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Improvement of Micro UAV Performance using Tandem-Wing Design

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Abstract:

The main objective for the present work is related with design of MAV to get high performance and long endurance used for surveillance and monitoring in military and civilian. The most important problem that faced the MAV is flying with low Reynolds numbers (Mach number is too law) and high lift with avoid high drag, the tandem-wing design is sucseceful and more reliable for this purpose because it reduced the drag to a half and gives good aerodynamic chractrastices when it's compared with the conventional wing design.

The dimensions of a MAV are 120mm length, wing span 130mm (from tip to tip) and 12g in weight (the standard weight of MAV about 5- 20 g) with rang 50m (is the distance that the aircraft cut from point to another).

The softwares that used in the present work are (Java foil, Soled works, ANSYS, J2) to prove the results.

For the aerodynamic coefficients (C_L, C_D) were checked for two models (Tandem wing and conventional wing) by using ANSYS. To ensure that the design is successful we made a

Simulation for the design by using (The J2 Universal Tool-Kit for Aircraft Dynamics) software and used to testing the aerodynamic characteristic and performers, stability and control. The major benefits of the tandem wings are to reduce drag to half and increase the lift rather than conventional wing by separating the two wings. Java foil was used to calculate the aerodynamics coefficients for the airfoil.

Keyword: (UAV design, M AV design, Aircraft Design)

1. Introduction

There are tens of thousands of unmanned aircraft (UAV) saw them fly in different sizes by fuel or batteries, used for different purposes alike civilian or military. An over- simplistic view of an unmanned aircraft is that it is an aircraft with its aircrew removed and replaced by a computer system and a radio- link. In reality it is more complex than that, and the aircraft must be properly designed, from the beginning, without aircrew and their accommodation, etc. The whole system benefits from its being designed, from the start, as a complete system which, briefly Comprises [1]:

a) A control station (CS) which consist of the system operators, the interfaces between the operators and the rest of the system;

b) The aircraft carrying the payload which may be of many types.

c) The system of communication between the CS which transmits control inputs to the aircraft and returns payload and other data from the aircraft to the CS (this is usually achieved by radio transmission).

d) Support equipment which may include maintenance and transport items.

2. Theoretical Part

A. Gnerale Diffintion Of The Mav:

The size of UAV depends on its mission; Therefore, they are a range from the HALE (High Altitude Long Endurance) with an aircraft of 35 m or greater wing span, down to the NAV (Nano Aircraft vehicle) which may be of only 40 mm wing span. The MAV (Micro Aircraft vehicle) was defined as a UAV having a wing-span no greater than 150 mm [1]. Small UAVs and MAVs are attracting growing interest for their multi- purpose applications [2]. This has now been somewhat relaxed but the MAV is principally required for operations in urban environments, particularly within buildings. It is required to fly slowly, and preferably to hover and to 'perch' – i.e. to be able to stop and to sit on a wall or post , they suffer from certain particular characteristics such as small

Reynolds number, low inertia, low flight speed, rolling instability and so on [3], which cause flight instability and make them highly prone to wind. To improve the performance of MAVs/UAVs, their aerodynamic parameters need to be introduced into flying control systems, as complementary information to inertial guiding systems and auto pilots. [4]

To meet this challenge, research is being conducted into some less conventional configurations such as flapping wing aircraft.

B. Histerical Of Mav:

The first feasibility study for Micro A i r Vehicles (MAVs) was performed by the RAND Corporation in 1993.[5] The authors indicated that the development of insect-size flying and crawling systems could help and give the US a significant military advantage in the coming years. During the following two years, a more detailed study was performed at Lincoln Laboratory. [6] This study resulted in a DARPA (Defense Advanced Research Projects Agency (US)) workshop on MAVs in 1995. In the fall of 1996, DARPA funded further MAV studies under the Small Business Innovation Research (SBIR) program. AeroVironment performed a Phase I study, which concluded that a six-inch MAV was feasible. In the spring of 1998, AeroVironment was awarded a Phase II SBIR contract, which resulted in the current Black Widow MAV configuration. Several universities have also been involved in MAV research. Competitions have been held since 1997 at the University of Florida and Arizona State University. The goals of the competitions have been to observe a target located 600 m from the launch site and to keep a two-ounce payload aloft for at least 2 minutes. [7]

Until these days the researches continue to introduce more designees for many purposes.

C. Design Gonfiguration:

The main goal of this current research is to design a Micro UAV system for long endurance used for surveillance and monitoring in military and civilian purpose like (Aerial photography, Agriculture, Fire Services and Forestry, ext.) having high level requirements in term of reliability and safety, adding to that affordable in cost.

Two models were designed and made a comparison between them where from the aerodynamic characteristics parameters.

The general structural layout of the plane was a V-tail design and high tandem-wing configuration for the first design, as in fig. (1), which allowed the aircraft six separate control surfaces for better flight control: four ailerons and two ruddervator.

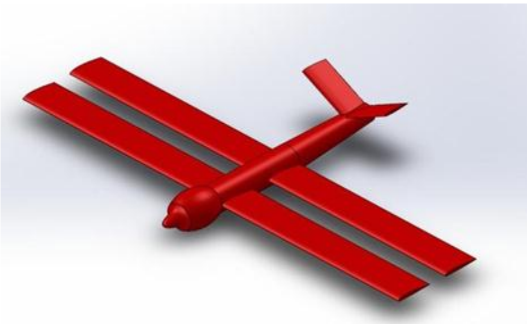

Figure 1: Tandem-wing UAV by using AutoCAD software

Primary concerns in the design of the wing were size, lifting capacity, wing loading, ease- of-design and construction, and drag effects. The major benefit of the tandem-wing is to reduce the drag-due-to-lift. To satisfy stability with tandem-wing it is usually necessary to move the center of gravity somewhat forward of the location for an even weight split, which may prevent the aft wing from attaining its full lift capability .The maximize efficiency of a tandem-wing desirable is to separate the two wings as far apart as possible to attain maximum total lift. It is common to use high- lift devices on the front wing. [8]

The second was a V- tail design and high wing which allowed the aircraft four separate control surfaces: two ailerons and two ruddervator. The advantages of high wing are to produce high lift, protect the wing from damaging while landing and easy to contact with the fuselage as shown in fig. (2).

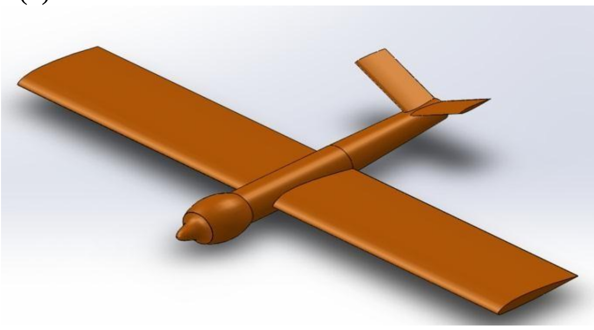

Figure 2: High Conventional wing UAV by using AutoCAD software

To start steeps of the design it must be determined (W/S) (the Ratio between weight and wing surface area):

Where the aircraft weighted is (12g)

For one Tandem wing the mean aerodynamic chord (c) is 20mm & Wingspan (b) =6 or 5 of chord length =120mm. so:

AR (Aspect Ratio) = b /c = 6 … (1)

S (The wing area) = b*c = 2400mm^2 … (2)

W/S = 0.005(g/mm^2)

For the conventional wing, the chord length is (40mm):

S (The wing area) =b*c= 40*120= 4800 mm^2 … (3)

AR (Aspect Ratio) = b /c = 3 … (4)

W/S = 0.0025(g/mm^2)

The primary concern when designing the tail was its ability to contribute to the stability of the aircraft. This meant that the tail, for a given moment arm, had to provide enough moment to counteract moments due to the wing-body combination, and the payload being located away from the aircraft's center of gravity. [9] The V-tail was chosen to reduce wetted area of the horizontal and vertical tail forces which results from horizontal and vertical projection of the force exerted upon the "V" surface and the tail dihedral angle would be found as bellow

[10]:

$C_{HT} = (L_{HT} * S_{HT}) / (c_w * S_w)$ … (5)

$C_{VT} = (L_{VT} * S_{VT}) / (b_w * S_w)$ … (6)

Where C_{HT} is a horizontal tail factor & C_{VT} is a vertical factor and for Homebuilt:

$C_{HT} = 0.5$ & $C_{VT} = 0.04$

cw is wing aerodynamic chord, Sw is wing area, bw is wing span, S_{VT} is a vertical tail area & S_{HT} is a horizontal tail area,

$L_{HT} = L_{VT} = 0.6\ L_f$ …(7)

L_{HT} & L_{VT} is the distance between 25% of Wing chord and 25%of tail chord.

$S_{HT} = 613.89\ mm^2$ & $S_{VT} = 245.56\ mm^2$

So the dihedral angle of V-tail (α_{TD}) will be:

$\alpha_{TD} = \arctan(\sqrt{S_{VT}/S_{HT}}) \rightarrow \alpha_{TD} = 57.7deg$… (8)

$S_T = (S_{HT}/2)/(\cos \alpha_{TD}) \rightarrow S_T = 229.7mm^2$ … (9)

(this one side of V-tail surface area)

c_T (V-tail chord) =0.6 *cw =15.6 mm … (10)

b_T (V-tail span) $= S_T * 2/c_T = 29.45$ mm … (11)

Even without the advantage of reduced wetted area, V-tail offer reduced interference drag but at some penalty in control input must be blended in a "mixer" to provide the proper movement of the V-tail "ruddervators". [8]

The main purpose of the body/empennage constriction is to contain the payload and electronics of the aircraft, and to provide a moment arm for the tail in order to maintain stability [11].

The building materials of the plane structural are balsa wood and carbon fiber for ribs and spars where determined and included in the construction process instructions. Balsa wood used with basswood for the majority of the structure because of its lower density (128.15kg/m3 vs. 448.52 kg/m3) but complemented basswood rods in structurally critical positions for its strength (60 MPa psi vs. 15.5 MPa). A carbon fiber rod takes in to account in preliminary design of wing ribs and spars for its high strength where basswood would not have been sufficient.

D. Power Calculation

Raskom referred to the most important factor in the equations of power which attach the design of aircraft and we will assume that the aircraft at steady flight; then total Weight (W) equal to the total Lift (L) and Thrust (T) equal to Drag (D) as in (1) and (2).

$W = L = \frac{1}{2} C_L\ \rho\ S\ V2$ … (12)

$D = T = \frac{1}{2} C_D\ \rho\ S\ V2$ … (13)

Where:-

C_L is a (Wing Lift Coefficient), C_D (Wing Drag Coefficient), ρ (Density of Air),

S (Wing Area), V (Aircraft speed).

So the power required for steady flight (P_{lev}) calculated from thrust (T) multiplied by velocity (V) as in (7).

$P_{lev} = T*V = (C_L/C_D^{2/3})(2ARg^3/\rho)^{1/2}(m^{3/2}/b)$ … (14)

Where:-

AR is a (Aspect Ratio), b (Wingspan),

m (Aircraft mass), g (Acceleration due to Gravity).

E. Calculation Of Mass:-

In general calculation of an aircraft weight, fuel weight is an important variable when calculating the takeoff weight versus the empty weight of the aircraft; therefore a weight analysis can be done by using the steps in Roskam [12] and Ryamer.

The following table shows the components of mass of solar aircraft

Components	Mass (g)
Payload	2
Avionics	1
Airframe	5
Batteries	3
Propulsion Group	1
Total	12

Table (3): the masses of component of MAV

3. Mission Requirements:

There are three important requirements effect on the design of the MAV:

1- The payload: which consists of the necessary equipment for the aircraft to do its mission like (camera, sensors, batteries, motor, and est.) so it must not over than 2(g) because all the accessories is very small ,light and it is available for this purpose.

2- Range and Endurance can't be limited except after the practical experiment and it depends on the power that the MAV get from motor.

3- The conditions of flight: the maximum height is assumed (50m) and should be noted that the MAV flies with lower height most of time flying. The speed of cruise is 3-5 (m/s) and it will be hand-launched at take-off and landing therefore there is no landing gear install to reduce the weight as could as possible which means more equipment would instill for extra missions. At landing produced suitable area and used a skid land where land softly without distorted the aircraft.

4. Results And Discussions:

Most aircraft will have some loiter requirement during the mission, like time of loiter before landing, therefore, it is better to optimize the wing loading (the ratio between the weight of aircraft and wing area) for cruise. MAV are generally expected to be launched by hand and therefore winged versions have very low wing loadings which must make them very vulnerable to atmospheric turbulence. All types are likely to have problems in precipitation. [1]

Aerodynamic Analyses:

This scaled model will be powered by an electrical motor. A research of a mutual in- flight interference is also planned, and will correspond to the case when a smaller (scaled) airplane enters into the wake shed behind the full scale airplane, because its light weight enough to raise the plane. This motor was mounted with the fuselage at the rearward because it can reduce aircraft skin friction drag because the motor location allows the aircraft to fly in undisturbed air and allow a reduction in aircraft wetted area by shortening the fuselage. The inflow caused by the propeller allows a much steeper fuselage closure angle without flow separation than otherwise possible. [8]

Based on the size of the aircraft and the speeds at which it would fly, we assumed that a high lift, low Reynolds number, airfoil (many respects, is the heart of the airplane) would be chosen a cambered and it was NACA3212 so we used Java foil software to get the analyses the aerodynamic parameters of the airfoil as shown in figures below which show the different between the two designees.

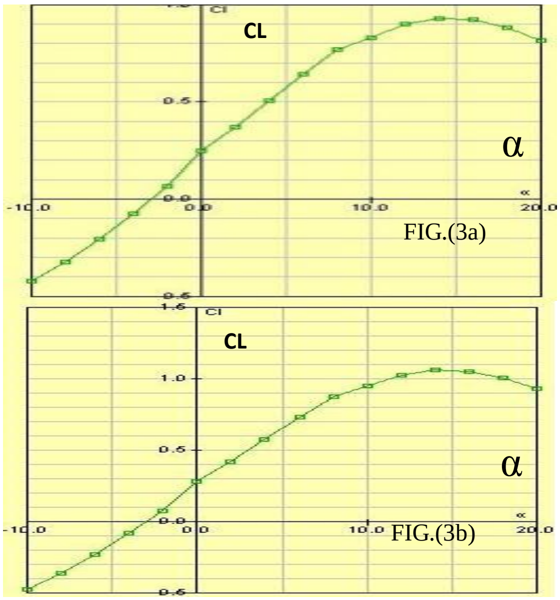

Figure 3: Relationship between Lift coefficient (CL) & angle of attack (α) from Java Foil

a. For the conventional Wing
b. For the Tandem-Wing

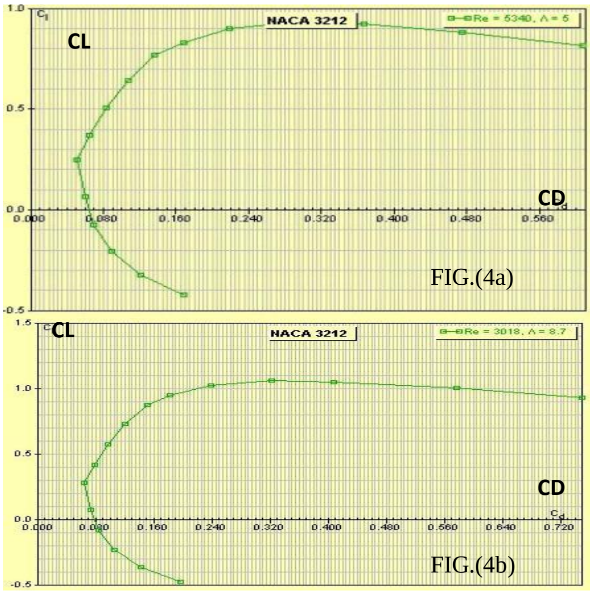

Figure 4: Relationship between Lift coefficient (CL) & Drag coefficient (CD) from Java Foil

a. For the conventional Wing
b. For the Tandem-Wing

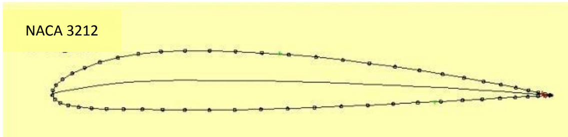

Figure 5: Airfoil Shape

The airfoil affects the cruise speed, takeoff and landing distance, stall speed, handing qualities (especially near the stall), and overall aerodynamic efficiency during all phases of flight. [8]

The ideal plan form of a wing for minimum induced drag is the elliptical plan form.[8] An elliptical wing is very difficult to construct; a tapered wing, however, has similar drag advantages while being far simpler to construct. The straight lines wing mean that it is easily constructed using balsa and glue.

The following tables show the estimate dimension of our models:

Table 1: the tandem Wing Dimensions

Reynolds Number	3018
Max. Lift Coefficient	1.04
Plan form Area for one wing	2400 mm^2
Root Chord	20 mm
Mean Aerodynamic Chord	20 mm
Aspect Ratio	6
Wingspan	120 mm
Total plan form Area	4800 mm^2
Wing loading (g/mm)	0.005

Table 2: The Conventional Wing Dimensions

Reynolds Number	5340
Max. Lift Coefficient	0.928
Total Plan form Area	4800 mm^2
Root Chord	40 mm
Mean Aerodynamic Chord	40 mm
Aspect Ratio	3
wingspan	120 mm
Wing loading (g/mm)	0.0025

Analyses of MAV design:

The software that help us to make analyses for the two designees are Solid Works which was used extensively to design the aircraft to allow for easy modification of the design then transmit the final design to anther software, ANSYS that gives the analyses of lift (force z), drag (force x), pressure distribution, velocity of streamline. Figures below show the different between two models.

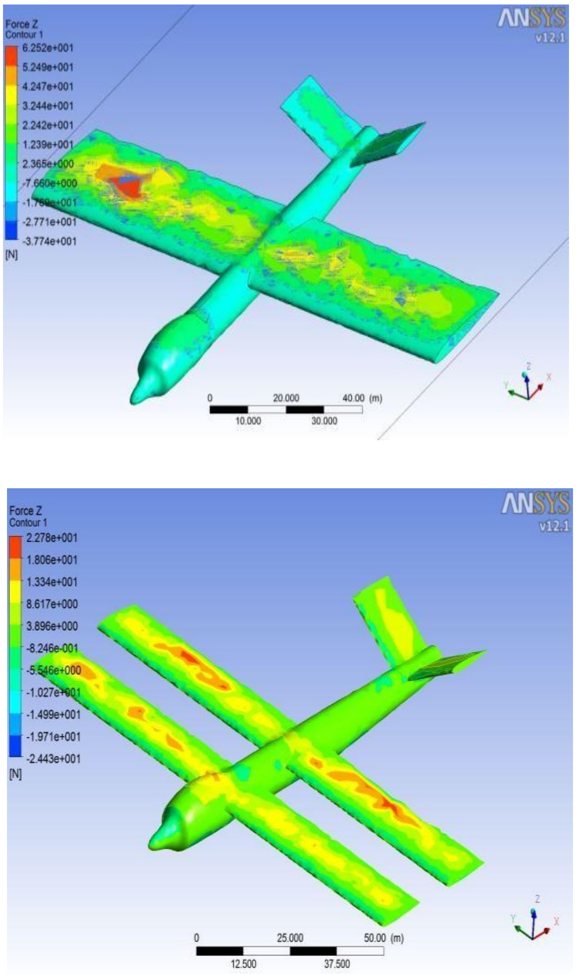

Figure 6: The comparison of Lift force between the two models.

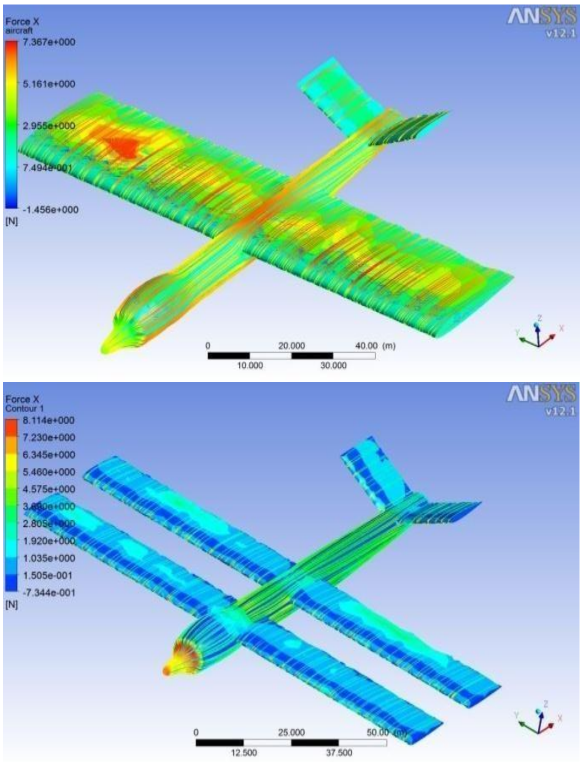

Figure7: The comparison of Drag force between the two models.

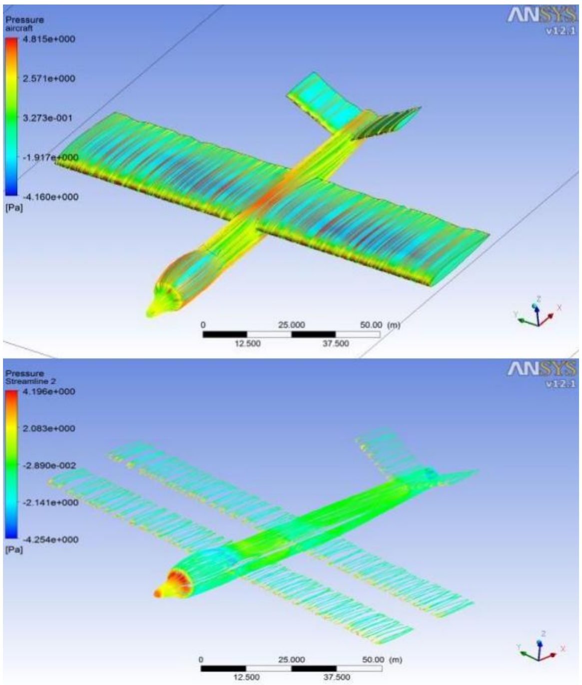

Figure 8: The comparison of Pressure distribution between the two models.

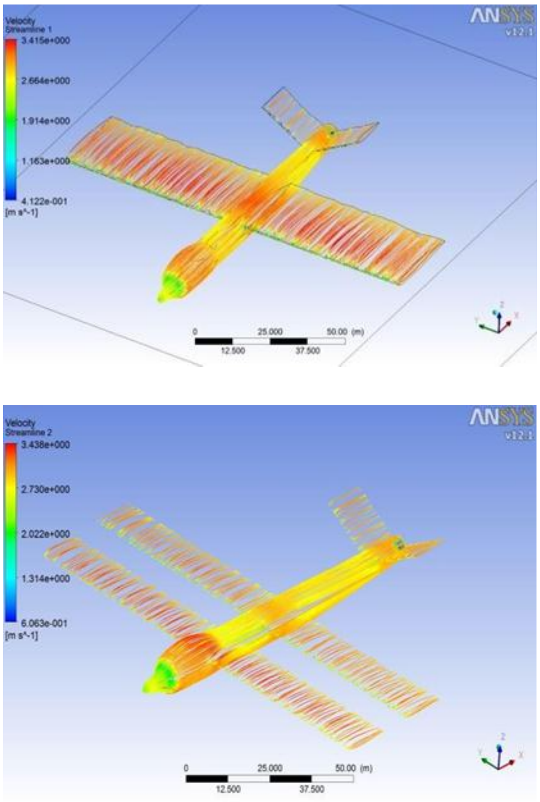

Figure 9: The comparison of The Velocity between the two models.

To make the simulation for the two models we used (J2 The j2 Universal Tool-Kit for Aircraft Dynamics) software (j2 Aircraft Dynamics develop flight modeling and analysis software for use by engineers to support in the design and development of any aircraft) .The j2 enables aircraft Stability and Control, Handling Qualities and even run the complete flight test program to be assessed from the very beginning of a project.

This is achieved through the ability to take even the smallest amount of data and start to "fly" the aircraft. As such key issues can be discovered and corrected earlier on where the cost of changes is much cheaper. J2 show that the two models are accepted and stable at steady flight conditions.

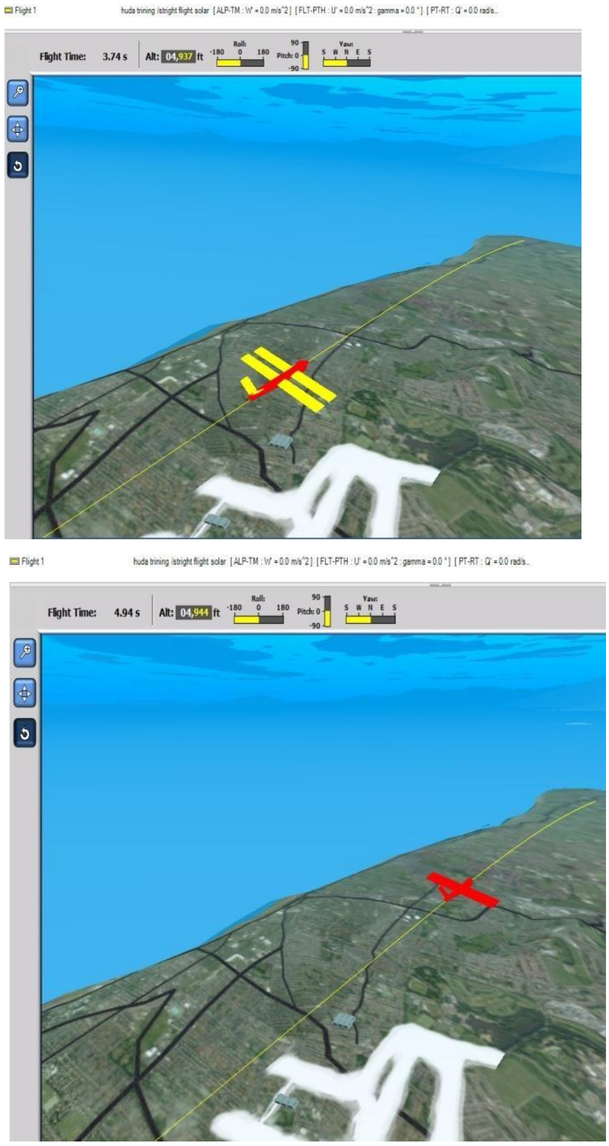

Figure 10: Shows the simulation of the two models by using J2 software.

1. Conclusions

The main goal of MAV designs is to produce a small aircraft that it overcome all the complexity of its mission without any problem, because it is not feasible , low cast, easy to carry or replacement in case of lose it and it do the seam mission of the large UAVS in less time than the others. It has been quite successful for useful missions that were previously deemed impossible. Additionally, the Micro Air Vehicle concept has opened the research Geat for many new avenues of researches in the fields of aerodynamics, propulsion, stability and control, multidisciplinary design optimization, microelectronics, and artificial intelligence. The most important problem that faced the MAV is flying with low Reynolds numbers and high lift with avoid high drag, the tandem-wing design is sucseceful for this purpose because it reduced the drag to a half and gives good aerodynamic chractrastices when it's compared with the conventional wing design. The softwares that used in the present work are (Java foil, Soled works, ANSYS, J2) prove those results and all tests done for the aircraft with motor.

5. References

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