters of the envelope design. Weight of the envelope should be small due to save payload capacity of the airship. Weight/area ratio is the main selection criteria of the envelope material. Also, material's physical characteristics are important parameters to design more robust airship against to environmental conditions.

There 3 types of envelope are used in design of airships and aerostat as Rigid, Semi-Rigid, and Non-Rigid. Rigid airships include a frame inside the envelope. This method is applied for large airships in order support to keep shape of the airship against the envelope material weight, load and dynamic loads during operation. Similar with rigid airships, Semi-Rigid airships have frame to support main envelope and their length and width. Comparatively, medium-size airships are constructed as semi-rigid airship. Unlike rigid and semi-rigid airships, non-rigid airships do not contain any frame. They keep their shape only by pressure of the gases inside [11]. In this work, due to the vehicle specifications, non-rigid envelope to be designed.

Material of the envelope is also important point. First in case, material weight should be considered. Because, to allocate more payload capacity to the vehicle, envelope weight should be as light as possible. On the other hand, material strength should have good pressure resistance. Other critical point is leakage resistance. Helium molecules are very small when comparing the other molecules. Therefore, envelope material should prevent the leakage as much as it can. Even some materials have

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almost no leakage. Apart from these specifications, most of the commercially available materials present UV protection, working under wide temperature range etc. [12].

Due to aerodynamic reasons, airship envelopes are designed as a hull shape. During volume and surface area calculation, ellipsoid formulas is considered to get approximate values for volume and surface area.

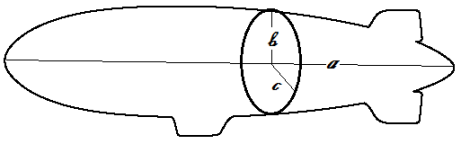


Fig. 3. Envelope Shape

V: Envelope Volume

S: Envelope Surface Area

$$V = \frac{4}{3} abc\ m^3 \quad (1)$$

$$S = 4\pi \sqrt[p]{\frac{a^p a^p + a^p b^p\ b^p c^p}{3}}\ \ m^2\ (p \cong 1{,}6) \quad (2)$$

B. Lifting Capacity

Static Lift of the lighter than air (LTA) gases can be explained with Archimedes' Principle. There is an upward force, called as buoyancy, is exerted on an object which is sunk in a Fluid. This force is equal to weight of the fluid displaced because of the object that is sunk in the fluid. The submerged volume ratio of the object depends on the density of the fluid and density of the object. If density of the object is not greater than fluid, object does not totally submerge [13].

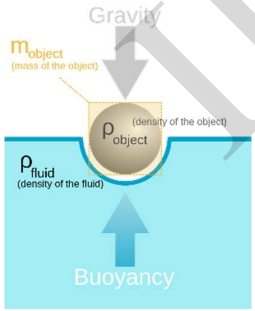


Fig. 4. Envelope Shape [14]

Hydrogen has the highest gases with respect to lifting capacity and it is very easy to obtain it. But it is a flammable gas. In many countries usage of the hydrogen in airship application is restricted by law. Although it is an expensive and not easily obtained, most used LTA gases in the hybrid airship applications is helium because of the safety reasons. Lifting capacity of helium is calculated under the standard conditions (1 atm pressure, 0°C temperature) as below:

ρ_{air}: air density

ρ_{he} : helium density

ρ_{env} : density of envelope material

M : amount of mass that helium lift

$$\rho_{air} = 1.292\ gr/cm^3$$

$$\rho_{he} = 0.179\ gr/cm^3$$

$$M = (\rho_{air} - \rho_{He})x\ 1\ cm^3 = (1.292 - 0.179)\ x\ 1 = 1.114\ g \quad (3)$$

As it seen above, $1\ cm^3$ helium can carry 1.114 g load under the standard condition.

To determine net payload capacity, envelope weight should be subtracted from total lifting capacity of helium gas in the envelope.

$$P = V * (\rho_{air} - \rho_{He}) - S*\rho_{env}\ \text{kg} \quad (4)$$

C. Propulsion System

Propulsion system is used to generate required thrust for the vehicle to move in any direction in the sky. 2 DC brushless motor will produce thrust by converting electrical power to be received from battery to mechanical energy. Each motor is controlled by an Electronic Speed Controller (ESC) unit. ESC adjusts electric current of the motor according to the control signal which is produced by a flight controller. Brushless motors are mounted over the servo motors and servo motors will control direction of thrust. Each servo motor will be able to move independent of each other. Therefore, apart from vertical and horizontal move of the vehicle, it will able to turn right or left by controlling thrust direction of each motor via servo motors.

Conventional aircrafts can rotate in three dimensions called as principle of axes; roll, pitch and yaw. In addition, to these rotational movements, some aircrafts have the ability to fly on vertical axis. Our vehicle will have also vertical take-off and landing (VTOL) functionality. All these movement is controlled with angle of servo motors and speed of brushless motors.

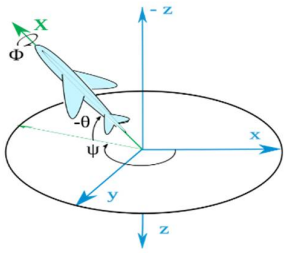


Fig. 5. Principle of Axes (15)

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There are 4 forces on an aircraft as it seen in figure 2.10. On vertical axis, gravity of the ground pull aircraft down. Lift forces pull aircraft to up. In fixed wing aircrafts, lift force is produced by wings by the function of speed, wing area, and wing shape. In hybrid airships, lift force is produced by LTA gases and motors thrust. On horizontal axis, thrust force which is produced by motors, pull aircraft forwards. Meanwhile, air resistance pulls aircraft back.

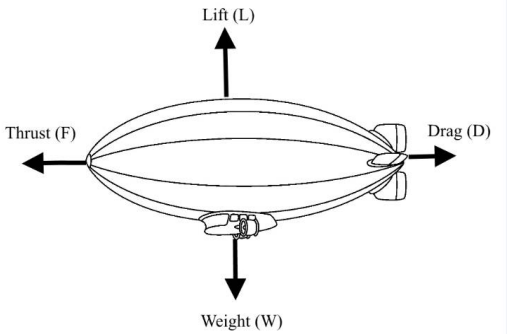


Fig. 6. Forces on the airship

Force on the vehicle could be examined with the variation of servo angles α_1 (right) and α_2 (left) motor speed ω_1 and ω_2.

Case 1: $\alpha_1 = \alpha_2 = 90^0$ and $\omega_1 = \omega_2 = \omega_2$

In this case, thrusts of motors are perpendicular to ground.

- If sum of lifting force of LTA gases and thrust force bigger than gravitational force, the vehicle can fly on vertical axis.
- If total force is zero, the vehicle saves its position on vertical axis.

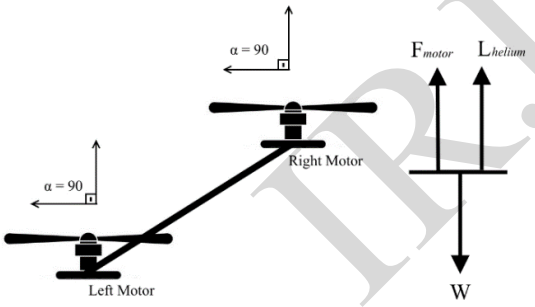


Fig. 8. Vertical Movement

$$F_{vertical} = (F_{motor} + L_{helium}) - W \quad (5)$$
$$F_{horizontal} = 0 \quad (6)$$

Case 2: $0^0 < \alpha_1 = \alpha_2 < 90^0$ and $\omega_1 = \omega_2 = \omega$

In this case, motors can produce thrust on both horizontal and vertical axis.

- If Sum of vertical and horizontal forces are zero, the vehicle saves its position.
- If thrust of forces on horizontal axis greater than drag force, the vehicle can move forward.
- If vertical thrust is greater than gravitational force, the vehicle makes pitch action and nose of the vehicle turn to up.
- If vertical thrust is lower than gravitational force, the vehicle makes pitch action and nose of the vehicle turn to down.

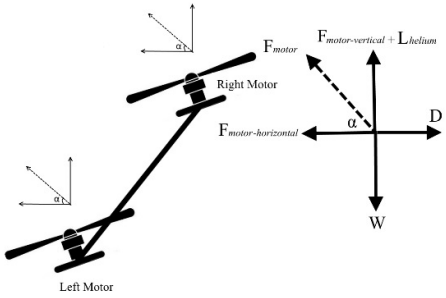


Fig. 7. Pitch Movement

$$F_{vertical} = (F_{motor}\ x\ sin\alpha + L_{helium}) - W \quad (7)$$
$$F_{horizontal} = F_{motor}\ x\ cos\alpha - D \quad (8)$$

Case 3: $\alpha_1 = \alpha$, $\alpha_2 = -\alpha$ and $\omega_1 = \omega_2 = \omega$

Similar with case-2, motors can produced thrust on both axis. But whatever the initial position of the motors, when rotating motors in reverse direction with a small and equal angle, the vehicle can rotate around vertical axis. Therefore, the vehicle can make the yaw movement. To minimize force change on vertical axis in order to save altitude, angle of α should be small.

- If horizontal thrust force of right motor is greater than left motor, the vehicle rotates to the right.
- If horizontal thrust force of right motor is less than left motor, the vehicle rotates to the right.

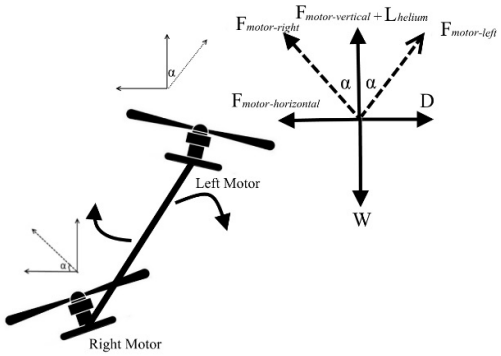


Fig. 9. Yaw Movement

$$F_{vertical} = F_{motor-right}\ x\ cos\alpha + F_{motor-left}\ x\ \cos(-\alpha) + L_{helium} - W \quad (9)$$

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Assumed that, each brushless motor produces same power. Therefore, equation (9) turns into to equation (10).

$$F_{motor-right} = F_{motor-left} = F_{motor} \quad (10)$$

$$F_{vertical} = 2\,x\,F_{motor}\,x\,cos\alpha + L_{helium} - W \quad (11)$$

$$F_{horizontal} = F_{motor-right}\,x\,sin\alpha + F_{motor-left}xsin(-\alpha) - D \quad (12)$$

$$= F_{motor-right}\,x\,sin\alpha - F_{motor-left}xsin(\alpha) - D$$

As stated in equation (10), each motor produces same power. Therefore, total horizontal motor power becomes 0. If vehicle moves forward during the time of yaw, only Drag force effects the vehicle in that time. If vehicle does not move on horizontal axis there is no horizontal force applied on the vehicle and net horizontal force is 0. In this case, vehicle makes rotational movement around center of gravity of the vehicle due to horizontal force which are produced by each motor. This movement called as yaw.

Case 4: $\alpha_1 = \alpha$ and $\omega_1 \neq \omega_2$

In this case, motor speeds are little bit different. Therefore, the vehicle can rotate around horizontal axis and make roll movement. But difference should be kept small in order to save position of the vehicle.

- If speed of right motor is greater than left motor, the vehicle rotates to left.
- If speed of right motor is less than left motor, the vehicle rotates to right.

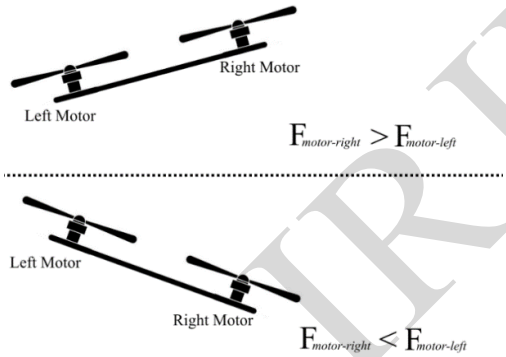


Fig. 10. Roll Movement

III. CONCLUSION

There is a continuous force on a flying object which pull the object down called as force of gravity. To keep the object in the sky, most of the energy capacity is used against to gravity. Fortunately, nature provides free resource to get rid of negative effect of gravity by using lifting gases like helium. Envelope encloses the lifting gas and generates lifting power together with the propulsion system. Critical design point of an envelope is the envelope volume. The higher volume means the more capacity envelope least. Volume of the envelope was defined to neutralize at last the weight of the entire system with a payload capacity. Therefore, energy source could be used only for flying. This work presents a high-level design to determine volume and payload capacity of the envelope.

Hybrid airship uses lifting capacity of the gas and mechanical power produced from propulsion system. Unlike conventional airships, this paper presents designing a propulsion system independently from the envelope. Even it can fly by its own without integration with an envelope. Propulsion system includes two dc brushless motors which are mounted on two servo motors. Servo motors provides ability to change direction of the motor thrust. Therefore, without using any ruder or tail, airship can fly to any direction.

ACKNOWLEDGMENT

Firstly, I would like to express my gratitude to my supervisor of this project, Asst. Prof. Dr. Özgür TAMER for valuable guidance and advices. He inspired me greatly to work in this project and encouraged me to overcome the problems I encountered during this period.

On the other hand, I would like to thank Dokuz Eylul University for providing me with a good environment and facilities to complete this project.

Finally, an honorable mention goes to my family and friends for their understandings and supports me in completing this project.

REFERENCES

[1] Richard K. Barnhart, Stephen B. Hottman, Douglas M. Marshall and Eric Shappee, *Introduction to Unmanned Aircraft Systems*, 1st ed., Newyork: CRC Press, 2012, pp.1

[2] Richard K. Barnhart, Stephen B. Hottman, Douglas M. Marshall and Eric Shappee, *Introduction to Unmanned Aircraft Systems*, 1st ed., Newyork: CRC Press, 2012, pp.2-5

[3] Richard K. Barnhart, Stephen B. Hottman, Douglas M. Marshall and Eric Shappee, I*ntroduction to Unmanned Aircraft Systems*, 1st ed., Newyork: CRC Press, 2012, pp.11

[4] A. Meola, "Drone market shows positive outlook with strong industry growth and trends", *Business Insider*, 2018. [Online]. Available: http://www.businessinsider.de/drone-industry-analysis-market-trends-growth-forecasts-2017-7. [Accessed: 21- Jan- 2018].

[5] Paul Robertson, "Hybrid Power in Light Aircraft: Design Considerations and Experiences of First Flight"

[6] Reg Austin, *Unmanned Aircraft Systems*. Sussex: 2010 John Wiley & Sons Ltd, 1st ed., Sussex: John Wiley & Sons Ltd, 2010, pp.2-4

[7] Richard K. Barnhart, Stephen B. Hottman, Douglas M. Marshall and Eric Shappee, *Introduction to Unmanned Aircraft Systems*, 1st ed., Newyork: CRC Press, 2012, pp.1

[8] "Lighter-Than-Air Vehicles." *National Technical Reports Library – NTIS* 2018. [Online]. Available: https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/ADA568211.xhtml. [Accessed: 01- Feb- 2018].

[9] *https://d2v9y0dukr6mq2.cloudfront.net/video/thumbnail/B-wmtY8xinajljp5/an-aerostat-blimp-or-balloon-is-used-by-us-*

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customs-and-border-patrol-to-conduct-surveillance-along-the-mexican-border_bsn2zgju__S0000.jpg. 2018.

[10] *https://www.flyingmag.com/sites/flyingmag.com/files/styles/1000_1x_/public/images/2017/05/airlander.jpg. 2018*

[11] "Airship", *en.wikipedia.org*, 2018. [Online]. Available: https://en.wikipedia.org/wiki/Airship. [Accessed: 01- Feb- 2018].

[12] H. Zhai and A. Euler, "Material Challenges for Lighter-Than-Air Systems in High Altitude Applications," AIAA 5th ATIO and16th Lighter-Than-Air Sys Tech. and Balloon Systems Conferences, 2005.

[13] "Buoyancy", *en.wikipedia.org*, 2018. [Online]. Available: https://en.wikipedia.org/wiki/Buoyancy. [Accessed: 01- Feb- 2018].

[14] *https://upload.wikimedia.org/wikipedia/commons/7/74/Buoyancy.svg. 2018.*

[15] *https://upload.wikimedia.org/wikipedia/commons/thumb/6/67/Plane.svg/687px-Plane.svg.png. 2018.*

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