DESIGN，ANALYSIS，FABRICATION AND FLIGHT TEST VALIDATION OF THE NWPU25 MICRO AIR VEHICLE

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Abstract

Micro Air Vehicle (MAV) is a booming new research field all over the world. The Northwestern Polytechnical University (NWPU) MAV Research and Development Center are among the first in China to explore the research and development of MAV. Up to now we have developed many types of MAV prototypes with different configurations and size.

This paper describes the design, analysis, fabrication and flight test validation of the NWPU25 MAV, which has the maximum endurance that has, up to now, been developed in China. Carrying the color video camera, the NWPU25 MAV successfully transmits real-time video back to the ground station. The successfully flight of NWPU25 prototype proves preliminarily that 25cm span micro air vehicle is feasible.

1 Introduction

Micro Air Vehicle (MAV) is a new type of aircraft with small-scale, lightweight, agility and stealth. There are many potential military and commercial applications for MAV, which bring it up into a booming research field [1,2]. Recent years the development of the Micro-Electro-Mechanical Systems (MEMS) supplies important technical foundations for the research of MAV [3].

MAV is not a simplified miniature of conventional aircraft, which aerodynamics, structure design, power deployment, flight dynamics and navigation control technique have different characteristic. Miniaturization of MAV's dimension brings many difficulties to the development of the MAV. Reviewing the development of the MAV, a lot of technical results were attained and a certain experiences were accumulated.

But all in all, the development of MAV is at its test phase, there is a long way to become a practical product. It faces many challenging problems, such as aerodynamics calculation and analysis of low Reynolds airfoils, design of the aerodynamic layout, selection of high thrust-to-weight propulsion system, components integration technique of the flight control system and so on [4].

Based on the current miniaturization level and relative research [5], we decided to develop a MAV, which has 25-centimeter span and called NWPU25. The following gives the whole development process of the NWPU25.

2 Wind Tunnel Test and Layout Selection

Instead of using computation fluid dynamics (CFD) method which was still incomplete and unfit for solving low Reynolds number aerodynamic issues of the MAV by now, wind tunnel testing was used as a main tool to study the aerodynamic characteristics of the MAV.

In order to facilitate our MAV research, a set of small MAV test wind tunnel, which has better fluid qualities, was designed and built. Figure1 shows the MAV test wind tunnel system including wind tunnel and measurement-control system.

Based on the developed MAV configurations and relative researches, the best design configuration of the MAV is flying wing, which has larger lift surface and payload capacity [6]. So flying wing configuration was used by the NWPU25.

Fig.1 The MAV Test Wind Tunnel System

In order to select wing planform for the NWPU25, fifteen different layout wing models were tested in MAV test wind tunnel. Through the analysis of the experiment data (seen fig.2), we chose tenth layout which has relatively maximum lift-to-drag ratio 4.8 as the wing layout of the NWPU25. The tenth layout is a quasi-octagon planform shown in figure3.

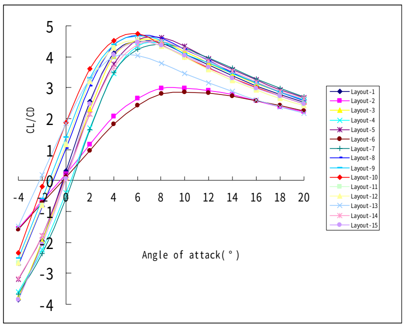

Fig.2 Lift to Drag Ratio Curves of the Fifteen Different Layouts

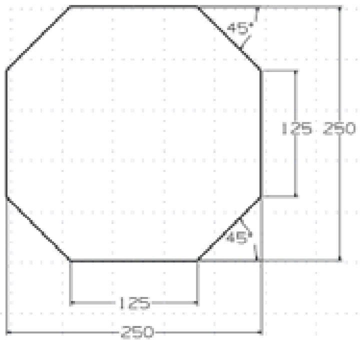

Fig.3 The Planform of the Tenth Layout

3 Components and Take-off Weights

The advantage of MAV design over conventional full-scale aircraft design is that the calculation of take-off weight can be performed with relatively little use of empirical data. This is due to the fact that most of the components to be carried, as well as their size and weight, can be known. The disadvantage, however, is that the vehicle must be designed so that it can accommodate these components.

At present most components carried on NWPU25 prototype MAV were off-the-shelf (and affordable) products. The NWPU25 has a propulsion system, radio control system, video system (payload), power system and structure system.

The propulsion system included a micro direct drive DC brushless electric motor which has high reliability, low noise and a matching propeller.

The radio control system comprises a 5.6g micro receiver with a receiver crystal to receive uplink command signal, a 8g electronic speed controller (ESC) to adjust the electric current, and two 5.4g micro servos to control two ailerons respectively.

Fig.4 Receiver and Servo

The conceiving aim of the NWPU25 was to become a flight platform which could carry video camera to perform visual surveillance and reconnaissance tasks in the future. The video system of the NWPU25 used onboard was a video camera integrated a video transmitter which was the smallest and lightest within off-the-shelf by now. The video system has a mass 8 grams and operates on 2.4GHz. In addition a monitor and a set of ground video reception equipment were also necessary (fig.5).

After a thorough search of commercially available battery technology, power system settled on Lithium polymer batteries which has high capacity and can provide high current required for operation of the electronic components. According to endurance about 30min, 82g batteries is required.

Fig.5 Video System (Camera and Reception)

The last item contributing to take-off weight is the structure system. The structure weight of NWPU25 is about 17 percent of the take-off weight. Using iterative method, the overall take-off weight 159.4g is attained, and the structure weight is 27.1g, this estimate was very close of the actual structural weight of the finally built vehicle.

Table1: Components of the NWPU25

Components	Mass (g)	Percent (%)
Propulsion system	18	11.3
Radio Control System	24.4	15.3
Video System	8	5
Power System	82	51.4
Structure System.	27.1	17
Total	159.5	100

4 Selection of Airfoil

For flying wing configuration MAV, two characteristics were considered on selecting the airfoil. First, the airfoil must have a positive pitch moment for pitch stability, and second, it must have a good lift to drag ratio at low Reynolds numbers of around 10^4-10^5.

Airfoil analysis was done using DesignFOIL airfoil analysis software package. Using this program, various low Reynolds number airfoils, as well as various flying wing airfoils were analyzed.

The S5010 airfoil provided the relatively best aerodynamic characteristics, which has high lift to drag ratio and a positive pitching moment. Figure 4 and Figure 5 give the aerodynamic characteristics curves respectively. From two figures we can see when lift-to-drag reaches about maximum value, the pitching moment is near to zero, which can lead to a minimum balance lift force loss. So the S5010 was used on the design of the NWPU25, which was also used by many other developed MAVs.

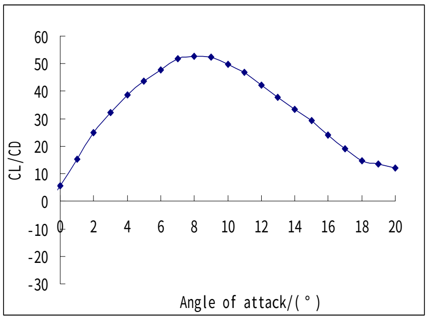

Fig.4 Lift-to-Drag Ratio of the S5010 Airfoil

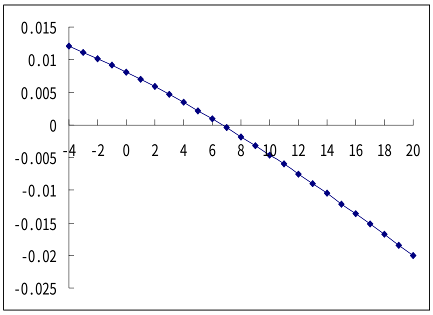

Fig.5 Moment Curve of the S5010 Airfoil

5 Stability and Control

Two points must be carefully under consideration to design the MAVs, the one is the center of gravity (CG), which is determined by the components layout. The other one is the aerodynamic center (AC), which is determined by the aerodynamic layout. The relatively location between the CG and the AC is important in the stability flight of the MAV.

The CG needs to be in front of the AC by a distance called the static stability margin. The static stability margin is the distance, as a percent chord, that the CG is in front of the AC.

The NWPU25 design used a static stability margin of 5%. According to aerodynamic layout, the location of the AC was calculated, and it located 6.85cm behind the leading edge of the root chord, and the average aerodynamic chord was 22.6cm. So the CG must be 5.72cm behind the leading edge of the root chord.

In order to make the CG locate the required position, the components layout was specially designed. Figure6 illustrates the layout of onboard components installed on NWPU25 prototype.

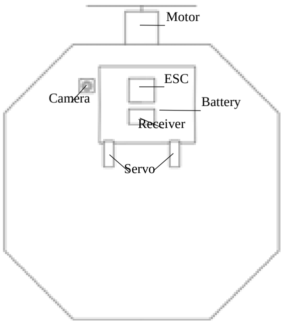

Fig.6 Layout of the Components Onboard

Besides having the center of gravity in front of the aerodynamic center it is also desirable to have the center of gravity as low as possible. This can be accomplished in two ways, by physically lowering the weight in the fuselage or wing, or by adding dihedral to the wing. Adding dihedral effectively lowers the position of the center of gravity. For fly wing layout aircraft dihedral was more important and feasible to roll stability than a low center of gravity. About 2 degree dihedral was used in the NWPU25.

A vertical tail above the wing of the NWPU25 was used to provide directional stability. Two ailerons were used to control pitching and rolling movements. When two ailerons move up and down at the same time, the MAV will pitch up and down, and when two ailerons move toward opposite direction, the MAV will roll left or right. Figure7 shows the control system of the NWPU25.

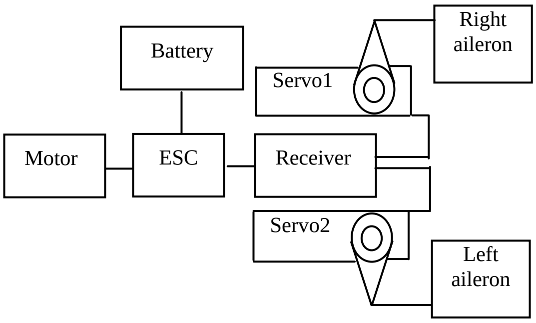

Fig.7 Control System of the NWPU25

6 Fabrication

There are many materials that can be used to fabricate MAV prototype, such as balsa, foam, plywood, latex rubber skin and carbon fiber or Kevlar. Considering the weight, strength, stiffness, payload capacity, and easy to shape, we chose foam for the NWPU25 prototype. In order to shape the airframe, a self-build hot wire cutting setup was used to cut the foam.

The following is the simple step of how to fabricate NWPU25 prototype. First step cut a piece of foam block into three parts, and according to the airfoil template cut off unwanted foam and form two external wings and one middle wing. Second step cut proper room in middle wing to accommodate all onboard components. Third step install all onboard components in their design position. Finally glue three parts together with adhesive, and the NWPU25 prototype was shaped up. Figure8 gives the NWPU25 prototype.

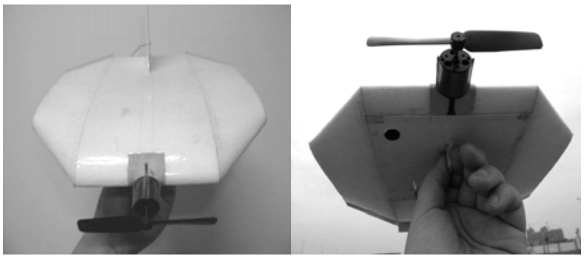

Fig.8 The NWPU25 Prototype

7 Flight Test

To validate the feasibility of the developed NWPU25 prototype, flight tests have been done many times, which show that the NWPU25 has sufficient longitudinal and directional stability, and two ailerons can provide sufficient moment for pitch and yaw control.

Carrying a color video camera with the weight of 8g, the NWPU25 successfully performed the flight test, and transmitted real-time video back to the ground station.

The maximum flight endurance has reached 45 minutes, which was the maximum endurance, up to now, in China. The figure 9 shows the flight tests of the NWPU25, and figure10 illustrates the real-time images acquired by the onboard camera and transmitted to the digital handy camera.

Fig.9 Flight Test of the NWPU25

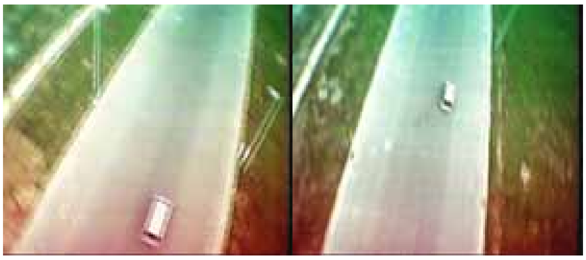

Fig.10 Video Footage from Onboard Camera

8 Conclusion

The success of the NWPU25 prototype not only proves that the 25cm span micro air vehicle is feasible but also shows that it can perform useful missions such as reconnaissance and surveillance.

The future work will focus on the following aspects: further miniaturize onboard components; develop more powerful and lightweight power source such as fuel cell; investigate multidisciplinary optimization design; ultimately realize automatic flight and so on.

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