Design and Study of Unmanned Aerial Vehicle Powered by Solar Cells by Using Advance Aircrafts Simulation Softwares

Shurouq Adnan Aziz   Huda Ali Munshid   Shaker Zeidan Saood
Omar Abdu Alrazaqk   Hayder Muhiy Rzoki
Husham Abdu- Almaliek Abdu-Al Majed
Ministry of Science and Technology/Directorate of Industrial
Research and Development
Baghdad-Iraq
E-mail: shurouq44@yahoo.com

Abstract

 The objective of this work is to design the Unmanned Aerial Vehicle (UAV) powered by solar cells, to provide maximum power which consumes by the electrical motor of the aircraft during takeoff at its maximum weight 11(kg). UAV was designed to use for multi-purposes tasks civil and military missions, such as surveillance, communication, intelligence and monitoring. Solar cells power magnitude was checked and selected their types as $Ga_{0.5}In_{0.5}P/Ga_{0.99}In_{0.01}As/Ga$ triple junction which has got practical average efficiency limit of 30%, that placed on the upper surface of wing as a matrix consist of 14 raw .Each raw contains 62 cells (0.04m×0.08m). Several advance software programs were used (Java foil, Advanced Aircraft Analysis version 2.5 (AAA2.5) and the j2 Universal Tool-Kit for Aircraft Dynamics).All of them, give the perfect aircraft design that is suitable operation of solar cells to get maximum power which is sufficient to produce maximum thrust for aircraft motor, and able to complete its mission during steady flight .The residual of solar cells power can be stored in batteries to use it as a power at night flight. The results were obtained from the present work which is nearest to the fact have more reliability and accurate by using these cells which install on the wing surface for producing the requirement power and by using the mentioned softwares specially J2 software which gives the authority to produce the aircraft due its theoretical simulation was applied on aircraft configuration with its real dimensions to predict suitable performance during its flight as a steep before for manufacture to avoid any manufacture cost loses for the model during test because of the cost of the cells and its position on the wing.

Keywords: Design, Unmanned Aerial Vehicle (UAV) and Solar Cells.

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تصميم ودراسة طائرة مسيرة تعمل بالخلايا الشمسية باستخدام برامجيات متطورة في محاكاة الطائرات

شروق عدنان عزيز   هدى علي منشد   شاكر زيدان سعود   عمر عبد الرزاق خضير
حيدر محيي رزوقي   هشام عبد الملك عبد المجيد
وزارة العلوم والتكنولوجيا / دائرة البحث والتطوير الصناعي
بغداد ـ العراق

الخلاصة

يتضمن البحث تصميم طائرة مسيرة تدار بقدرة الخلايا الشمسية لتوفير أعلى طاقة ممكنة لمحرك الطائرة للاقلاع والتي وزنها الاجمالي 11كغم. صممت هذه الطائرة لعدة استخدامات ومهام مدنية وعسكرية مثل المسح الجوي، الاتصالات، العمل الاستخباراتي والمراقبة. حسب مقدار قدرة الخلايا الشمسية اللازمة لرفع الطائرة واختيرت الخلية نوع ($Ga_{0.5}In_{0.5}P/Ga_{0.99}In_{0.01}As/Ge$)ثلاثية الارتباطوبكفاءة 30% اذ فرض تثبيتها على سطح الجناح بشكل مصفوفة تتكون من 14صف و 62 خلية بأبعاد (0.04م*0.08م) لكل خلية. استخدمت عدة برامجيات متطورة وهي Java Foil،(AAA2.5) Advanced Aircraft Analysis version 2.5 و J2 والتي جميعها كانت تصب في اعطاء التصميم الامثل للطائرة بما يلائم وعمل تلك الخلايا الشمسية لغرض الحصول على اعلى قدرة تكون كافية لتجهيز محرك الطائرة لاعطاء اعلى دفع (Thrust)بالاضافة الى الحصول على اطول وقت ممكن لتحليق الطائرة في الجو لتنفيذ مهامها والمتبقي من الطاقة الفائضة يمكن خزنها في البطاريات لغرض استخدامها ليلاً. تم الحصول على نتائج حقيقية من العمل الحالي وهي اقرب ما تكون للواقع عبر الاستخدام الامثل لتلك الخلايا عبر البرامجيات المذكورة اعلاه وبالاخص برنامج (J2) للسماح ببناء وتصنيع الطائرة الشمسية لانه يجري محاكاة للطائرة نظرياً وبابعادها الحقيقية للتنبؤ عن اداءها اثناء الطيران كخطوة تسبق عملية التصنيع لتلافي اي خسائر مادية للنموذج المصنع بسبب كلفة تلك الخلايا ووضعيتها على سطح الجناح .

الكلمات المفتاحية: تصميم، طائرة مسيرة و الخلايا الشمسية.

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Introduction

There are many kinds of unmanned air vehicles (UAV), which are used for many tasks such as surveillance, communication, intelligence and monitoring. Most of UAV are using liquid fuel as an energy source by combusting to produce aircraft power for takeoff and flight. In spite of this kind of high fuel energy combustion products as a result of environment challenges that faced by the world because of telling pollution and their exhaust emotions into the atmosphere and high fuel costs cause more difficult for producing these types of aircrafts. Therefore, solar energy is the best choice to produce clean energy using for takeoff and flight these aircrafts. In spite of the cost of producing and maintenance of these kinds of solar powered UAVs as compared with fuel jet aircraft, they can save millions of dollars over a long period of time and help to protect the environment.

Camp Irwin in California designed an unmanned air vehicle called Sunrise I in 1974, flew 20 minutes in flight at an altitude of around 100m, while the second version of sunrise II designed for new cells with higher efficiency 14% delivered a power of 600 watt(Bett,2009). Fred and Larry were used the concept to charge a battery on the ground using their solar panels and then achieve short duration flights (Hartney,2011). In 2006, André Noth of the Swiss Federal Institute of Technology Zurich began test flights of the Sky-Sailor and 2008, he flew the plane for 27 hours and landed with a fully charged battery (Hurd, 2009).The work done by Ref. Noth (2008) gives table of the time stage for the progress the solar aviation since 1974 to 2008.

The great behind is that it is general enough to be applied to a wide range of size, from small model aircraft to large scale, high altitude platform. In other hand, the goal of this research is to design an aircraft flight by solar energy and does not need to land for refueling to continue its mission.

Materials and Methods

Theoretical Part

A solar cell is a PIN Junction similar to diodes in its work, made of semiconductor material so that the light falling on the surface can be implement to the contact area where the rays falling on the cell transformed into electrical energy(Nelson, 2003). The basic material used in manufacturing the solar cell is a silicon quadrivalent linked as atoms bonds of covalent introduce arrangement crystalline similar to the arrangement of carbon atoms in the crystal diamonds, which are insulator atoms just in the degree of absolute zero. In order to increases the degree of conductivity of Silicon, there are three ways. Firstly, applied high temperature, by applying high voltage and when exposed to radiation of sufficient energy.

Cell Performance

In order to produce greatest amount of electrical power from a given illumination level, cell material which is used depends on spectrum of light. Energy of incoming photons is determined by

$$E_P = h c / \lambda \text{ -----------1}$$

where: E_p is energy of photons in joules, h is planks constant(joules. second), c is speed of light (meters/second) and λ is the wavelength of radiation in meter $(1.11*10^{-6}m)$.We know the E_p needs to be greater than energy gap E_g (the amount of energy that must be imparted to an electron in the valence shell of a semiconductor for that electron which moves to the conduction band),the energy radiation

is inversely proportional to wavelength, the λ of light that converted to electricity by silicon solar cell must be less than $(1.11*10^{-6}m)$ (Hurd,2009). The atmospheric air mass coefficient is another most important external factor which is commonly used to characterize the performance of solar cells under standardized conditions, and often referred to using the syntax "AM" followed by a number. This coefficient effects on sun`s flux, and givens in the figure (1):
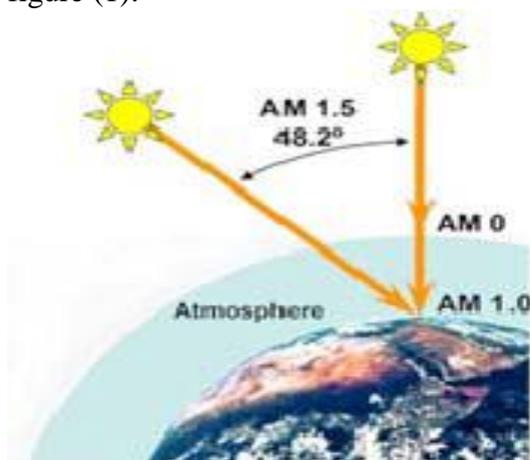

Fig.(1)Solar Spectrum Air – mass Numbers

$$AM = 1 / \cos\theta z\ldots\ldots2$$

Where θz is incident angle of solar ray. There are three types of AM (Solar Spectrum Air – Mass Numbers):

1. AM0 refers to free space, the above equation does not hold for AM0.
2. AM1 refers to the minimum air mass of the earth atmosphere where the sun is in the zenith.
3. AM1.5 refers to the air mass at angle about 48^0.

More values for AM refer to more thickness for the earth`s atmosphere(Hurd,2009).

Characteristics of Solar Cell

There are five parameters explain the electrical characteristics of solar cell

1. Open-circuit voltage represents by (V_{oc}) that is measured with an open circuit
2. Short-circuit current represents by (I_{sc}) that is measured with an shorted electricity
3. Maximum power (P_M)
4. Fill factor (FF) is the ratio between the actual power to the theoretical power
   $$FF=P_M /V_{oc}I_{sc}---------------3$$
5. Energy conversion efficiency represents by (η) that is a measure of the ability of the cell to convert electromagnetic energy of light into electrical power from the cell(Hurd. 2009).
   $$\eta=I_{sc}*V_{oc}*FF/P_{light}*A_a-----4$$
   $$\eta=P_{out}/P_{in}----------------------5$$

P_{light} is (the power of incident photons in W/m^2)and A_a is(a solar cell area in m^2).

The kind of solar cell that we estimate chosen it, is a standard $Ga_{0.5}In_{0.5}P/Ga_{0.99}In_{0.01}As/Ga$ triple junction. Its practical average efficiency limits of 30% for AM0. Its name ASUR SPACE (3G30) which belong to(ASUR SPACE Solar power GmbH, Germany).That cells have light weight (1 gm) and their dimensions are $(0.04m\times0.08m)$ and each cell gives 0.42 (W) (Köstler *et al*,2011). We distribute them on a wingspan and they can be added on a horizontal tail. Table(1) gives the specifications of this cell (Beet *et al*,2009):

Table (1) Specifications of Solar Cells

specifications	At AM0	AM1.5
Isc (amp)	0.535	0.0147
Voc (Volt)	2.735	2.69
FF	86.1%	86.6%
η	30.6%	34.1%

The most important design parameters of a small solar–powered unmanned aerial vehicle are presented by:-

1.Consideration about the absorbed energy from the sun to offer sufficient

power to operate the motor and charge the battery to start the operation again.

2. It should offer lift (L) equal to the total weight (W) of the aircraft for the required altitude.

3. It should have aerodynamic characteristics suitable with the power taken from the sun.

4. Level of flight and the Range depend on the experiment and the power that we have got from the solar cells.

Mission Requirements

1 The payload consists of the necessary equipment for the aircraft to do its mission (Camera, Sensors, Batteries, Motor, Auto Pilot, .etc.). All these parts do not overcome 2(kg), because any increment in weight leads to reduce the number of solar cells which lead to decrease the power that comes from them.

2 Range / Endurance: the range cannot be limited because it depends on the value of the solar power that the UAV has got from sun and the time which the aircraft starts its mission. Endurance will be at least for five hours at cruising altitude.

3 The conditions of flight: the maximum height is assumed to be 1000(m) and we should be referred that the UAV flies with lower height most of time flying. The speed of cruise (V) is 27.8 (m/s). At take-off, we will be used launcher but at landing, a suitable area will be prepared and used a skid land where it can land softly without distorted the aircraft. Therefore there is no landing gear installed to reduce the weight.

4 Crew members: the mission needs four members to operate the UAV, two members will need to launch the aircraft by using launcher, one will pilot the UAV by using Radio Controller (R/C) then operate the autopilot to continue the flight path and one will be responsible for data

analysis and flight tracking during the mission and return the aircraft at the end of its mission. The autopilot connected to ground station system, operating either as a single computer or in parallel with other computer running analysis software such as MATLAB, supports data viewing and input back to the aircraft. The ground station iscapable of running on multiple platforms and laptops simultaneously for live analysis.

Results and Discussions

There are three items discussed for explaining the procedure of solar-powered UAV design and how the effective weight of solar cells and aircraft performance.

1. General Configuration

The system of solar–powered UAVs is electrical single engine propeller propulsion (RCX A2822-8 2600Kv Out runner Brushless motor) where (Kv=rpm/volt) because it gives larger amount of power than other kinds of electric motors, it prevents any noise and advised using it for UAV because the electrical motor consume minimum power from solar cells for operation. In other hand, electric motor is light weight and easy to install on the tip of fuselage with a suitable propeller diameter (7*3/6*4). The material of propeller was made of composites material called (APC) to reduce the drag force and increase the efficiency. To keep high efficiency for the motor, it was necessary to use gearbox to connect the propeller and motor. Table (2) represents the specifications of the motor.

Table (2) The Specifications of the Motor

Motor Size	Ø3.175*33mm
Weight	38g
KV(rpm/v)	2600
Max. power	260W
Max. Current	24A
Suitable Buttery	2-3S Li-Po

The diameter of fuselage limits the propeller size and wherever the diameter of propeller is large, the efficiency will be high and its diameter was chosen to be 10% of fuselage length (Raymer. 1992).

The fuselage was a cylindrical shape, its length (3.75m) and maximum height (0.33m), it must be suitable to fit the propeller and made of balsa wood which is very light to reduce the weight and the drag force, connected to one tail boom to reduce the weight and based the empennage group on it.

       The wingspan was a very important part in the design of solar powered aircraft not only for its aerodynamic characteristics like (lift coefficient (C_L), drag coefficient (C_D),ratio of lift to drag (L/D),Wing loading (W/S)) but it also suitable for adding the solar cells on its surface. Therefore the solar-powered UAVs have along wingspan. We designed the wingspan with 5(m) and put it on the top surface of fuselage which called high wing to produce a high lift, easy to contact with fuselage and gives best lateral stability as shown in figure (2). The area of the wing is a big area to distribute the cells on it. The wing is a straight wing because the aircraft cruse with low speed but it has dihedral angle 6 deg. upward in last quarter from the tips to reduce the danger of damage (the angle of dihedral is simply the angle above horizontal at which the wing is mounted) as shown in figure (2). The taper ratio (the ratio between wing tip chord to wing root chord) was indicated by (Raymer,1992) that for a rectangular un swept wing, it should be closed to 0.45 in order to have an elliptical lift distribution throughout on the wing but for our design the taper ratio will be one (Raymer,1992). We chose airfoil NACA63-1212 which has thickness of 12% from the ratio of

thickness to chord because it gives low drag and the chamber leads to keep laminar flow along the airfoil (McCormick, 1979). We use AutoCAD program in drawing the aircraft and its projects as in fig (2) and fig.(3).
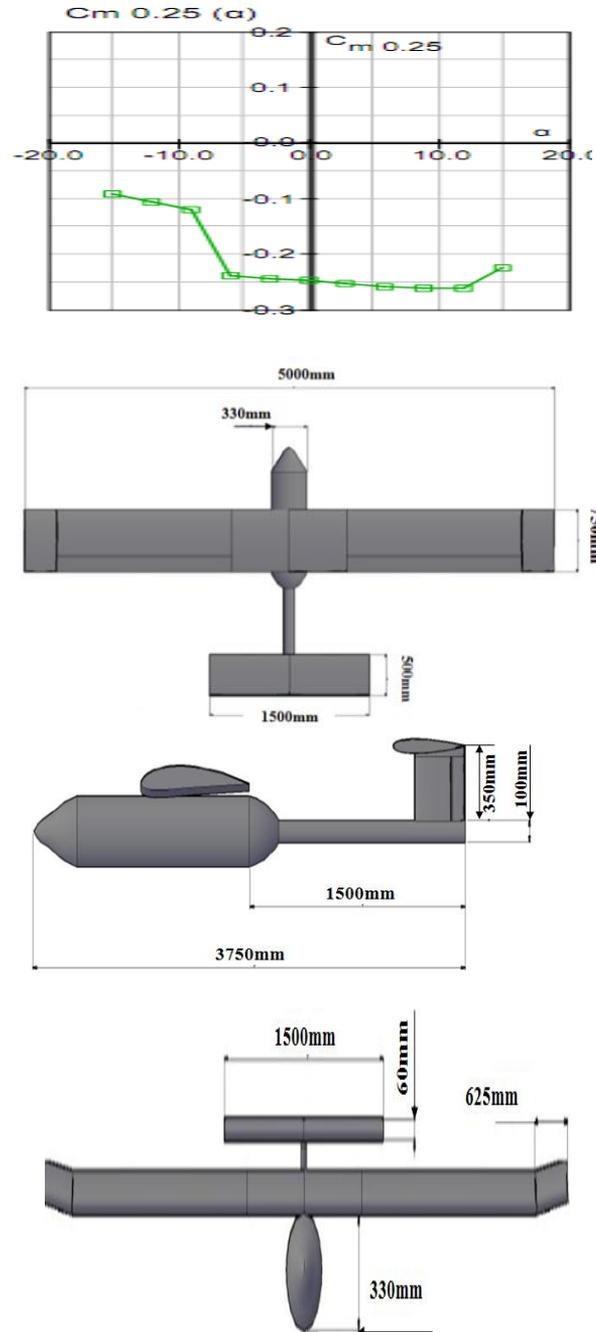

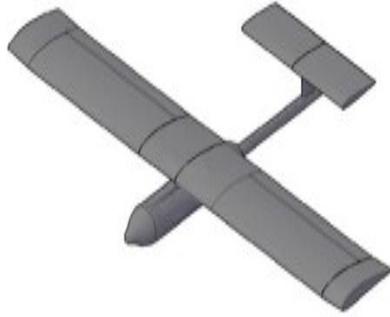Fig.(2) The Projects of Solar- powered UAV Design by Auto CAD Program

Fig.(3) Solar- powered UAV Design by Auto CAD Program

We use Java foil software to analyse airfoil (the airfoil produced (2/3) of total lift) where fig (4) shows the relationship between lift coefficient (C_L) and drag coefficient (C_D) for the wing of our model where (C_{Lmax}=1.9 at C_D=0.025) this means the load factor (L/D) (the ratio between lift coefficient (C_L) and drag coefficient (C_D) for the wing) is high ratio that is frequently advantageous to have the smallest turn radius and largest turn rate for maneuvering performance of an airplane and the ratio of L/D indicates airfoil efficiency.
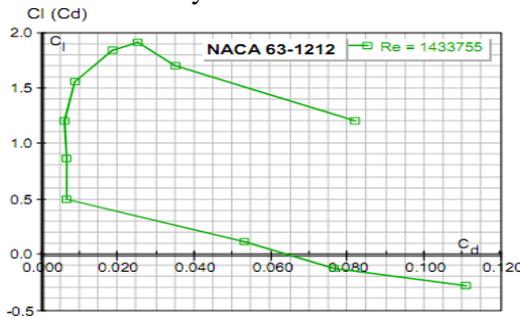
Fig.(4) Relationship between Lift Coefficient (C_L) and Drag Coefficient (C_D) from Java Foil

Fig.(5A) shows the relationship between lift coefficient (C_L) and angle of attack α (the angle between chord line of airfoil and the direction of aircraft path).This figure gives (C_{Lmax}=1.9 at α=10˚)for the wing of our model where lift will be maximum and drag will be minimum but C_{Lmax} is a critical value because the flow

around the wing, tends to separate from the airfoil and leads to cut the lift on the wing and the aircraft will be stall. Therefore ($C_{L\ design}$) must be lower than (1.9). Fig.(5B) shows the relationship between pitching moment coefficient (C_m) and angle of attack α which refereed to the longitudinal static stability of the aircraft and it is stable because ($\partial C_m/\partial \alpha < 0$).
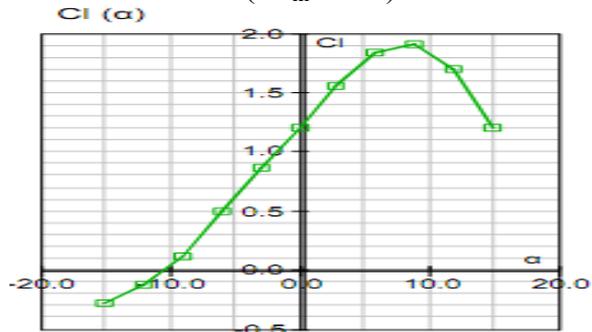

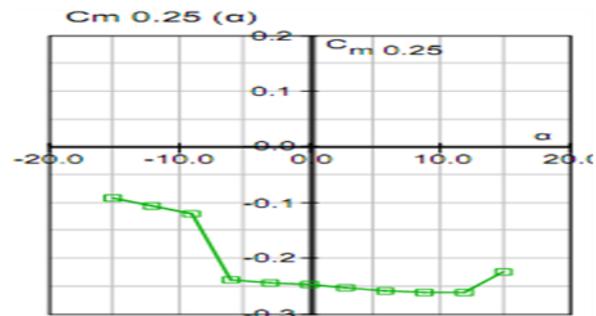Fig. (5A) Relationship between Lift Coefficient (C_L) and Angle of Attack (α) from Java Foil

Fig.(5B) Relationship between Patching Moment Coefficient (Cm) and Angle of Attack (α) from Java Foil.

Fig.(6) shows the airfoil shape and from fig.(7) we can see the flow around the airfoil that refers to the pressure distribution where the deferent between the pressure on the upper surface and the lower surface produced lift for the aircraft:

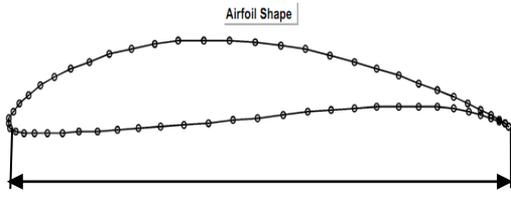$$C_L = \int_0^1 (C_{PL} - C_{PU})dx - - - -(6)$$

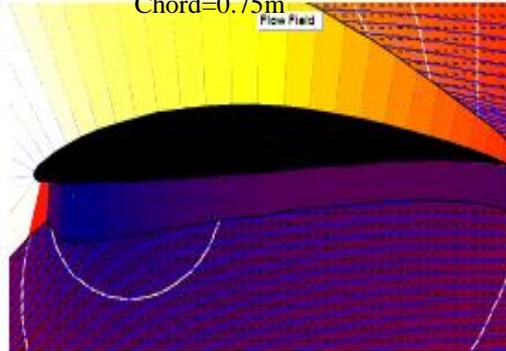Fig.(6) Airfoil Shape

Chord=0.75m

Fig.(7) The Flow around the Airfoil

The empennage is T-tail that allows adding more cells which means increment in the power. The following table shows the dimension of our model which calculated as below:

Wing area(S) =

Wingspan (b)*Chord (c)

Aspect Ratio (AR) =b/c

Length of aircraft (L) =0.75* b

Wing loading = W/S

Table(3)Mission Parameters and Calculation of Weight and Wing Loading

Wingspan(b)	5 m
Chord (c)	0.75 m
Aspect Ratio (AR)	6.67
Wing area (S)	3.75 m^2
Length (L)	3.75 m
Weight(W)	11kg
Wing Loading (W/S)	29.33(kg/m^2)

2. Power Calculation

(Noth *et al* .,2007) referred to the most important factor which is a power of solar cells and the equations of power which attach the design of aircraft at steady flight where total Weight (W) equal to the total Lift (L)

and Thrust (T) equal to Drag (D) as in (7) and (8).

$$W =L = ½ C_L \rho S V^2\text{------------------}7$$

$$D =T = ½ C_D \rho S V^2\text{------------------}8$$

ρ (Air Density at 1000m=1.112kg/m^3), V (cruse speed =27.8m/s)

So the power required for steady flight (P_{lev}) calculated from thrust (T) that calculate from equation (7) multiplied by cruise speed (V) which equals to   27.8(m/s) as in flight conditions above: P_{lev}=T*V------------9

P_{lev}=16.114*27.8=447.96W

3. Mass Calculation

In general calculation of an aircraft weight, fuel weight is an important variable for calculating the takeoff weight versus the empty weight of the aircraft while in solar powered UAV there is no fuel weight, therefore a weight analysis cannot be done by using the steps in (Roskam, 1985-1990) or (Raymer, 1992), while (Noth,*et al.,* 2007) determined the components of weight by inserting the relative parameters that related by the aircraft. (Noth,*et al.,* 2007) explains that the mass of aircraft consists of fixed mass (m_{fixed}) which is the sum of avionics total mass (m_{av}) and payload total mass (m_{pld}) as in (10)

$$m_{fixed} = m_{av} + m_{pld}\text{------------------}10$$

and airframe total mass (m_{af})which depends on wingspan (b) and Aspect Ratio(AR) calculated from equation (11):

$$m_{af} = K_{af} AR^{X2}b^{X1}\text{----------------}11$$

K_{af}(Airframe Constant), X1(Sizing Exponent for wingspan), X2 (Sizing Exponent for Aspect Ratio).

X1 and X2 stay constant but K_{af} is 20% of the value of (Noth, 2007) used in his model (Hartiny, 2011).

The mass of solar cells m_{sc} based on the area of the cell A_{sc} which can be calculated from the dimensions of the cell (0.08m * 0.04m) (Köstler *et al*.,

2011). So the mass of solar cells determined from (12)

$$m_{sc} = A_{sc}(K_{sc} + K_{enc}) ------------- 12$$

K_{enc} (Encapsulation Mass Density), K_{sc} (Solar cell mass Density).

The number of cells that we install on the wing can be calculated from:-
No. of solar cells on wingspan
=wingspan (b)/length of cell---------13
= 5m/0.08m = 62sc
No. of solar cells on chord= (wing chord–aileron chord)/width of cell---14
= (0.75m – 0.1875m)/0.04m =14sc
The total no. of cell =62* 14 =868sc
The total power output will be:-
P_{out} =868sc* 0.42 W/sc = 364.56W

The output power is sufficient to charge the battery of the motor along the period of flight and we can add cells on the horizontal tail if we need more power. We must refer to the kind of the battery because it was very important in solar-powered aircraft where the motor used it at first step of flight and used it to operate the motor at night flight. Its kind is Lithium–ion which weighted 260 (gm) and gives 11(v), 4.6(A) and 50.6 (W). We used (7) batteries connected in parallel that produce a current equal to (32 A) and it is very sufficient to preliminary operation of the motor to start takeoff and it is very easy to connected to the motor. The following table shows the components of mass of solar aircraft.

Table (4) The Masses of Component of Aircraft

Components	Mass (kg)
Payload	2
Avionics	1
Airframe	4.912
Batteries	1.82
Solar panels	0.868
Propulsion Group	0.4
Total	11

Now we use AAA2.5 (Advanced Aircraft Analysis 2.5) software which based on Roskam methods in a design of airframe of solar powered UAV which is shown in (Roskam, 1985-1990). The software provides a powerful framework to support the iterative and non-unique process of aircraft preliminary design. It allows students and preliminary design engineers to rapidly evolve a preliminary

aircraft configuration from early weight sizing through open-loop and closed-loop dynamic stability and sensitivity analysis and working within regulatory and cost constraints. The results of AAA2.5 software appeared the design of half wingspan in fig.(8) and horizontal tail in fig.(9). We can see from fig.(10) that the maximum value of total lift coefficient for the aircraft is (1.541) and fig.(11) gives the distribution of lift is an elliptic which means the wing gives a good lift force to the aircraft and a good wing loading (W/S) (the maximum weight of aircraft divided on wing area) . Fig.(12) shows The load factor (L/D) which is the amount of lift generated by a wing or airfoil compared to its drag. Aircraft with higher L/D ratios are more efficient than those with lower L/D ratios. In uncelebrated flight with the lift and drag data steady, the proportions of the C_L and coefficient of drag (C_D) can be calculated from fig.(12) where the L/D ratio is determined by dividing the C_L by the C_D, If the aircraft is operated in steady flight at L/D_{MAX}, the total drag force is minimum .Fig.(13) shows drag polar which appeared that drag coefficient never becomes zero. Drag polar is very important to performance analysis and can often be difficult to optioned from an aircraft manufacture. For the aircraft with symmetrical wing section the drag polar:

$$C_D = C_{DO} + C_L^2/(\epsilon \pi AR)\text{---------------}(15)$$

AR is the aspect ratio, and ϵ is an efficiency factor close to unity. C_{D0} includes contributions such as friction and form drag.
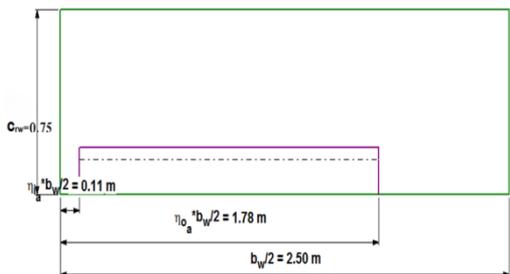

Fig. (8) The Design of Half Wingspan from AAA2.5 Software
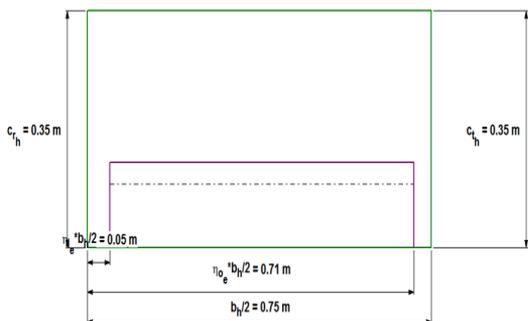

Fig. (9) The Design of Horizontal Tail from AAA2.5

To make simulation for the model 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
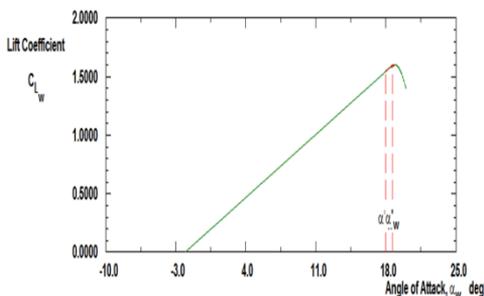
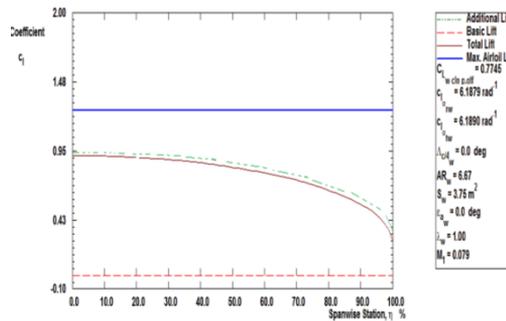**Fig. (10) Lift Coefficient CL and Angle of Attack α (deg.) from AAA2.5**

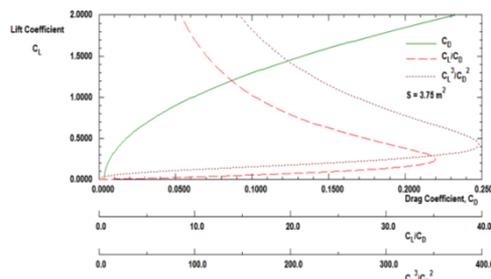**Fig.(11) The Distribution of Lift on the Wingspan from AAA2.5**

Fig. (12) Lift Coefficient CL and Drag Coefficient CD, Lift to Drag Ratio (CL/CD), CL2/CD3fro AAA2.5
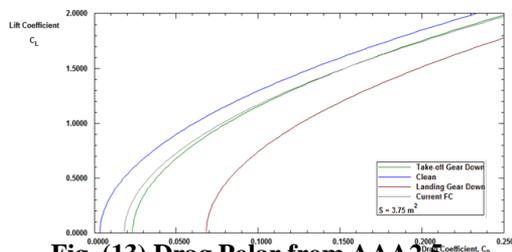

Fig. (13) Drag Polar from AAA2.5

run the complete flight test program to be assessed from the very beginning of a project. This software is achieved, through the ability to take even the smallest amount of data and start by flight the aircraft and it can be discovered and corrected earlier on where the cost of changes is much cheaper. J2 show that our model is accepted and stable at steady flight conditions as shown in fig.(14).
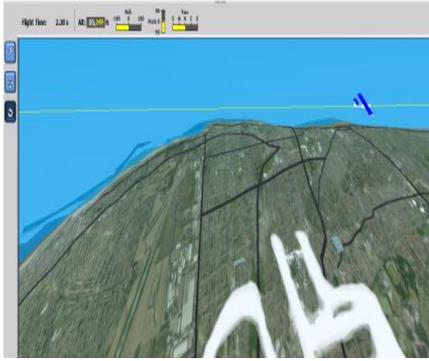
Fig.(14) Aircraft Flies at Steady Flight as in (J2) Software.

Conclusions

1. The weight of aircraft is the most important parameter in aircraft design. So that, it is restricted and depends on power of solar cells which is in our model no more than 11(kg).

2. The present investigation gives the capability of solar cells to produce the power required for takeoff and steady flight and overcome.

3. The most important result here is that there is no more fuel consumption because of the capability of solar cells to produce the power required for operating the electric motor of the aircraft.

4. Eliminations of environment pollution by using renewable energy.

5. Computer programs have prepared and constructed depending upon (Java foil and AAA2.5 softwares) were designed for aerodynamic Vehicle", M. Sc. Thesis, Department of Mechanical and Aerospace Engineering, San Jose University.

analysis of modern aerodynamic configuration with the capability of predicting (aircraft lift coefficient, drag coefficient, pressure coefficient for both upper and lower surface of wing, lift distribution on wing surface and drag polar). While J2 was prepared for flight analysis and UAVs stability by selecting the geometry, flow conditions, defining which specific results are desired and specifying whether steady state or time dependent of the analysis by observing and the behavior of result dependent variables. From J2 software we made simulation for our model to make sure that the aircraft is stable at straight flight that means we can manufacture our model with good results.

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