Design, Fabrication of IIUM Unmanned Air Vehicle

Ashraf A. Omar*, Ahmad Firdaus Ismail, Muhammad Zakaria, and Youshafidi Yusof
Department of Mechanical Engineering, Kulliyyah of Engineering
International Islamic University Malaysia
P.O. Box 10, 50728, Kuala Lumpur
aao@iiu.edu.my

Abstract: In this paper, UAV model was designed and built by the research team from aerospace engineering in IIUM. The aircraft was designed to perform low altitude surveillance. The design process was started with a conceptual sketch, sizing, and estimation of aerodynamics parameters and, stability and control forces of the aircraft. Then the design process was followed by the selection of propulsion system and the improvements of the conceptual design. The construction process of the aircraft was carried out using various composite structure methods. After the aircraft constructed, the first flight test was conducted to test the aircraft performance. Based on the first flight test results, some modifications to some aircraft components were carried out to improve the performance and stability of the aircraft. Then the final finishing was preformed which included painting of the aircraft and smoothing of the surfaces. The aircraft already has undergone six successful flight tests.
Keywords: UAV, design process, fabrication process, composite structure, flight test

1. Introduction

For a new airplane design, there must be some established requirements which serve as jumping off the point for a design process, and which serve as the focused goal for the completed design [11]. In recent times UAVs have proved their worth operationally in theatres such as Kosovo and Bosnia where their advantage over the conventional tactics have become very noticeable [5-7]. As result the interest in procurement and R& D of UAVs has increased through the world. The use of UAVs in civil and commercial applications has been considered by many countries for several years. A number of Unmanned Aerial Vehicles (UAVs) presently exist, both domestically and internationally. Their payload weight carrying capability, their accommodations (volume, environment), their mission profile (altitude, range, duration) and their command, control and data acquisition capabilities vary significantly. Routine civil access to these various UAV assets is in an embryonic state and is only just now emerging [12].

To build a UAV requires skills from across the spectrum of engineering. For instance, Mechanical engineering for the aircraft shape and structure, Mechatronic and computer systems engineering for the design and integration of the flight control system, and Electrical and Electronic engineering and Telecommunications engineering for telemetry and sensor package integration.

Radio controlled (R/C) vehicles are controlled with a wireless, hand-held transmitter which communicates with the vehicle through radio frequencies, providing the advantage of long-range control. The range of a vehicle is the area in which the R/C vehicle can receive the radio frequency signals from the vehicle’s transmitter. The range can be anywhere from 50 to over 1500 feet and varies from vehicle to vehicle. Remote control airplane usually needs 4 or more channels of remote control. These channels are needed to control the control surfaces and the throttle for controlling the speed.

UAV technology is gaining increasing favor as a means of providing a cost effective and reliable method for replacing or supplementing manned and space based platforms [14]. As such, the purpose of this work is to build knowledge and skills in a growth area while also allowing the students involved to practically apply their skills. Further, much of the technology is applicable to many other industrial and scientific applications such as mobile robotics and control system implementation.

In this work small size remote controlled airplane (Unmanned Air Vehicle, UAV) was designed to be simple and easy to fly and free from difficulties associated with stalling and spinning and it should meet the following requirements: Short range, low altitude and low cost.

2. Design Process

In conceptual design, the design requirements are used to guide and evaluate the development of the overall aircraft configuration arrangement. This design arrangement includes wing and tail overall geometry (areas, sweeps, etc.), fuselage shape and internal locations of crew, payload, passengers, and equipment, engine installation, landing gear, and other design features. In choosing the wing and tail airfoils, several considerations have been taken in account including maximum possible lift to drag ratio and highest stall angle of attack. Based on those considerations, airfoil type NACA 23012 was selected to be used for the main wing and NACA 0009 for tail.

The high wing configuration was selected for the designed UAV because it provides better streamlining for cruising flight and gives better lift to drag ratio during climbing and gliding flight. The aspect ratio of 6 was used which is consider acceptable value for homebuilt aircraft [9]. Hoerner shape also was used for the wingtip since it is the easy tip to fabricate, simple and very suitable for low speed or subsonic aircraft. The Hoerner wing tip is a sharp edged wing tip with the upper surface continuing the upper surface of the wing. The lower surface is 'undercut' and cantered approximately 30 degree to the horizontal. Wing incidence angle of 2° wing dihedral of zero were [9].

3. Mission Profiles

The Mission profile of the aircraft is shown in figure 1 was designed according to the project objectives. Aircraft takeoff gross weight was estimated using fraction weight method and was found to be 23.7 lb. The estimation of the takeoff weight was also carried out using Advance Aircraft Analysis (AAA) software and the obtained result agreed with fraction weight methods. Wing loading required for stall, climb, takeoff and landing were estimated. To ensure that the wing provides enough lift in all circumstances, lowest of the estimated wing loadings was used. The lowest wing loading was found to be 2.89 lb/ft^2 which is the wing loading needed to meet the stall requirement.

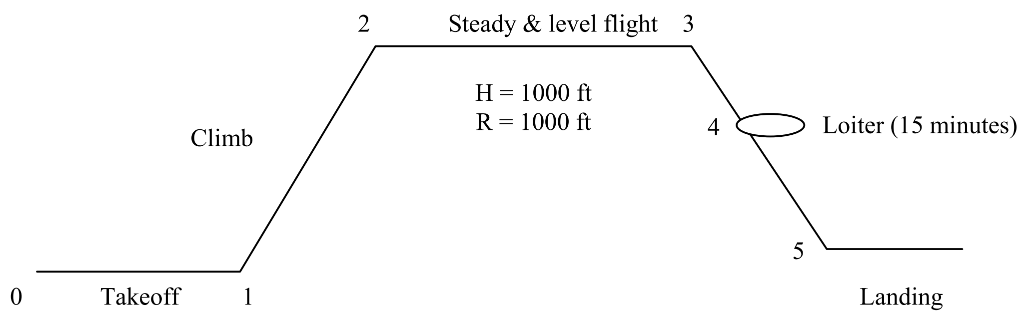

Fig. 1: Mission Profile

The selected wing loading value was used to calculate landing distance which found to be 237.7 ft.

4. Estimation of Power to Weight Ratio

The typical values for P/W for different class of aircraft can be found in Reference 9. Power to weight ratio for homebuilt airplane was given as 0.08 hp/lb. Since the takeoff weight has been estimated, then the engine output power was calculated as P= (hp/W)(W_0)=(23.651) (0.08)= 1.89 hp. To make sure that the estimated power was obtained correctly, the thrust matching methods was performed to recalculate the engine power needed and the result showed that the needed power for this aircraft should be equal or higher than 1.8 hp.

5. Initial Sizing

Aircraft sizing is the process where the designers have to determine the size of the aircraft to carryout its mission divided to

1) Fuselage Length

The length of the fuselage as shown in figure 2 can be estimated using the following relation $Length(l) = aW_0^C$ where the value of *a* and *C* coefficients are given in reference 9, for homebuilt aircraft are given as a = 3.5, and C = 0.23. Fuselage length was calculated and found to be 7 ft. The length of tail arm was found to be 4.57 ft which is 60% of the fuselage length.

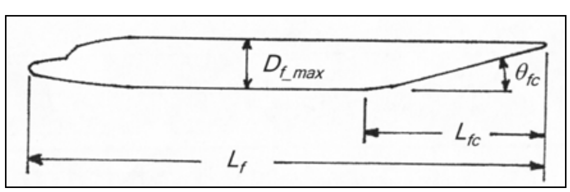

Fig. 2: Fuselage Parameter

Advance Aircraft Analysis (AAA) Software, Version 2.5 was used to calculate the maximum diameters and length of the fuselage which were found to be 1.076 ft and 3.766 ft, respectively. The AAA software also used to obtain the wetted area for the fuselage which found to be $S_{wet_f} = 24.4\,ft^2$.

2) Wing and Tail Size

Based on the selected wing loading, the wing platform area of 8.18 ft^2 was obtained. The wing span was estimated as 7ft, the wing chord was obtained as 1.17 ft. Based on the design guidelines for tail sizing which are given by reference 9, the aspect ratio of the vertical tail (AR_{VT}) assumed to be 2ft which is presented 30% of the aspect ratio of the wing and the length of the vertical tail was assumed to be 4.5 which are presented 60% of the fuselage length. Then the tail sizing relations given by reference 9 were used to calculate the vertical tail area (S_{VT}) which found to be 0.509 ft^2. The aspect and taper ratios of the vertical tail were selected to be 2 and 0.4, respectively. The vertical tail span was calculated and found to be 1 ft and the root and tip chord of the tail also obtained as 0.73 ft and 0.29 ft, respectively. Same procedure can be used for the horizontal tail which leads to AR_{HT}=4.0ft, S_{HT}=1.5ft^2, A_{HT}=4.0, λ=0.4, b_{HT} = 2.5 ft, C_{HTroot}=1.24 ft and C_{HTtip}=1.24 ft.

6. Estimation of the Drag and Location of the Aircraft Center of Gravity

The parasite drag estimation was based on the components build up methods, more details on components build up method can be found in reference 9. Two types of drag were considered for each aircraft component; they are parasite drag and induced drag. The total parasite drag coefficients after add 5% for the drag due to leaks and protuberances was found to be 0.0276. For induced drag, the Oslwad factor (e) and induced drag coefficient (K) was estimated and found to be 0.87 and 0.06, respectively.

According to the dimension parameters obtained so far as shown in figure 3. For better stability and to keep aircraft nose up during the flight, the center of gravity must be kept not far behind the aerodynamic center. The location of the center of gravity was found at 2.174 ft away from aircraft nose.

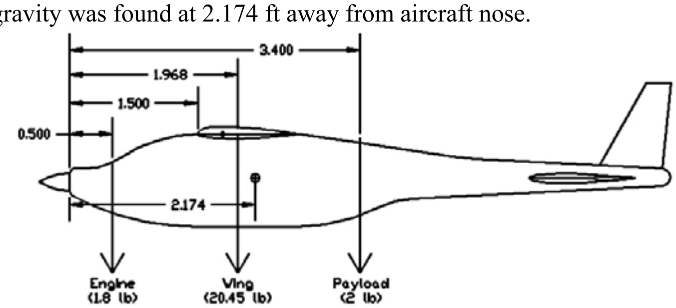

Fig. 3: Estimation of Center of Gravity

7. Static and Directional Static Stability

In order to an aircraft achieve static stability, the slope of the pitching moment coefficient versus angle of attack should be negative: $\frac{dC_m}{d\alpha} < 0$. The contribution of Aircraft components on the static stability can be found by obtaining $C_{m\alpha}$ for each components. Then the total aircraft Cm vs α can be found. Figure 4 shows the total moment vs angle for the designed aircraft.

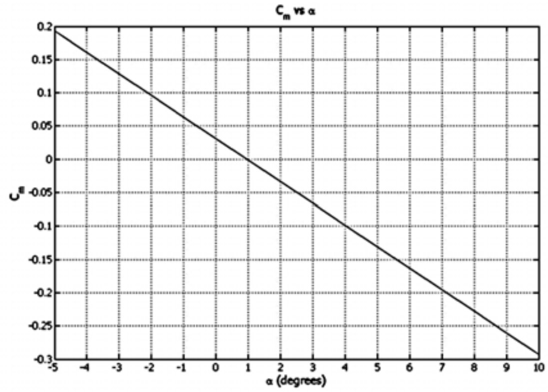

Fig. 4: Aircraft Moment Coefficient (C_m) vs Angle of Attack (α)

Figure 4 shows that the aircraft longitudinal statically stable. This curve also clearly shows that the pitching moment of the aircraft will be zero at wing angle of attack, $\alpha = 1°$.

To make sure that the aircraft is directional statically stable, the airplane should tend to return naturally to an equilibrium condition when subjected to some form of yawing disturbance. The total $C_{n\beta}$ found to be equal 0.0006/degree.

8. Propulsion System

Two stokes engines is the most suitable engine for ultra light aircraft. The big advantage with two stroke engines is their mechanical simplicity and consequent weight and cost saving. For the above mentioned advantages, two-stroke engine (Thunder Tiger PRO-120) was chosen to be the propulsion system of the designed aircraft. The maximum power of the engine is 3.2 BHP, the engine maximum RPM is 14000 revolutions per minutes and the practical RPM is between 1800 to 14000 RPM. Previously, the required power was found to be 1.8 hp, the output power for the selecting engine is much higher than required power, having strong engine will help to improve the aircraft performance and shortage the takeoff distance.

9. Design Improvement

To increase the payload of the aircraft, the wing loading was reduced by increasing wing span to 10 ft instead of 7 ft. With the new wing span, the performance parameters of the aircraft were recalculated. The performance parameters were calculated as $V_{\max} \geq$ 60 ft/s, $V_{CLIMB} \geq$ 45 ft/s, $V_{stall} \leq$ 35 ft/s, takeoff distance ≤ 1000 ft over 50 ft at sea level, rate of climb $\geq$ 600 fpm (feet per min), $V_{cruise} = 50$ ft/s and cruise altitude (H) = 8000ft, $S_a =$ Obstacle clearance landing distance = 45 ft, wing loading (W/S)=1.75 lb/ft^2, and landing distance =161.67 ft.

In order to suit the increasing of wing span, the fuselage volume was increased to give more space for payloads storage. This increases in fuselage volume done by increasing fuselage width from 0.7 ft to 0.83 ft and reducing the fuselage length and maximum height from 7.04 ft to 6.05 ft and from .08 to 0.9 ft, respectively. Decreasing fuselage height will help to reduce drag, and increasing fuselage width will help to reduce complexity in installation of the payloads, meanwhile, the expansion of the fuselage width will be better if the fuselage shape designed aerodynamically.

10. Landing Gear and Sizing of the Tire

Tail dragger type of landing gear was used for designed aircraft. The dragger landing gear type as shown in figure 5 was selected because it is easy to built, efficient for small airplane especially remote control airplane, provides good propeller clearance, has less drag and weight, and allows the wing to generate more lift for rough-field operation. Calculation was performed to obtain the suitable size of the tire it found that the tire with diameter of 4.28 inch and width of 1.82 inch is needed for main wheel tire. Solid spring absorber was used as landing gear shock absorbers.

11. Final Design

After all the above mentioned changes in the geometries and dimension, figure shows the final configuration of the designed aircraft model. The designed aircraft dimension as length: 6.048 ft (1.84 m), wingspan: 10 ft (3.05 m), wing area: 11.7 ft^2 (1.07 m^2), maximum height: 1.77 ft (0.54 m) and maximum take off weight was estimated as 19.84 lb (9 kg).

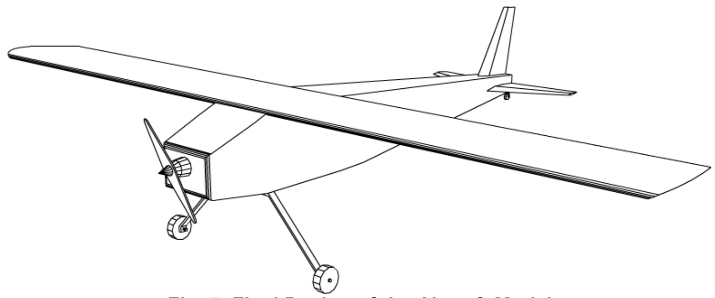

Fig. 5: Final Design of the Aircraft Model

12. Construction Process

The moldless composite construction technique was used to build the most designed aircraft components. This technique allows the builder to construct a part by forming a core material to a desired shape and then laminating the reinforcement material to the shaped piece to make up the final part. The core structure, usually foam like material, allows the builder to employ virtually any shape desired. Moldless techniques allow the builder to produce a safe, superior airplane without the requirement of expensive equipment or extensive experience. Polystyrene foam of density of 1.5 lb per cubic foot was used to construct the designed aircraft. For constructing the wing, thick and lightweight foam was selected. Below are diagrams that show two typical wing cross sections used for construct the wing.

Templates were papered for the wing sections. A constant chord wing requires two identical templates while a tapered wing requires two of the appropriate size and section. The templates are numbered on both sides as shown in figure 6.

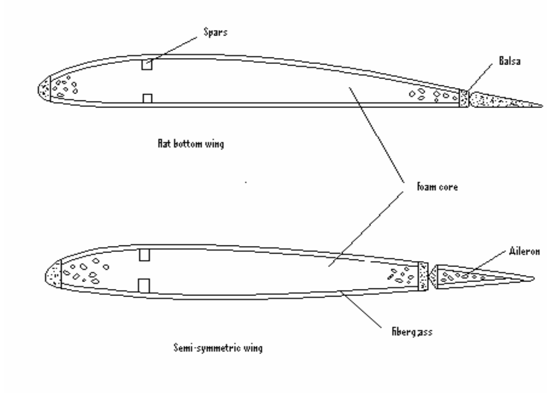

Fig. 6: Composite Wing Cross Section

The prepared template was attached to the foam with thumb tack. Locating the templates accurately is essential to the quality of the finished cores. Cutting the core is essentially a more one person operation. One person sets the pace of the wire movement but calling out the numbers on the template as they are passed while the other person follows the lead.

To construct the straight and symmetry fuselage, the foam cubes were attached to the fuselage to the obtained size. Then the attached foams will be squared and foam will be marked according to the fuselage dimension. Then the template will be attached along the dimension line, and after that the cutting process was performed. Finally, using the same methods, the shaping of the nose part of the fuselage was carried out without any problems. The complete core structure of the aircraft is shown in figure 7.

Fig. 7: The Complete Core Structure

After completion of the core structure, the process of laying up the glass fiber reinforcement with epoxy resins was carried out. The mixture of the epoxy resin was applied to the core structure as the first layer. Then the coated core structure was wrapped with the glass fiber as the second layer. The final step is to apply again the epoxy resin mixture to the glass fiber. Finally, the surface finishing process was carried out using sand paper and surface finish sander machine.

The control surface of the UAV is made from balsa wood and servos and linkages were attached. The servos and the linkages were placed in such a way allowed any modification in future. The internal loads of the UAV are consists of the discrete tank, receiver, batteries and the cameras mounting. Since the storage space on the fuselage is sufficient, no problem was faced during installing internal parts which were mounting by using foam and balsa wood. Engine firewall was built using three piece of plywood to make sure is strong enough to support the engine weight. First step in building the engine firewall is to attach all the plywood, and epoxy was used to attach them together.

13. Flying Test

The designed UAV was flown several times and proven to be stable and able to achieve its objectives including recording video clips form the air showing IIUM Gombak campus. Most the flight tests were carried out the IIUM Gombak campus without any technique problems. The designed aircraft was able takeoff and land in very short distance. Figure 8 showing the final aircraft model during flying test.

Fig. 8: Final Aircraft Model during Flying

14. Conclusions

The design of the UAV model has been carried out successful. Some difficulties encountered during the design process, however with the help of the references and computer software, the faced problems were solved successfully. The foam, epoxy and fiberglass were the main material used to construct the designed UAV. Some modification to the aircraft dimension was performed after every flight test to improve aircraft stability and performance. The objectives of the project have been successfully achieved. The designed UAV flown six times and was able to takeoff and land in very short distance. The flight tests prove that the designed UAV is stable and achieved acceptable flight performance. The designed UAV was able to take good quality motion pictures around IIUM Gombak campus.

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