A remotely-controlled micro airship for wireless coverage

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Permalink (DOI): https://doi.org/10.23917/arstech.v3i2.1190

**ARTICLE INFO**

Article history:
Received 07 October 2022
Revised 26 November 2022
Accepted 02 December 2022
Available online 27 December 2022
Published regularly 31 December 2022

**Keywords:**
Airship design
Air vehicles
Remote control
Thrust vectoring
Wireless coverage

**ABSTRACT**

This paper describes the design process and prototype development of a remotely controlled airship for wireless coverage. The airship is designed to be used as a platform to provide wireless coverage for rural areas. The design process follows a systematic design process for lighter-than-air vehicles, modified to impart slight heaviness to the vehicle. A remotely-controlled, thrust vectoring electric propulsion system offsets the slight vehicle heaviness. The electric propulsion system comprises two tilting rotors for takeoff, cruise, hovering, and horizontal manoeuvring. A rudder-less, rotor-less, cruciform fin design was implemented. A reduced-scale prototype of the airship was developed to prove the design concept. The airship prototype was successfully tested in an indoor environment.

1. INTRODUCTION

No country has full wireless network coverage over its entire land. Building wireless network infrastructure usually requires huge costs, equipment, and many working days. Governments and mobile service providers usually allocate their resources to areas of high population. Therefore, it is not an uncommon experience to have many areas with no or weak wireless coverage, especially remote areas with no or very limited number of inhabitants. Direct satellite wireless coverage is possible, but it requires special receiving devices and is offered at a cost which is unaffordable to the main users. In addition, there are several global and local events such as Formula One, and similar racing competitions which witness the gathering of hundreds or thousands of people for few days in rural areas which may fall outside the skirts of the
existing mobile networks [1]. Providing mobile services for the participants in such limited time events by working on a strategy called “coverage on-demand” poses a challenge for mobile service providers [2-4].

Another need for temporary wireless coverage arises after the destruction of the wireless network infrastructure following a natural disaster or an act of war. A prominent and emerging solution to the problem of lack of wireless network is to employ flying vehicles to transmit signals to users on the ground when needed. Temporary airborne wireless network stations can alleviate the disconnection problem of rescue workers and affected population without having to wait for the costlier and time-consuming construction of ground-based towers [3,5]. Airships or aerostats have been proposed as low-cost alternative for high-altitude platforms (HAPs) operating in the stratosphere (up to 22 km) to provide communication facilities for delivery of future broadband wireless communications [2,6]. Airships are proposed as a platform to provide wireless coverage. The airship can be built to carry a base station and an antenna, and it can provide LTE coverage over certain regions for specified periods of time. The design features and attributes that an airborne wireless transmitter platform possesses, can help to provide wireless coverage seamlessly and efficiently. Airborne wireless coverage may also help rural regions transition from poor, unreliable, and sluggish service to ultrafast, cutting-edge 4G and 5G networks. A typical HAPs mobile network architecture is shown in Figure 1.

Low altitude aerostats have also been proposed as a platform for cost-effective wireless communication as an alternative to fixed tower networks, to fill the digital gap in rural areas. Aerostat platforms carrying wireless communication equipment at altitudes of few-hundred-meters can establish last-mile wireless over a radius of around 10 km. The Lighter-Than-Air Systems Laboratory of Indian Institute of Technology Bombay designed, fabricated, and tested a low-altitude aerostat for wireless coverage [7]. The United States-based company Altareos has developed autonomous, tethered, aerostats which can be used for wireless coverage flying for few days at altitudes of few hundred meters (an example is shown in Figure 2. [8].

The principle of operation of lighter-than-air (LTA) vehicles such as an airship is the same. An LTA vehicle displace a volume of air which has greater mass than the total mass of the lifting gas (a gas of less density than air such as helium), the total vehicle structure, the fuel (if any), and the useful payload – which generates an aerostatic lift according to Archimedes’ principle. When buoyant gas forces are in perfect balance with the overall vehicle weight, it will float. When lift forces exceed gravity forces, the vehicle will climb, and when the opposite happens it will descend. Aerodynamic lift and propulsive forces may also be employed to assist buoyant or aerostatic lift. Airship buoyant lift is nearly independent of flying altitude as long as the pressure altitude of the airship is not exceeded, and the lifting gas may expand within the boundaries of the gas envelope [9].

Figure 1. Typical HAPs mobile network architecture [6].

Figure 2. Altareos ST-Flex tethered aerostat [8].

This paper describes the design, fabrication, and testing of micro airship which can be flown at low altitudes (below 100 m AGL) and which can provide temporary wireless coverage over relatively wide areas. This micro airship is developed as a proof of concept for using airships for wireless coverage. The structure of the airship is a non-rigid airship or blimp that has no internal structural framework. The airship is powered by an electric propulsion system and is controlled remotely by an operator on the ground. The payload is the
communication equipment needed for wireless coverage. A suitable power source, such as rechargeable batteries, or fuel cells, must also be carried to provide power to the payload and the electric propulsion and flight control systems. We aim to develop an airship with low energy consumption that can hover for a long time before it needs to be recharged or refuelled. Another goal for the design of the airship is to make it available at low cost.

2. AIRSHIP DESIGN

2.1. Performance Analysis

There are three main established structural design concepts for airships: rigid, non-rigid, and semi-rigid [9, 10]. We select a non-rigid design (formerly referred to as blimp or dirigible; the term dirigible is rarely used now). The internal gas pressure of the non-rigid airship keeps its hull shape. Normally, a non-rigid airship design consists of one or more flexible bag (also referred to as balloonet) which is placed inside the main envelope of the non-rigid design. The function of the flexible bag is to keep the pressure difference constant because the density, pressure, and temperature of the lifting gas are continually changing [9, 10]. We select for our airship a non-rigid structural design with no balloonet. This design concept was selected for its simpler design, less weight, and lower cost compared to the other design concepts.

2.2. Airship Mission and Performance

The mission of the micro airship is composed of four main phases: takeoff and climb, hovering, cruise, descent, and landing. All the phases will be analysed at constant speed since airships usually fly at a constant speed. The heavity, $H$, of an airship is defined as the gross weight, $W$, minus the buoyancy or aerostatic lift, $B$, or

$$ H = W - B $$

The buoyancy lift is calculated from

$$ B = (\rho - \rho_g) V g $$

where $\rho$ is the atmospheric density, $\rho_g$ is the density of the lifting gas, $V$ is the volume of the envelope, and $g$ is the acceleration of gravity. The buoyancy ratio, $BR$, of an airship is defined as the ratio of buoyant lift to the gross weight of the airship, thus

$$ H = W (1 - BR) $$

A conventional airship will have $BR$ more than 85% at takeoff and between 95% and 98% at landing assuming weight reduction due to fuel consumption. The remaining heavity is offset by aerodynamic lift, $L$, and/or any vectored thrust force, $T$. Bodies of revolution are not effective in producing aerodynamic lift, therefore vectored thrust is needed to offset the vehicle heavity [9]. The propulsion system selected for the micro airship is an electric propulsion system which is powered by rechargeable lithium-ion batteries [11]. This results in invariant vehicle weight, hence buoyancy ratio. In order to alleviate the power requirement to offset the vehicle heaviness using vectored thrust, throughout all the phases, a buoyancy ratio of 97% is assumed.

The takeoff and climb phase begin with lift-off and continues until the airship reaches the desired altitude. The rate of climb is determined by balancing the vertical upward forces, and the downward vertical forces. In the hovering phase, the airship stays in the air at a fixed position. Propulsive thrust will be required to offset the heaviness of the airship. During the cruise phase, the airship moves horizontally from one point to another at a constant speed and at constant angle of attack. The thrust will be assumed to make an angle $\gamma$ with the horizontal.

The last phase is descent and landing, which is when the airship decreases its altitude, and it is opposite to the climb phase. During this phase, the airship will fly vertically downward with constant speed. In this phase, the motors will be switched off, so the airship will descend solely due to its heaviness. The force diagrams for the performance analysis of the airship are shown in Figure 3.

The aerodynamic lift, $L$, and drag, $D$, on the airship are dominated by the envelope and the fins and are calculated from

$$ L = q C_L S_{ref} $$

$$ D = q C_D S_{ref} $$

where $q = 1/2 \rho v^2$ is the dynamic pressure of the freestream, and $v$ is the flight velocity; $C_L$ is the lift coefficient of the airship; $C_D$ is the drag coefficient of the airship; and $S_{ref} = V^{2/3}$ is the reference area of the envelope [12].

The equations of motion of the airship for the four phases are given by

Takeoff and climb:

$$ T = W - B + D = H + D = W (1 - BR) + D $$

Hovering:

$$ T = W - B = H = W (1 - BR) $$

Cruise:

$$ T \sin \gamma = W - B - L = H - L = W (1 - BR) - L $$

$$ T \cos \gamma = D $$

Descent and landing:

$$ T = 0 $$

$$ D = W - B = H = W (1 - BR) $$
2.3. Envelope Design

The design of the airship follows a systematic design process of an LTA vehicle [13]. For an LTA vehicle, the volume is a key geometric design parameter. We select a geometric design of the airship envelope with fixed proportions such that the volume of the envelope can be varied by varying one geometric dimension being the maximum diameter of the axisymmetric envelope. The design process of the envelope begins by selecting an initial diameter. The first step is then to calculate the weight of the envelope using the surface of the envelope material. The envelope material must be chosen effectively to achieve sufficient strength, durability, low weight, low leakage of gas, and ease of fabrication and sealing [10]. Small airship envelopes are usually fabricated using single ply fabrics that are made up of a single laminate or single sheet. Polyvinyl chloride (PVC), nylon, polyester, and Kevlar are some of the single ply fabrics employed. Polyurethane (PU) and Polyvinyl Chloride (PVC) have excellent gas retention properties. However, PVC is far less expensive than PU, hence it is often used. Second, the aerostatic lift force of the envelope is calculated using the density of the lifting gas. The lifting gas is a gas lower density than the surrounding atmospheric air. Hot air was used in early airships, but soon proved ineffective giving way to hydrogen and helium [9]. Hydrogen is more effective as a lifting gas compared to helium. However, because it is highly flammable and chemically reactive it is very challenging to use it safely. Therefore, helium, which is a noble gas, became the standard lifting gas for airships after the historical Hindenburg disaster [9, 14].

Next, the weight of the gondola including all other necessary equipment for operation of the airship (the flight controller, propulsion system, etc.) and the payload are added to the weight of the envelope to obtain the gross weight of the vehicle. The buoyancy ratio can then be calculated from

\[ BR = \frac{B}{W} \]  \hspace{1cm} (12)

The shape of the envelope is determined by trade-off between aerodynamics and buoyancy. Aerodynamics demands a body of revolution with a high fineness ratio, \( FR \), whereas buoyancy requires a spherical body. Non-rigid airship designs have body shapes with \( FR \) between 3 and 5. Higher \( FR \) is not possible with non-rigid airship designs [10]. Lower \( FR \) will be possible if the airship is designed to act as an aerostat.

We design the airship with a target buoyancy ratio of 97%. The envelope shape used is a modified GNVR shape. The GNVR shape consists of three sections, the front section is portion elliptic, the middle section is arc of circle, whereas the end section is parabolic [15].

The material used for the envelope is PVC coated nylon which has a density of 120 g/m² [16]. The
maximum diameter is iterated until the target buoyancy ratio is achieved with reasonable tolerance. The envelope fineness ratio of the envelope is taken as 2.26. A two-dimensional drawing of the envelope is shown in Figure 4 compared to the GNVR shape. The volume, surface area, and centroid of the envelope are determined from a CAD model of the envelope created in CATIA using corresponding tools. The final envelope design parameters are given in Table 1. The envelope was fabricated by a US company specialized in manufacturing blimps used for advertisements.

![Image of Modified GNVR envelope](image)

*Figure 4. Modified GNVR envelope.*

<table>
<thead>
<tr>
<th>Table 1. Design parameters of the airship envelope.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design parameter</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td>Shape</td>
</tr>
<tr>
<td>Fineness ratio (FR)</td>
</tr>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Density</td>
</tr>
</tbody>
</table>

2.3. Fin Design

Airship envelopes are usually equipped with a system of fins near the envelope tail. A vertical fin to provide static stability about the airship vertical axis (directional static stability), and a horizontal fin to provide static stability about the lateral axis (longitudinal static stability). Moveable surfaces on the fins are sometimes employed to allow the control of the airship attitude. The vertical fin area is always equal to or less than the horizontal fin area.

The fin sizing of an airship can be done by considering a pair of opposing tail surfaces, including the area between the tails, in order to form a full-span surface that is equal to a typical aircraft wing. The tail surface’s lift curve slope is calculated using a simple calculation based on the tail aspect ratio and sweep angle from finite wing theory. Since fins have significant and that weight is located aft, it is important to minimize fin weight. Controlling the location is also important for airships [9]. We select for the airship a four equally sized fins: two horizontal fins and two vertical fins. Because the airship is designed to fly at very low speed, aerodynamic control will not be effective (lift is proportional to the square of flight speed).

Therefore, we employ thrust vector control rather than aerodynamic control and the fins will not be equipped with moveable surfaces. This will also simplify the design of the airship. The fins are fabricated using polypropylene corrugated sheets which has increased strength. The sheets have a density of 750 g/m². The fins are attached to the envelope using Velcro strips and supported by connecting strings. The design of the fins follows suggested design ratios [9] given in Table 2. The fin design parameters are given in Table 3.

<table>
<thead>
<tr>
<th>Table 2. Fin design formulae.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design ratio</td>
</tr>
<tr>
<td>Tail Area Ratio</td>
</tr>
<tr>
<td>Fin Aspect Ratio</td>
</tr>
<tr>
<td>Fin Taper Ratio</td>
</tr>
<tr>
<td>Span to Root Chord Ratio</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Fin design parameters.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Parameter</td>
</tr>
<tr>
<td>Fin root chord</td>
</tr>
<tr>
<td>Fin tip chord</td>
</tr>
<tr>
<td>Fin height</td>
</tr>
<tr>
<td>Fin area</td>
</tr>
</tbody>
</table>

2.4. Gondola Design

The gondola is one of the most important components of an airship. It houses all the flight equipment as well as the payload. A gondola can be open and closed. It is possible to customize the weight, size, storage space, and structure of the gondola to achieve more flexibility. The gondola will include space for the propulsion system, flight controller, and payload. We select a simple closed design of the gondola, which is light weight, allows easy access to the components inside, and is readily available at
reasonable cost. The size of the gondola should be large enough to accommodate all the components with reasonable separation in order to avoid overheating of the electronic components. The gondola is made of a 330x230x205 mm plastic storage box with buckle locking lid.

2.5. Stability Analysis

For determination of the centres of buoyancy and gravity of the airship, a reference coordinate system is defined such that its origin is located at the envelope nose, the x-axis is pointing rearward along the centreline of the envelope, the y-axis is pointing vertically downward, and the z-axis is pointing horizontally rightward. The centre of buoyancy of the envelope plays a crucial role in the stability of an airship. It was calculated to be 1.61 m from the envelope nose along its centreline. Another crucial point for stability analysis is the centre of gravity. The airship is divided into several components. For each component, the mass and location of centre of gravity with respect to some coordinate systems are determined. Then, the x-coordinate of the centre of gravity of the airship is calculated from

\[ x_{cg} = \frac{\Sigma m_i x_i}{\Sigma m_i} \]  

(13)

where \( x_i \) is the x-coordinate of the center of mass of component \( i \) having mass \( m_i \). The other coordinates of the center of gravity are calculated similarly. Table 4 gives the detailed calculations of the center of gravity of the airship. The coordinates of the centre of gravity were found to be \( x_{cg} = 1.676 \text{ m}, y_{cg} = 0.243 \text{ m}, z_{cg} = 0 \).

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [kg]</th>
<th>x [m]</th>
<th>y [m]</th>
<th>z [m]</th>
<th>( m^x ) [kg.m]</th>
<th>( m^y ) [kg.m]</th>
<th>( m^z ) [kg.m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical fin - top</td>
<td>0.040</td>
<td>3.507</td>
<td>-0.475</td>
<td>0.000</td>
<td>0.140</td>
<td>-0.019</td>
<td>0.000</td>
</tr>
<tr>
<td>Vertical fin - bottom</td>
<td>0.040</td>
<td>3.507</td>
<td>0.475</td>
<td>0.000</td>
<td>0.140</td>
<td>0.019</td>
<td>0.000</td>
</tr>
<tr>
<td>Horizontal fin - right</td>
<td>0.040</td>
<td>3.507</td>
<td>0.000</td>
<td>0.480</td>
<td>0.140</td>
<td>0.000</td>
<td>0.019</td>
</tr>
<tr>
<td>Horizontal fin - left</td>
<td>0.040</td>
<td>3.507</td>
<td>0.000</td>
<td>-0.480</td>
<td>0.140</td>
<td>0.000</td>
<td>-0.019</td>
</tr>
<tr>
<td>Envelope</td>
<td>2.800</td>
<td>1.742</td>
<td>0.000</td>
<td>0.000</td>
<td>4.878</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Empty gondola</td>
<td>0.330</td>
<td>1.156</td>
<td>0.977</td>
<td>0.000</td>
<td>0.381</td>
<td>0.322</td>
<td>0.000</td>
</tr>
<tr>
<td>Electric motor 1</td>
<td>0.070</td>
<td>1.156</td>
<td>0.975</td>
<td>0.290</td>
<td>0.081</td>
<td>0.068</td>
<td>0.020</td>
</tr>
<tr>
<td>Electric motor 2</td>
<td>0.070</td>
<td>1.156</td>
<td>0.975</td>
<td>-0.290</td>
<td>0.081</td>
<td>0.068</td>
<td>-0.020</td>
</tr>
<tr>
<td>Servo 1</td>
<td>0.055</td>
<td>1.156</td>
<td>0.977</td>
<td>0.100</td>
<td>0.064</td>
<td>0.054</td>
<td>0.006</td>
</tr>
<tr>
<td>Servo 2</td>
<td>0.055</td>
<td>1.156</td>
<td>0.977</td>
<td>-0.100</td>
<td>0.064</td>
<td>0.054</td>
<td>-0.006</td>
</tr>
<tr>
<td>Battery</td>
<td>0.188</td>
<td>1.284</td>
<td>1.067</td>
<td>0.000</td>
<td>0.241</td>
<td>0.201</td>
<td>0.000</td>
</tr>
<tr>
<td>Flight controller</td>
<td>0.016</td>
<td>1.133</td>
<td>1.065</td>
<td>0.000</td>
<td>0.018</td>
<td>0.017</td>
<td>0.000</td>
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<tr>
<td>Router</td>
<td>0.080</td>
<td>1.043</td>
<td>1.059</td>
<td>0.000</td>
<td>0.083</td>
<td>0.085</td>
<td>0.000</td>
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<tr>
<td>Radio control transmitter</td>
<td>0.015</td>
<td>1.210</td>
<td>1.070</td>
<td>0.030</td>
<td>0.018</td>
<td>0.016</td>
<td>0.000</td>
</tr>
<tr>
<td>Power management board</td>
<td>0.007</td>
<td>1.210</td>
<td>1.075</td>
<td>-0.040</td>
<td>0.008</td>
<td>0.008</td>
<td>0.000</td>
</tr>
<tr>
<td>Shaft 1</td>
<td>0.030</td>
<td>1.156</td>
<td>0.967</td>
<td>0.200</td>
<td>0.035</td>
<td>0.029</td>
<td>0.006</td>
</tr>
<tr>
<td>Shaft 2</td>
<td>0.030</td>
<td>1.156</td>
<td>0.967</td>
<td>-0.200</td>
<td>0.035</td>
<td>0.029</td>
<td>-0.006</td>
</tr>
<tr>
<td>Summation, ( \Sigma )</td>
<td>3.906</td>
<td></td>
<td></td>
<td></td>
<td>6.547</td>
<td>0.950</td>
<td>0.000</td>
</tr>
<tr>
<td>( \Sigma M/\Sigma m ) [m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.676</td>
<td>0.243</td>
<td>0.000</td>
</tr>
</tbody>
</table>
3. AIRSHIP DEVELOPMENT AND TESTING

3.1. Propulsion System

The propulsion system consists of two 5.0”x4.5” tri-blade propellers driven by RS2205-2300 brushless motors to produce thrust. Each propeller-motor has maximum thrust of 1024 g weight. Each of the two brushless motors is connected to a shaft which can be rotated using a servo motor in order to tilt the propeller, hence provide the required thrust vectoring. The brushless motors speeds are controlled using LittleBee 20 A electronic speed controller (ESC). The tilting of each propeller is controlled by a MG995 servo motor which has an operating speed of 0.2 s / 60° at no load when powered by 4.8 V.

3.2. Flight Control System

The flight controller used for the control of the airship is a Pixhawk 4 Mini autopilot. The Pixhawk 4 Mini uses the Pixhawk 4 FMU processor and memory while removing interfaces that are not utilized very often. The on-board sensors include ICM-20689 accel/gyro, IST8310 magnetometer, BMI055 accel/gyro, and MS5611 barometer. In addition to the on-board sensors, a Holybro M8N GPS module is used to obtain positioning data of the airship when operated outdoor.

The flight controller, the electric motors and other electronic components of the airship are powered by a 2200 mAh three-cell ZOP Power rechargeable battery. A PM06 power management board is used to provide each component with the required power at a suitable voltage. All the components are connected to the power management board, which is then connected to the rechargeable battery. Figure 5 shows the power distribution board connections.

A six-channel Flysky FS-i6, radio transmitter and Flysky FS-iA6B receiver are used for the remote control of the airship.

PX4 autopilot was used the flight control software and QGroundControl was used as the ground control software.

![Power distribution board connection diagram.](image)

Figure 5. Power distribution board connection diagram.

3.3. Fin Attachment

The fins are made from 4mm thick lightweight polypropylene. The attachment will be secured to the envelope using a lightweight cables and Velcro will cover the bottom side of the fin.

3.4. Payload

For our project, we will choose femtocell as the type to demonstrate the efficiency of the idea, and it will be more suitable for the micro airship prototype. Furthermore, we choose 4G/LTE Mobile Router DWR-930M to provide wireless coverage. It has a maximum range sufficient for a medium-size house, or a summer camp. The router is rechargeable which means that does not require power from the main power source.

3.5. Gondola Arrangement

All the components inside the gondola are attached to the floor of the gondola using Velcro (see Figure 6). This keeps the components fixed when manoeuvring the airship and allows the removal any component easily for inspection or replacement.

![Gondola design with positioning of the components.](image)

Figure 6. Gondola design with positioning of the components.
3.6. Flight Testing

Before testing the airship, the envelope had been inflated by first filling it with helium, then with air. A compact size wireless router was used for payload demonstration which resulted in a reduction in the airship gross weight. To compensate for this reduction in the airship gross weight, the envelope was filled with a mix of 99.999% pure helium and regular atmospheric air. Following that, all subsystems are assembled. Following the assembly, we verified that each subsystem is stable and in the appropriate position. The flight control and propulsion system were tested while the airship is tethered. When testing was satisfactory, the airship was released and tested for takeoff and climb; hovering; cruise; and descent and landing phases inside one of the high-rise buildings in UAE university. The testing confirmed that the airship has the capability to fly at the desired altitude. Figure 7 shows the airship during indoor flight testing. The wireless router payload was tested for providing wireless 4G network over a wide area for multiple users using different platforms as shown in Figure 8.

![Figure 7. Indoor testing of the airship flight control system.](image)

4. CONCLUSION

In this paper, we demonstrated the design, development and flight testing of a remotely controlled micro airship for wireless coverage. The design of the micro airship followed a systematic LTA design procedure which was modified to suit a micro size airship. The airship envelope was sized to have the lifting capacity required by the wireless communication payload, in addition to the necessary flight equipment. The gondola was sized to be large enough to accommodate all the flight equipment and the payload without exposing the electronic components to excessive heating. The gondola box allows firm attachment to the envelope, yet easy access to the components inside. The propulsion system was all electric using two tilting propellers driven by brushless electric motors. The tilting of the propellers allows for varying thrust vectoring required by the different phases of flight. The propellers have the capability to be tilted independently which allows for the manoeuvring of the airship without having to add a fin rotor or a rudder. The fins were sized appropriately for a micro airship designed for low-speed flight. No rudder or rotor was added to the fins. Velcro and lightweight cables were used to attach the various subsystems together. The flight testing of the airship with the payload was satisfactory.

However, the yawing response of the airship was very slow, which was expected since the moment arms of the propulsive rotors are much smaller than that of a typical fin rotor. For faster yawing response, a rotor can be added to one of the vertical fins. A rudder will not be very effective unless the airship is flown at higher flight speed. A further possible development of the airship is to make it flight autonomous. Autonomous flight of the airship will alleviate the burden of having to control its flight when it is needed for wireless coverage.

CONFLICTS OF INTEREST

The author affirms that this publication is not affected by any conflicts of interest.

ACKNOWLEDGEMENT

The authors acknowledge the financial and logistic support from the United Arab Emirates University, UAE to build the airship prototype.
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