3rd US-European Competition and Workshop on Micro Air Vehicle Systems (MAV07) & European Micro Air Vehicle Conference and Flight Competition (EMAV2007), 17-21 September 2007, Toulouse, France

Design of HOMA Micro Air Vehicle at IUT

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As IUT Student Aerospace team, in our first attempt of designing micro flying vehicles, we intended to participate in the international US-European competitions. We developed a 40 cm wingspan flying wing to compete in the outdoor mission. Our motto is improving aerodynamic and surveillance features of the MAVs and develop an easy-to-build, reliable, low cost, repairable micro aerial vehicle which is suitable for both surveillance and endurance missions.

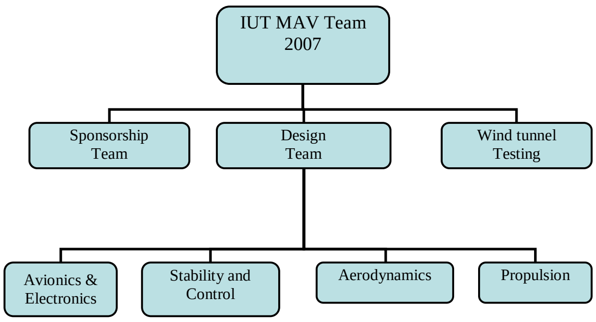
Nomenclature

AR	=	aspect ratio
C_m	=	pitching moment coefficient
C_{lmax}	=	maximum lift coefficient
c	=	chord
t	=	maximum camber thickness
t/c	=	thickness ratio
L/D	=	lift to drag ratio
α_{stall}	=	stall angle
Re	=	reynolds number
SM	=	static margin
AC	=	aerodynamic center
MAC	=	mean aerodynamic chord
CG	=	center of gravity

I. Introduction

Development of a reliable MAV with surveillance and high endurance capability has been under the focus of many researches in recent years. The preliminary goal of MAV competitions is to find new ideas for developing these features of MAVs.

Isfahan University of technology (IUT) aerospace team was established as a scientific student branch of Mechanical Engineering Dep. in October 2005. Our previous project was designing and manufacturing a UAV. Inasmuch as this competition was our first experience in MAV designing, we had to start our project from the very initial steps. Our design philosophy is based upon improving aerodynamic features, surveillance capability, and controlling the systems autonomously. To fulfill the mission requirements we designed a delta planform flying wing with 40cm wingspan, flying at a maximum speed of 22m/s with full throttle setting and about 380gr take-off weight.



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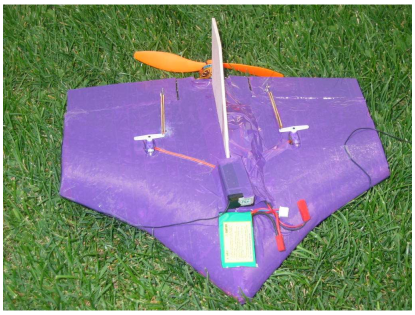


Fig. 1.First Prototype

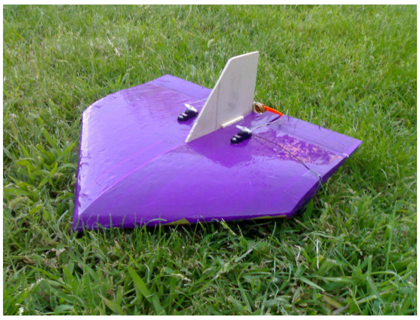


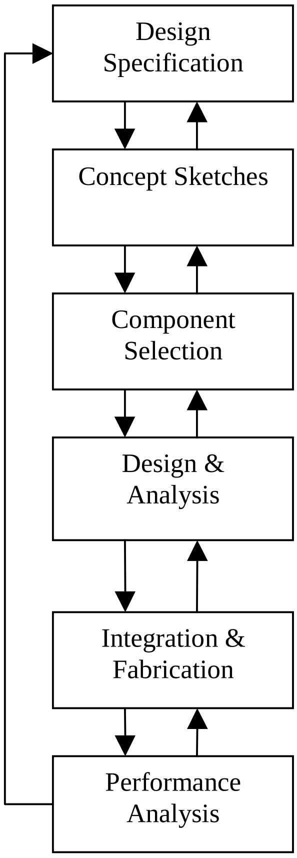
Fig. 2. Final Modificaion

II. Designing process

After literature review, Raymer[1] method was chosen as the main design algorithm. Iterative process of designing includes analytical activities along with empirical investigations

Design Specifications were conducted from MAV07 outdoor mission. Having some notional concepts in mind, base on the imposed specifications, the components, including all the subsystems were chosen. Considering those sketches and the selected components, design and analysis section could determine the vehicle weight and size. Aerodynamic and stability analysis would enhance the initial layout. The concepts which get the best score are then selected to be fabricated and ultimately equipped for flight tests. The flight tests outcome would be used for further modifications to make the design iteration go on.

The last but not the least, making a data base out of the former developed MAVs can always suggest a very helpful initial estimation of the selected parameters.



- ### Concept Sketches

To choose some preliminary configurations, we had some brainstorming sessions, evaluating possible options. We investigated on some criteria including aerodynamic features of their base geometry, simplicity of construction, flight stability, feasibility of components' internal placement, camera position and its line of sight to be in center line and also not being a sort of weird concept as the first experience.

Considering all of these parameters, flying wings with Inverse-Zimmermann and delta planforms were selected.

III. Subsystems

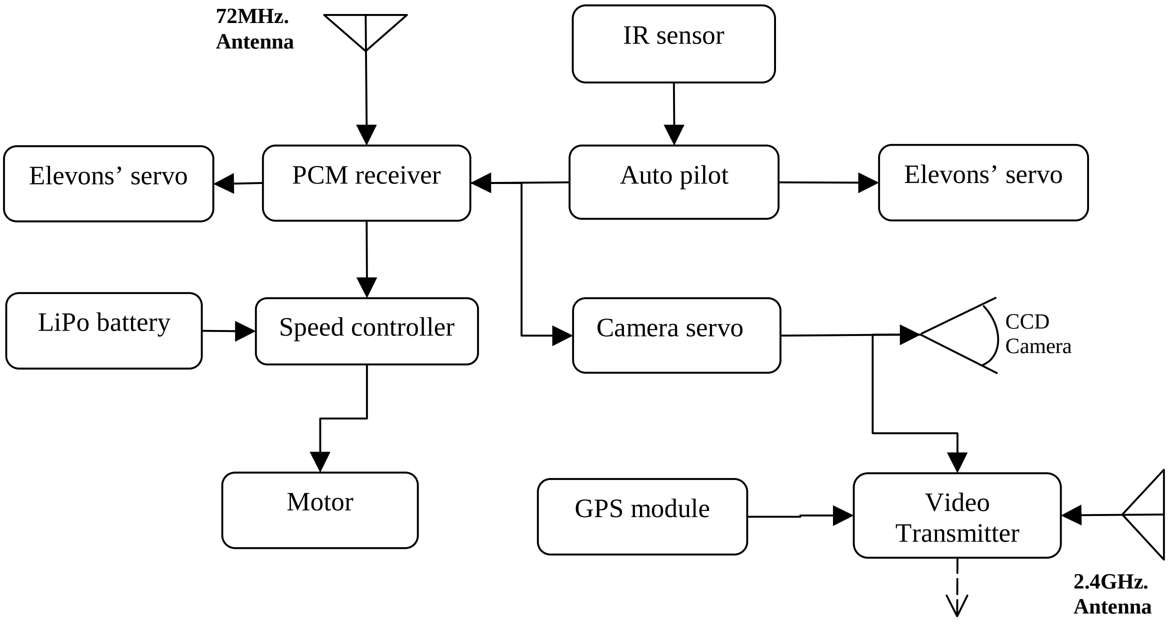
One of the most important features in selecting the electronic subsystems is their frequency and power consumption that should be compatible with the competition rules. Other important features are size, weight, connector's type and their cost.

1. Auto pilot

MAVs are small in size and typically difficult to control, so to keep our MAV stable during the flight time a programmable Tony autopilot board (40gr, 2.4GH) has been used. The board works with 5V DC.

This board controls the elevons and provides the stability in both roll and pitch axis. This task is more important when the MAV is beyond the sight of the pilot. The board has two acceleration axis and infrared sensors to manage the pitch and roll control. Its barometric sensor is sensitive to air pressure, so when the air pressure column on the MAV changes, it shows feedback in pitch axis to return to its pre-defined altitude.

If the auto pilot fails the pilot can control the elevons with his Radio control from the ground station. Other aspects of our MAV have not been autonomous yet since it's still under improvement. The auto pilot works separately from the other electrical parts. A schematic of the subsystems block diagram is presented below.



2. Global Positioning System

The LEA-4T (17*2.4mm, 2.1gr) GPS module, has been used on our MAV, since it provides high sensitivity, exceptionally low power consumption and USB connectivity. It can be programmed to control the rudder movements to make the MAV reach the desired mission field coordinates. The pilot also has the ability to control the yaw manually with his radio control. In this case the GPS sends the data through modem to the ground station that will be shown on the monitor screen.

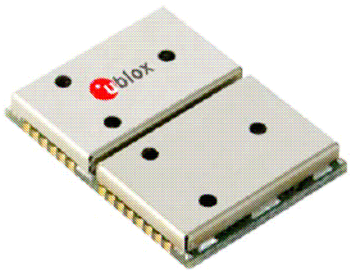


Fig. 3. GPS Module

3. Camera system

CM-588 (16*8*8mm, 2.5gr) camera was chosen. It has over 380 lines of resolution, and works with 7-12 V DC power supply, 35mA current draw. MX5000 video transmitter has been used to send data to the ground station. A rotating system was made so that the camera is capable of 90° turning and identifying the targets. The servo in the rotating system is controlled manually by the pilot.

Fig. 4. CM 588

4. Ground Station

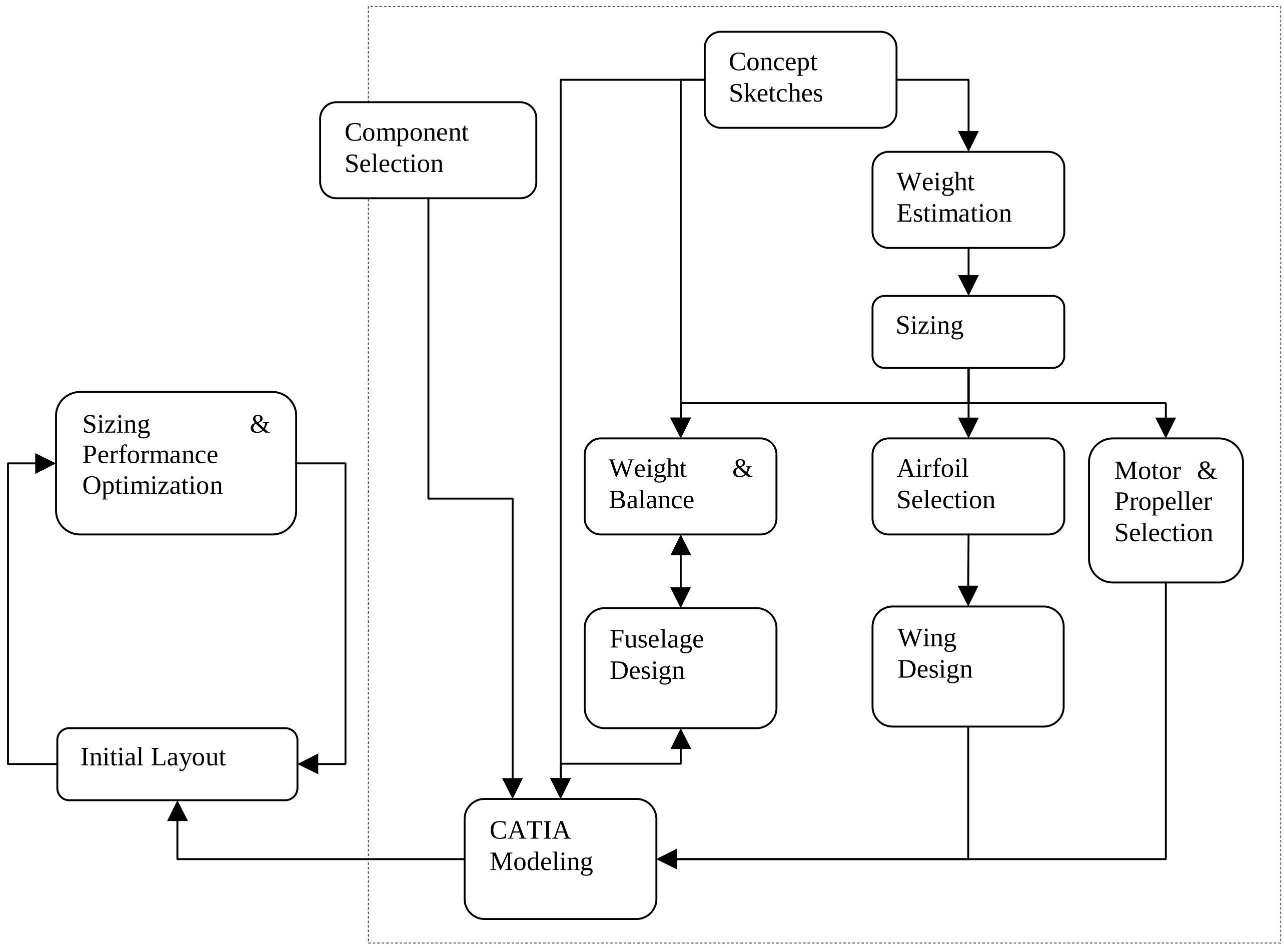
Our ground station consists of a laptop, a radio control and a VRX-24L receiver. Antennas for different parts were selected due to their compatibility and power consumption.

Ground Station unit

Component	Description
Reciever	VRX-24L
Rf amplifier	AMP18M-24
Receiver antenna	PN24S
Modem	24Xsream, 2.4GHZ
Laptop	

IV. Design and Analysis

Our flowchart of "Design and Analysis" is shown below.



According to the Sizing procedure[2], the take-off weights of the selected configurations were estimated. The constraints which are dominating over the performance requirements taken out of the mission analysis are prerequisite to follow on design activities. Consequently using Mattingly[2] method would have led us to derive mainly, airfoil maximum lift coefficient (C_{Lmax}), wing area and required thrust, which were used for airfoil selection, wing design, motor and propeller selection respectively.

The initial layout was done after the modeling had already been completed in CATIA software. An optimization cycle was then applied to get the modified design.

- **Weight estimation**

Traditional method was used to estimate the take-off weight, considering an empirical equation derived from gathered MAV information with the same configuration i.e. flying wing.

$$W_{PP} = W_{motor} + W_{prop} + W_{ESC}$$
$$W_{airframe} = W_{fuselage} + W_{wing} + W_{tail}$$
$$W_{Payload} = W_{servos} + W_{sensor} + W_{subsystems}$$

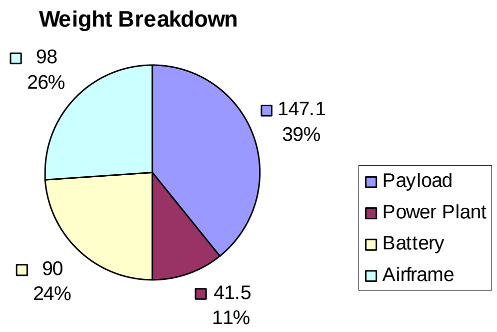


Fig. 5. Weight breakdown

- **Constraint Analysis**

The constraint analysis was done along with weight estimation and mission analysis. The constraints impacts on some maneuvers such as stall speed, cruise speed and constant speed climb are calculated by the application of MATLAB code, using the corresponding equations[3].

Eventually the design area was clarified as shown below in order to satisfy the overriding constraint and have the minimum wing area and required thrust. (According to the mission analysis done by MAV07 scoring rules, reducing the size is a crucial aspect of the final score).

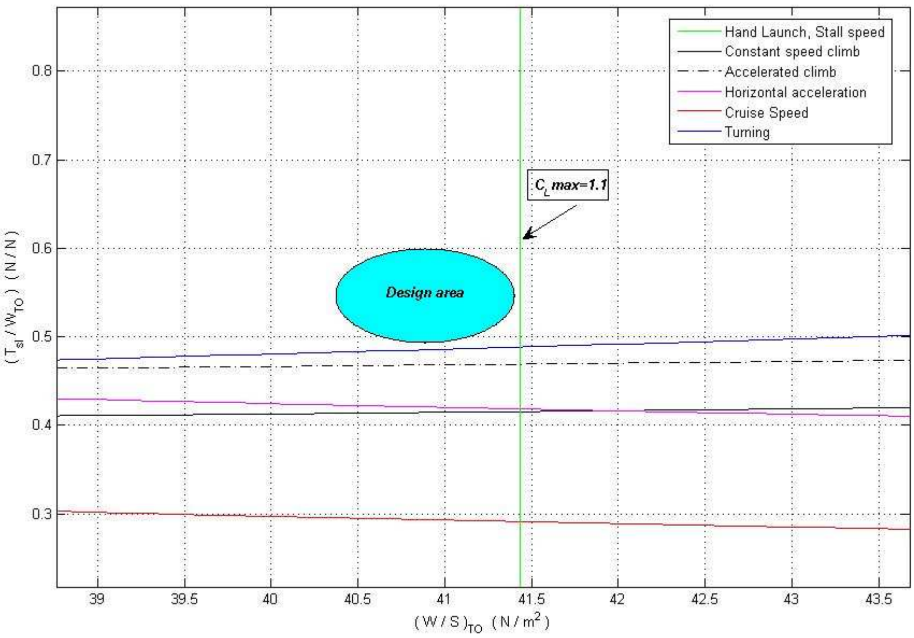


Fig. 6. Constraint analysis diagram

The following table shows our MAV final specifications which have been determined after some trade-offs.

IUT-MAV specification

Take off Weight	380gr
Wing span	400mm
Wing area	0.12m2
AR	1.33
Cruise speed	22m/s
Stall speed	8.5m/s
Loiter speed	15.5m/s

- **Weight & Balance**

Weight & balance analysis was done due to the selected configurations and sized dimensions. This resulted in determining approximate CG position.

Airborne components

Part	Description	Weight (gram)
Video transmitter	MX5000	6
Transmitter antenna	AN 24 S	5
Modem	Xstream OEM RF module	24
Modem antenna	A24-HASM-450	10
CCD video camera	CM588	2.5
GPS module	LEA-4T	2.1r
Auto pilot board	Tony auto pilot	40
Micro receiver	PCM	11
Motor	AXI2204/54	26.5
Propeller	EP7060	3.2
Speed controller	AXI	8
Servo	HS-81MG(*2)	19
Paint ball release mechanism		5

The components internal placement was done by the application of CATIA modeling software and is finalized according to the proper location of the relevant CG

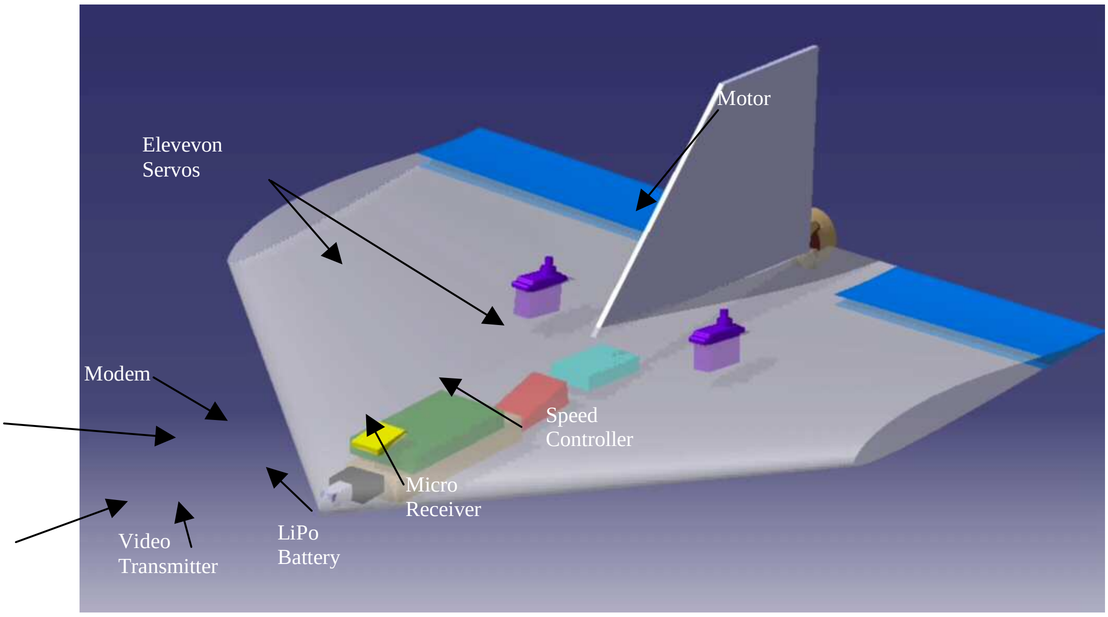


Fig. 7. Component internal placement

To locate CG position properly, the following equation was used:

$$SM = \left((AC - CG)/MAC\right)*100 \text{ (Ref 4)}$$

SM is generally in the range of 5-15, to track down the best place. Component internal arrangement for four different static margins of 5, 8, 10 and 15 percent was done and stability status in pitch axis was studied carefully.

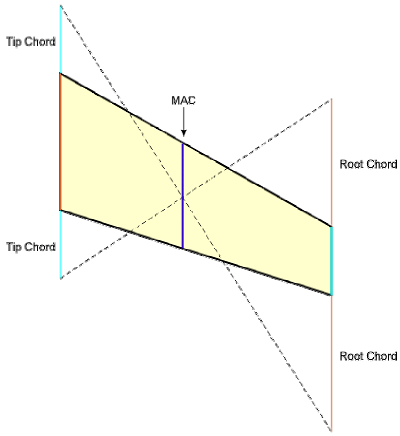


Fig. 8.equivalent wing method

SM = (AC - CG) / MAC	MAC : Due to 0.85 of root chord			
SM	**0.05**	**0.08**	**0.10**	**0.15**
MAC	**211.858**	**211.858**	**211.858**	**211.858**
AC : 1/4 chord of MAC	**52.964**	**52.964**	**52.964**	**52.964**
CG	**42.3711**	**36.01536**	**31.7782**	**21.1853**

The dimensions range of control surfaces were defined by statistics analysis. Elevons width turned out to be in the range of 1/10 to 1/4 main root chord of the wing. Further evaluations showed that 1/8 ratio was more suitable for our MAV.

- **Airfoil**

MAVs fly in low Reynolds numbers (usually in the range below 600,000)[5]. Suitable airfoils for this flight regime have special characteristics and there's little documented data available about them. So since we didn't have any former study on low Reynolds number airfoils, we had to put a lot of time and effort studying and analyzing these airfoils.

Our affairs were twofold:

1. Preliminary selection
2. Verifying and optimization

Our Important parameters in the preliminary selection are presented below[6]:

1. **Flight regime** (operating Reynolds number).
2. $\mathbf{C_{Lmax}}$: according to sizing should be more than 1.1.
3. $\mathbf{C_m}$: for stability reasons and to avoid using a horizontal stabilizer must be approximately zero.
4. **L/D**: according to the sizing should be more than 5.5.
5. **t/c:** To avoid LSB effects and reduce drag, should be thin and also thick enough to put the components in the wing.
6. $\boldsymbol{\alpha_{stall}}$**:** Defining the operating rage of angle of attack for MAV
7. **Airfoil geometry:** airfoils with trailing edge reflex are more stable facing with the side wind gusts.

Unfortunately we had no access to a suitable wind tunnel to get our airfoils polar diagrams and other necessary information; therefore we made the best out of computational analysis. To verify the software results; some available wind tunnel test results in the articles and other teams' documents were used.

The selected software to do the analysis was Xfoil, as it was designed especially for low Reynolds number and proved to be more efficient and reliable than the other softwares.

First we gathered a data base of suitable airfoils for this flight regime. After studying and analyzing them according to the above parameters and sizing results, S5010 airfoil was selected which fulfills almost all of our requirements and there was no need of further modification on it up to now. The results were compared with the UIUC wind tunnel testing of S5010 and proved to be satisfying.

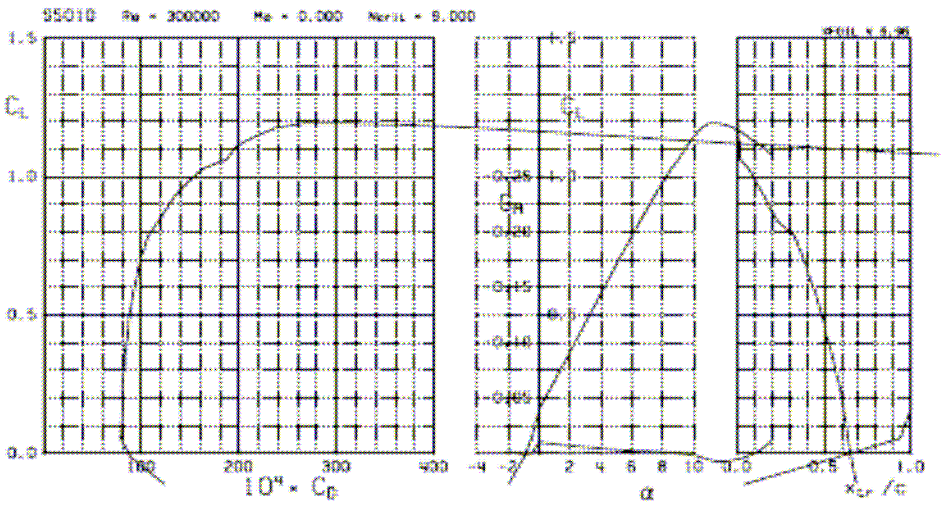


Fig. 9. S5010 Xfoil results

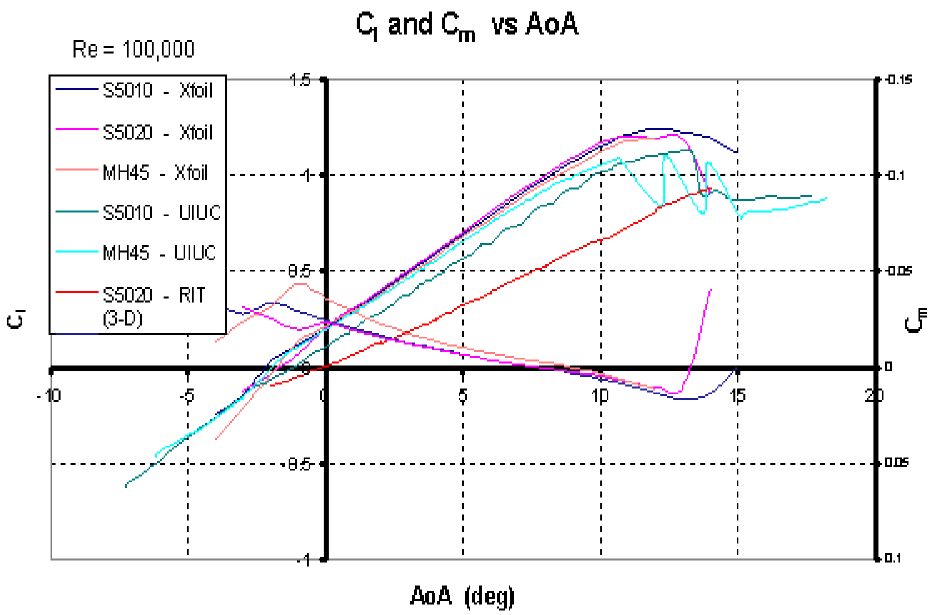


Fig. 10. S5010 UIUC wind tunnel results

V. Propulsion system

Pros and cons of both electric and internal combustion engines were studied carefully, and then we decided to use electric motor because of these advantages:

1. The fuel in the combustion engine adds extra weight on the system and we should consider the effects of weight reduction in design process, this makes the design more complicated.
2. Electric motor efficiency is effected less by the environmental circumstances.
3. Lower weight
4. Less vibration
5. Lower cost and more efficiency

Then we performed a comprehensive study on available motors and propellers in the market by focusing on their power consumption, weight, voltage, current drain and their cost.

MOTOR	Kv (rpm/v)	POWER(w)	WEIGHT(gr)	CURRENT DRAIN(Amp)	NORMAL VOLTAGE(v)	SHAFT DIA(mm)	3D (g)	PRICE($)	Ranking
EA20 50S	1088	65	29	9	10V 2-3Li-Po	3		38.9	6
REX 220-1300	1300	80	31	8-11	10V 2-3Li-Po	3.17		52	5
REX 220-1800	1800	80	31	8-11	10V 2-3Li-Po	3.17		52	5
REX 220-2300	2300	80	31	8-11	10V 2-3Li-Po	3.17		52	5
CYLCPLR05	1480	100	25	*	2S-3S Li-Po	*		64.99	4
EFLM1150	1380	85	24	7	2S-3S Li-Po	3.17	170-225	47.99	3
20-30-2650	2650	61	45	10	*	2		*	9
Astro 010	*	75	49	*	*	*		*	8
EFLM1200	1080	110	45	9	2S-3S Li-Po	3.17	200-400	49.99	7
p/n 801M	2300	75	32		2S-3S Li-Po	3.17		59.95	2
AXI 2203/46	1720	*	18.5	2.5-7	2S Li-Po	3	160	59.95	1

This study ended in selecting AXI2203/46.

Fig. 11. electric motor

The next step was choosing the appropriate propeller which should have been selected by the use of wind tunnel or a load cell to measure the available thrust in order to be bigger than the required thrust taken out of constraint analysis. However, we could not manage to do so and finally we chose the appropriate propeller producing the required thrust and also acceptable efficiency during endurance tests through several flights which ultimately yielded to be EP7060.

Fig. 12. Propeller

VI. Integration and Fabrication

- **CATIA drawings:**

All of the drawings were prepared in metric system.

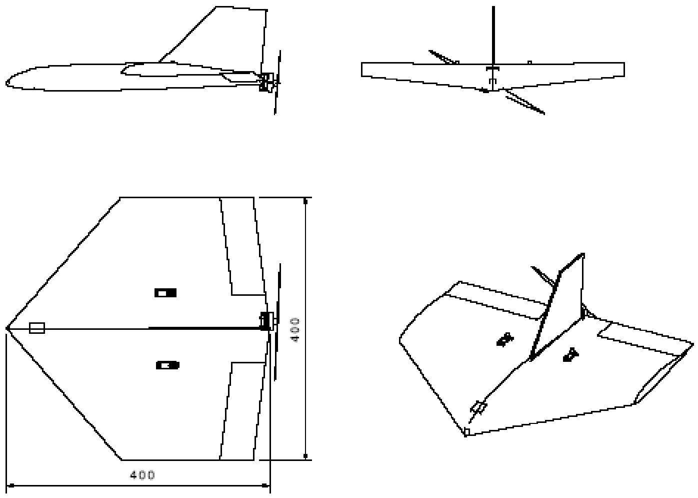
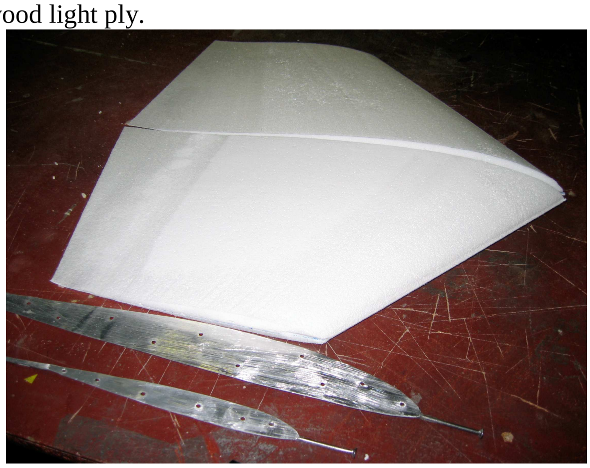


Fig. 13. CATIA drawing

- **Construction:**

Important features in selecting materials and fabrication tactics were: low weight, high strength, low cost, availability of the materials etc.

Considering these parameters, we decided to build our MAV's airframe out of foam and the control surfaces with balsa wood light ply.



Our fabrication process can be summarized in the following steps:

- The wing's tip and root airfoils were cut out of aluminum by the use of wire cut.
- Foam blocks were prepared according to CATIA manufacturing drawings.
- Airfoil sections were attached to the sides of the blocks and the wings were cut with a hot wire.
- Foam and balsa parts were assembled according to CATIA drawings.
- The wings were glued and the servos and components’ were installed properly.

Further structure reinforcement is pending for more flight tests' results.

VII. Flight tests

Flight test which lead to performance analysis is the last step of the design cycle. These flight tests revealed the design problems and provided an iterative process to optimize and trim the vehicle. Mostly after each flight test a new refinement was done on our MAV to improve the maneuvering capability, reducing the size and take off weight and increasing the endurance.

Since our MAV is small in size and trimming its flight status in the initial real flights was difficult, it was decided to have a MAV with 2-times scaled, exactly identical to the main one, to start the first flight tests and study the stability and maneuverability more precisely.

Initial flight tests were performed to find the proper CG position. The CG location was varied in each test to trace the appropriate one with respect to stability issues. Initial tests of the 2-times scaled revealed instability in roll axis. To refine the problem, the design was modified with a 5° dihedral angle.

As we had a tough timetable for the coming competition (MAV07), soon after this flight we began our tests over the main prototype. The first MAV flight was really unstable and couldn't stay airborne even for a few seconds. The first solution was changing the installation angle of the motor mount to reduce the motor torque. But the problem still remained unsolved. More investigations indicated that the main problem was due to our high stall speed and being hand launched. The stall speed of first prototype was 36 km/h, so the launch speed had to be more than 44km/h hence we couldn't provide this speed by hand launching. To solve the problem we increased the wing area and a few modifications were done on the planform. These changes resulted in reducing the stall speed of our vehicle.

We managed to fly over 20 minutes in 1650m local altitude (Isfahan).

The following flight tests were a big success!

Fig. 14. Flight test

Acknowledgment

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