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Design, Fabrication and Flight Testing of a Surveillance UAV

Moumen Idres, Burhani Makame, Bala Nabil Ahmad, Saleh Naji, Ahmad Safiuddin

Department of Mechanical Engineering
Faculty of Engineering
International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia
midres@iium.edu.my

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Abstract. Unmanned Aerial Vehicle (UAV) is becoming increasingly popular because it can perform variety of functions. These functions include surveillance, reconnaissance, monitoring, data collection and rescue operation. The purpose of this work is to design, fabricate and fly a low weight, low cost, small size UAV for a surveillance mission. The design is carried out based on Advanced Aircraft Analysis (AAA) software. The design process starts with the design specifications for a typical surveillance mission. Aircraft weight, wing loading and power loading were estimated in performance sizing process. Geometry was estimated using preliminary sizing. Aerodynamics of the aircraft was determined, which enabled the performance and stability to be analysed. If the desired performance is not achieved, the sizing is readjusted until a final design is reached. The aircraft was manufactured using foam, carbon rods, and fibreglass. The aircraft successfully flew at the first trial flight. This was followed by a successful flight with aerial photography.

Introduction

Unmanned aerial vehicles (UAVs) are capable of flying either remotely or autonomously. They are used heavily in military applications and they are gaining more relevance in civil applications. Methodologies for aircraft design vary from one designer to another. Conceptual design softwares are available such as AAA [1], AVID ACS-ACSYNT [2], and Piano [3]. They cover sizing, aerodynamics, stability and control, geometry, structures etc. AAA software is a powerful engineering tool that provides an automated and efficient way of evaluating an aircraft through conceptual design. For UAV construction, the primary concern is weight reduction without compromising strength. This can be achieved using innovative materials such as composites and fiberglass. In this work, a small UAV is designed using AAA software, manufactured and flight tested for a specific surveillance mission. Aircraft wing and tail is made from foam and carbon rods, while the fuselage is made from composite fiberglass. The aircraft is successfully flight tested.

Design Procedure

The design procedure is based on AAA software [1]. It is summarized in the following steps:

- Both aircraft mission and design specifications are determined based on a review of UAVs of a similar mission.
- Weight module is used to estimate the take-off weight and center of gravity.
- Performance sizing module is used to determine optimum wing loading and power loading such that the aircraft can perform its mission.
- Geometry module is used to estimate the dimensions of the UAV. These include wing, fuselage, tail and control surfaces.
- Aerodynamics module is used to obtain the lift, drag and moment coefficients.
- Performance analysis is conducted to revise the engineering specifications and obtain stall speed, power speed, maximum cruise speed, range, endurance, climb, glide etc.
- Stability and control module is used to determine the stability parameters of the UAV, these include static margin, lift slope, pitching moment slope, etc.

- If performance is not satisfactory the design parameters are changed and the whole procedure is repeated.

Details of the design procedure are explained in [4-6]. A brief description of the design steps is mentioned here. Fig. 1 shows the aircraft mission profile. This includes takeoff, climb, cruise, loitering and landing.

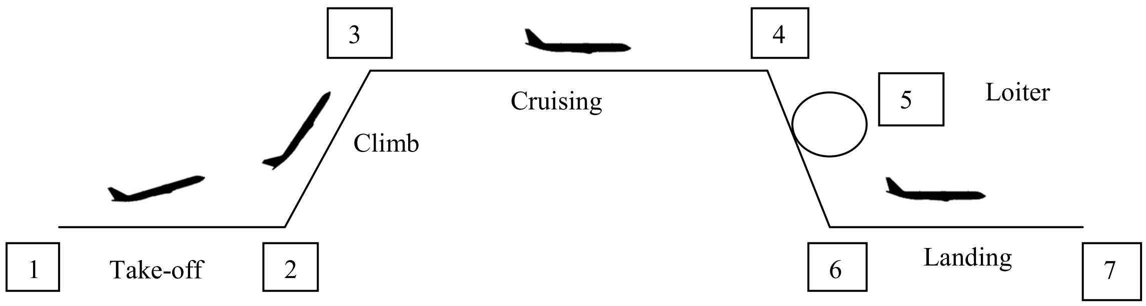

Figure 1 Aircraft mission profile

The take-off weight is estimated using the following equations

$$W_{to} = W_{payload} + W_{crew} + W_{fuel} + W_{empty} \quad (1)$$

$$\log_{10} W_{to} = A + B \log_{10} W_{empty} \quad (2)$$

W refers to weight and *A* and *B* are statistical/historical constants for the W_{to}-W_{empty} relationship [5]. Performance sizing is used to determine the optimum combination of wing loading and power loading. This leads to the estimation of the wing area and the engine power required for a balanced performance throughout the mission. The aircraft equation of motion is written for every flight condition in the form of power loading (weight/power) as function of the wing loading (weight/wing area). This includes take-off, climbing, cruise, stall, turning and landing. Graphically, we identify the design space, i.e. wing loading and power loading combinations which satisfy all flight conditions. In geometry module, the geometries of the main components of the UAV are determined. This includes wing, tail, and fuselage. Lift, drag and moment coefficients are evaluated in the aerodynamics module. Wing cross section (airfoil) is selected. Standard aerodynamic calculations are used to find lift coefficient as function of angle of attack, drag polar curve and pitching moment as function of angle of attack. The stability and control module is used to determine the flying characteristics of the UAV. Using design features like wing dihedral and vertical tail, both yaw and roll static stability are ensured. Pitching stability is analyzed by determining the static margin and the moment coefficient derivative.

Design Results

The design specifications are: weight = 3-5 kg, stall speed = 30-40 km/h, cruise speed = 40-70 km/h, rate of climb = 100-200 m/min, take-off and landing distance = 20-60 m, endurance = 60 min, range = 5 km, cruise altitude = 300-500 m, wing aspect ratio = 7-10, wing span = 1.5- 2.5 m, fuselage length = 1.5-2 m, and tail configuration is T-tail. As described in the design procedure, design iterations are required to reach a satisfactory design. Here, we report the final design iteration. Using A=0.34 and B=0.96 in Eq. 2, the weight was estimated to be 4 kg. Performance sizing plots are shown in Fig. 1. The design space is bounded by maximum speed cruise, takeoff and stall. In choosing a design point, a high wing loading (small wing area) and a high power loading (minimum power required) are preferable. (50 N/m^2, 130 N/kW) was selected as aircraft design point, which results in a wing area of 0.78 m^2 and engine power of 0.3 kW. Table 1 shows the final design results and Fig. 2 shows a 3D drawing of the UAV.

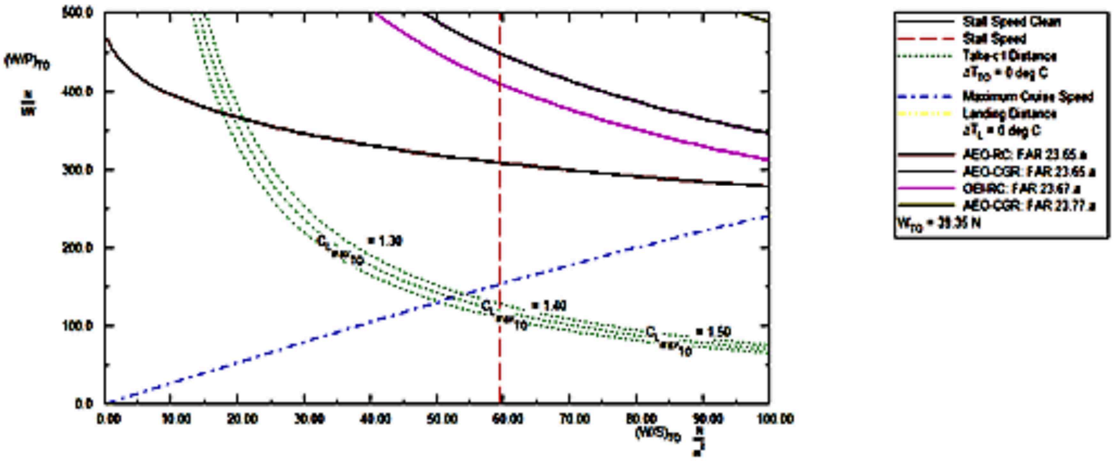

Figure 1 Performance sizing plot.

Table 1 Final design data

Weight	4 kg, C.G. at 0.47 m from the nose along the fuselage centreline.
Performance and Aerodynamics	stall speed =23 km/h, maximum cruise speed = 70 km/h, landing distance = 11 m, take-off distance = 27 m, climb speed = 55 km/h, rate of climb = 2.446 m/s (146.76 m/min), rate of descent during gliding = 3.18 m/s, glide angle = -12.3 deg, time to glide from 500 m = 3 minutes, ground range during gliding = 2 km, maximum lift coefficient = 1.4, Lift curve slope ($C_{L\alpha}$) = 6.022 rad/s, zero angle of attack lift coefficient (C_{L0})=0.2586, zero angle of attack drag coefficient (C_{D0}) = 0.7, pitching moment slop ($C_{m\alpha}$) = -0.4466, zero lift moment coefficient (C_{m0}) = -0.0721, static margin = 9.41%
Geometry	Fuselage: length = 1.65 m, maximum width = 0.3 m, maximum height = 0.28 m Wing: NACA 4412 airfoil, area = 0.78 m^2, span = 2.5 m, aspect ratio = 8, root chord = 0.35, tip chord = 0.28 m. Horizontal Tail: moment arm = 1.2 m, volume ratio = 0.5, area = 0.11 m^2, aspect ratio = 4.5, span = 0.69 m, root chord = 0.17, tip chord = 0.14 m. Vertical tail: area = 0.06 m^2, aspect ratio = 1.4, span = 0.29 m, root chord = 0.24 m, tip chord = 0.17 m.

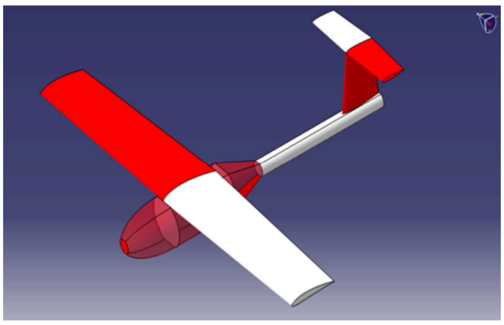

Figure 2 CATIA 3D model drawing of the UAV

Fabrication and Equipments

Materials are selected considering availability, formability and cost. A combination of foam, fiberglass, carbon rods and toughlon is used. This combination satisfies the criterions of high strength and light weight. Epoxy is used as the matrix in the epoxy/fiberglass composite for the fuselage. Foam is used to construct wing and tail, where carbon rods are placed inside to provide structural strength. Hot wire cutting is used to form the shape of the wing and tail. Sandpaper is used to smooth the surface and toughlon is applied as a protective layer. Fiberglass is a lightweight, high strength material, easily formed using molding process. The fuselage was constructed from fibreglass composite. CATIA [7] model was turned into a code and a CNC machine was used to cut a foam mould for the fuselage. Layers of epoxy and fibreglass were applied on top of the mould.

Equipment required for the UAV are DC electric motor, battery, electronic speed controller (ESC), servos, and radio FM transmitter-receiver. The battery is a 300 W lithium-polymer battery weighing about 0.6 kg. Servos are used for control surfaces (2 for the ailerons, 2 for the elevators and 1 for the rudder). Propeller motor is the Turnigy sk 5055 550 kV. It provides a maximum thrust of 6 kg and is capable 580 RPM. Total cost of the aircraft is RM2605.

Flight Testing

Before flying the aircraft, a serious of tests were conducted on ground to make sure that the aircraft is ready to fly. This includes taxiing and checking control surfaces response. Mass balancing is conducted in the longitudinal and lateral directions. In the longitudinal direction, aircraft was pitching upward. To overcome this, a small weight is added forward of the CG on the plate inside the fuselage. In the lateral direction, one wing turned out to be slightly heavier than the other, to compensate for this we added weights to the lighter wings to achieve balance. Finally, the aircraft was tested for flight. It flew gracefully with a stable pattern. It completes several circles and then lands safely. Another flight was conducted with video camera on board. This flight was also successful.

Conclusion

An UAV for aerial missions was successfully designed. AAA software was used for the design process. This includes weight estimation, performance sizing, aerodynamics and geometry calculations. The design procedure is iterative, where design parameters are changed until a satisfactory performance is achieved. The aircraft was manufactured using a combination of foam, carbon rods and fiberglass. The aircraft was successfully flown with a camera on board.

Acknowledgements

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