Journal of Aeronautics & Aerospace Engineering
ISSN: 2168-9792
Harasani, J Aeronaut Aerospace Eng 2015, 4:2
DOI: 10.4172/2168-9792.1000148
Research Article
Open Access

Designing and Fly Testing a Long Endurance Solar Unmanned Air Vehicle

Harasani W*

Faculty of Engineering, King Abdul Aziz University, Saudi Arabia

Abstract

The scope of the present work was to design, build and fly test a solar UAV, Sun Falcon 2 for long endurance day and night flight operations. A software program was written to design the UAV with appropriate aerodynamic attributes, power requirements and other flight mission constraints to keep the vehicle airborne for multi day and night operations. More specifically the design called for an least 12 hours of endurance during the day with solar panels deployed to absorb sufficient daylight energy to top up the on board batteries for the complete subsequent night flight mission. With Sun radiation levels averaging at about 6003 W/m2 during the Saudi day it was not too difficult to conform to multi day and night design requirements. The prototype Sun Falcon 2 has already been built and flight tested with satisfactory performance records satisfying the design criteria.

Keywords: Unmanned Air Vehicle; Fly testing; Designing

Introduction

This article reports on the second leg of the collaboration between the students and the staff of the Tokai and King Abdul Aziz universities tasked to design long duration UAVs. The present work, thus is followed on from the first design of Sun Falcon 1[1] which was successfully designed and flight tested at both locations Tokai University and King Abdul Aziz University. While solar powered aircraft are not unknown to the industry especially with the famous Gossamer [2] version of vehicles flying ever higher, heavier and longer to confirm the viability of solar power as a reliable means to power airborne vehicles. Elsewhere German Akaflieg group coming up with such large sized UAV's as the VELA2, NACRE and AMPAIR have proven that a variety of different UAV configurations can be flown but few as pointed out in Reference 1 and by Noth and Siegwart [3] UAVs have demonstrated the continuous day/night capability using the solar power.

Design Procedure

The overall design procedure demands an accurate weight estimation which can be supported comprehensively by the configuration aerodynamics throughout the complete itinerary of the flight mission. An even more demanding challenge is the adequate supply of the power dispensation especially during the sundown hours. The methodology is heavily based on the principle that the on board batteries would be sufficiently charged during the day operation by the on board solar panels to cover the power requirements during the night hours. Obviously there is an iterative process which optimises the weight against the aerodynamic loads and stability as well as the available power demands [4].

In terms of the actual design and performance specifications, the Sun Falcon 2 was estimated to have a 200 g weight with a continuous flight capability lasting at least 5 days (120 hours) with a cruise velocity of 30 km/h. It will have a climb rate of about 2 m/s operating by an electrical motor powered by a battery replenishable by solar panels. It will take-off in a normal fashion from an appropriate ground terrain and remain airborne at an altitude of about 500 m. A typical flight mission would then require the UAV to climb to a maximum height of 500 m, remain airborne continuously for 120 hours loiter at that altitude and ten descend to a prescribed location [5]. The final design will be subject to the safety regulations of the European Aviation Safety Agency and Certification Safety of Very Light Airplanes (CS-VLA).

Power Requirements

Power required to maintain uniform flight in cruise, is one of the most important parameters in sustained flight over a long period of time. This parameter in turn is dependent upon the aerodynamic performance of the vehicle, particularly the drag,

$$D = \frac{\rho * V^2 * C_D * S}{2} \quad (1)$$

Where

$$C_D = C_{Di} + C_{Do} \quad (2)$$

$$C_D = C_{Di} + C_{Do} \quad (3)$$

$$C_{Di} = \frac{C_L^2}{e * AR * \pi} \quad (4)$$

$$C_{Do} = 0.455 \times \mathrm{Log}(Re)^2 \quad (5)$$

Where is the Oswald's efficiency factor and Re is the Reynold's number

According to the induced drag and viscous drag calculation, the total drag can be obtained by equation 6

$$D = \frac{\rho * V^2 * (Cd_0 \times \text{Total Flat Plat Area}) + (Cd_i \times S)}{2} \quad (6)$$

Since the required thrust is equal to the drag, the require power can be calculated from equation 7

$$P = \frac{\text{Thrust} * V}{\eta_m * \eta_p} \quad (7)$$

***Corresponding author:** Harasani W, Faculty of Engineering, King Abdul Aziz University, Jeddah, Saudi Arabia, Tel: 966-555681050, E-mail: wharasani@kau.edu.sa

Received November 04, 2015; **Accepted** November 21, 2015; **Published** November 28, 2015

Citation: Harasani W (2015) Designing and Fly Testing a Long Endurance Solar Unmanned Air Vehicle. J Aeronaut Aerospace Eng 4: 148. doi:10.4172/2168-9792.1000148

Weight Estimates

Along with the aerodynamic performance of the vehicle the weight of the components of vehicle must be obtained with extreme accuracy. The total weight of the vehicle, which must in all cases be

less than the aerodynamic lift $L=\frac{\rho V^2 C_L S}{2}$ is

given by the equation:

Total Weight = Weight of Batteries + Payload + Weight of Solar Cells + Weight of Airframe (7)

The weight of solar cells and the weight of airframe will be calculated from the following two equations:

$$\text{Weight of Solar Cells [kg]} = \text{Solar Module Area} * 0.8 \quad (8)$$

$$\text{Weight of Air frame [kg]} = \frac{0.2 * S^{1.55} * AR^{1.3}}{9.81} \quad (9)$$

Another important feature of solar based flight is to have an accurate estimate of the energy generated from the solar cells which must exceed the energy requirements of the vehicle.

Energy Requirements

Energy needed is calculated from adding the energy needed from motor and energy needed to charge th-e batteries.

Energy needed at Day[w_h] = Energy motar [W. h]+ Energy to charge battery [W_h]

And the power required can be calculated from the equation:

Where energy needed for motars and energy to Charge battery can be calculated by the equation

$$\text{Energy to mortar} = \text{Required power [w]} * \text{Day time [h]} \quad (10)$$

And the power required can be calculated from the equation :

Energy to charge battery [W_h] =

$$\frac{\text{Capacity of Battery}[\text{mAh}] * \text{volt}[\text{v}] * \text{Number of Batteries}}{1000} \quad (11)$$

The length of day the day time is assumed to be 12 hours in this analysis, and the number of batteries can be obtained from were 13 in the next section. From the batteries specifications in Table 1 the capacity of battery and volt can be found.

The above energy required has to be balanced against the energy available from the solar cells. The energy generated by solar cell is given by equation 12:

$$\text{Energy generated by Solar, cell [Wh]} = \eta * \Omega_{rad}\left[\frac{\text{W.hr}}{\text{m}^2}\right] * S\left[\text{m}^2\right] \quad (12)$$

Where Ωr is the radiation vector obtained from the Jeddah Met Office and S is the wing area and

is the solar cell efficiency.

Where minimum capacity and charging current can be found from the battery specifications and the number of batteries required can be obtained from equation 13

$$\text{Number of Batteries} = \frac{\text{Total energy at night}\left[w_h\right]}{\text{Single Battery Energy}\left[w_h\right]} \quad (13)$$

The total energy and single battery energy can be calculated from

Description	Amount	Unit
Wing span length	7.5	[m]
Aspect ratio	19.66	--
Total amount of global radiation	6006	[W.h/m²]
Chord at root	0.4	[m]
Cruise speed	33.4	[km/h]
Altitude	500	[m]
Efficiency of the propeller	0.8	--
Efficiency of the motor	0.85	--
Efficiency of the solar module	0.23	--
Predicted Weigh of the airframe	5	[kg]
Predicted Weight of the solar module	2.06	[kg]
Predicted Weight of the battery (Lithium ion)	3.69	[kg]
Predicted Weight of the plane	10.86	[kg]
Power during cruise	70	[W]

Table 1: Sun Falcon 2 Design Parameters.

equation 14 and 15 respectively:

$$\text{Energy needed at}\left[W_h\right] = \text{Night Time}\left[\text{hr}\right] * \text{Power Need}\left[W\right] \quad (14)$$

$$\text{Single Battery Energy}\left[W_h\right] = \frac{\text{Minimum Capacity}\left[\text{mAh}\right] * \text{Voltage}\left[V\right]}{1000} \quad (15)$$

The time needed to charge batteries is given by the following equation:

$$\text{Time to charge battery}\left[h\right] = \frac{\left(\text{min capacity}\left[\text{mAh}\right]\right) * \text{number of battery}/1000}{\text{Charging current}\left[A\right]} \quad (16)$$

Figure 1 displays an EXCEL based SUNDOME flow chart diagram, in which the individual compartments are updated as the iterative design procedure is advanced to converge towards the final design. It has the ability to iterate between configuration aerodynamics, weight, energy and power requirements as well as the critical time to energy absorption from the daylight operations. The mission parameters are introduced into the mission specification module which feeds such information towards the aerodynamics module which uses such basic performance coefficients as the lift, drag and configuration geometry to arrive at the power and energy generations and other motor specifications. This information is in turn used in the power plant design to arrive at the solar cell and battery weight, area and power requirements. A final decision module interrogates whether the available energy and weight quantities satisfy the appropriate constraints and meet the critical time needed to replenish the battery charge for night operation in a repetitive manner. If the constraints are not satisfied than the frame geometry in terms of the aspect ratio and airframe weight is updated to repeat the convergence iteration.

Typical configuration geometry, aerodynamics, mission specification, and other energy and power requirements as well as battery and solar power requirements at any instant as they are updated during successive design iterations is shown in the Figure 2.

The configuration which was used to provide various geometry, weight and other aerodynamic characteristics is shown in Figure 3. The wing aerofoil section is based on an S8037 airfoil without a fuselage having an inverted V tail configuration supported by a tail boom which is extended forward for an appropriate c.g location. Detailed geometry

Citation: Harasani W (2015) Designing and Fly Testing a Long Endurance Solar Unmanned Air Vehicle. J Aeronaut Aerospace Eng 4: 148. doi:10.4172/2168-9792.1000148

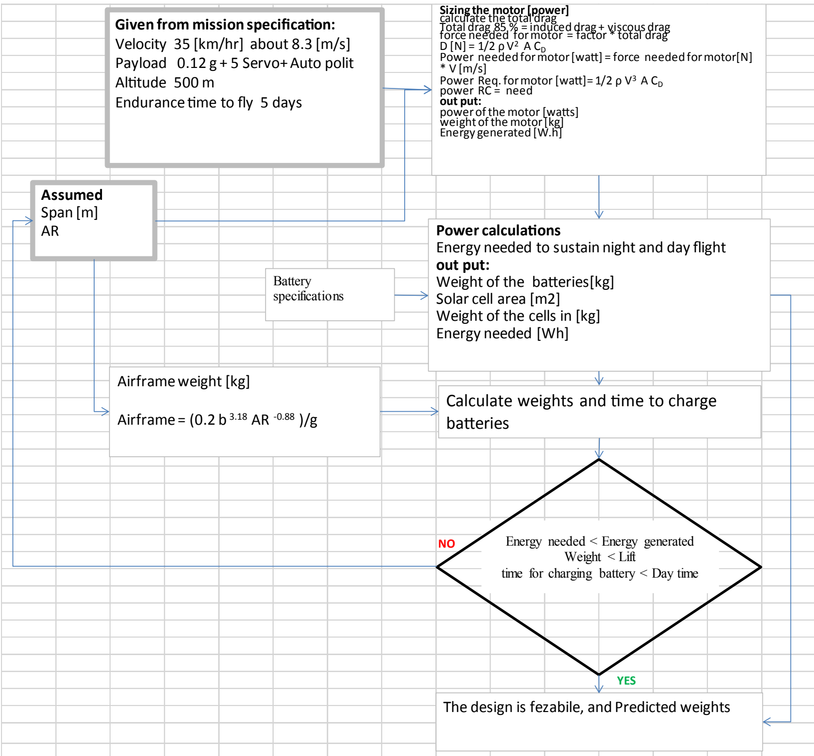

Figure 1: Sundowm flow chart.

Mission	
Cruising Velocity [km/hr]	33.48
Cruising Altitude H [m]	500.00
Payload [Kg] (Camera and Data Transmitter)	0.12
Rate of Climb R/C [m/s]	2.00
day time time [h]	12.00

Configuration	
Wing Span [m]	7.50
AR	19.66

Given Data	
Cruising CL	1.00
Oswald Efficiency Factor e (for High Mounted Wing)	0.80
Viscosity [Pa*s]	0.0000182
Sea Level Temperature To [K]	288.00
Gas Constant R[J/(K*Kg)]	287.00
Decrease Rate of Temperature a [K/m]	0.0065
Sea Level Pressure Po [Pa]	101325.00
Sea Level Density ρo [kg/m^3]	1.226
Efficiency of Motor(0.85) * Propeller(0.8)	0.680
Solar Cell Efficiency	0.23
Minimum Average Daily Horizontal Radiation [W*hr/m^2]	4300.00
Battery Weight [kg/(W*hr)]	0.005
Margin Time of Battery Usage [h:m]	0.014

Calculated Parameter	
Temperature T [K]	284.75
Pressure P [Pa]	95454.86
Density ρ [kg/m^3]	1.17
Cruising Velocity [m/s]	9.30
Wing Area S [m^2]	2.86
Chord Length c[m]	0.38
Reynolds Number Re	2.277E+05
Total Flat Plate Area [m^2] {Wing, Fuselage, Tail, and others (=2.6*Wing Area)}	7.44
Induced Drag Coefficient Cdi	0.020
Flat Plate Turbulent Viscous Drag Coefficient Cd0	0.00599
Total Drag [N]	5.18
Solar Module Area [m^2]	2.58
Night time [h]	12.00

Airframe	
Weight of Airframe [kg] (Including Weight of Motor, Controller, Propeller, Electric Circuit, Solar Cell, and Actuator)	5.00

Motor and Propeller	
Required Thrust T [N]	5.18
Required needed Power [W]	70.78
Weight of Motor [kg]	0.8
Charging current [A]	20

Stalling Speed	
Maximum CL	1.00
Stalling Speed at Maximum CL and Sea Level [m/s]	1.69
Airfoil: S8037	

predicted Weights	
weight of solar cells [kg]	2.060
weight of batteries [kg]	3.69
total weight [kg]	10.86

Battery specifications	
Nominal Capacity min [mAh]	2950
Nominal Capacity Typical [mAh]	3100
Approx. Weight [g]	45.5
Nominal Voltage [V]	3.6
Energy for a single battery, [W.h]	10.62

Night flight	
Night flight hours [h]	12.00
Energy total needed [W.h]	850
Number of Batteries needed	81
Weight of batteries [kg]	3.6855
Day flight	
Solar Energy per [m2, Wh/m2]	989
Energy needed from motor [W.h]	850
Energy from battery needed to charge [W.h]	903.96
Energy needed from solar [W.h]	1753.96
Solar cells area from Energy needed [m2]	1.7735

Energy Balance	
Energy generated from solar power [W.h]	2546.7
Energy needed < Energy generated	OK

Weight Balance	
Total Weight W [kg]	10.86
Lift L [N]	144.52
Lift L [Kg]	15
Lift must > weight predicted	OK

Time Balance	
time to charge battery [hr]	11.9475
time to charge < day time	OK

Figure 2: Unit Excel Sheet.

Citation: Harasani W (2015) Designing and Fly Testing a Long Endurance Solar Unmanned Air Vehicle. J Aeronaut Aerospace Eng 4: 148. doi:10.4172/2168-9792.1000148

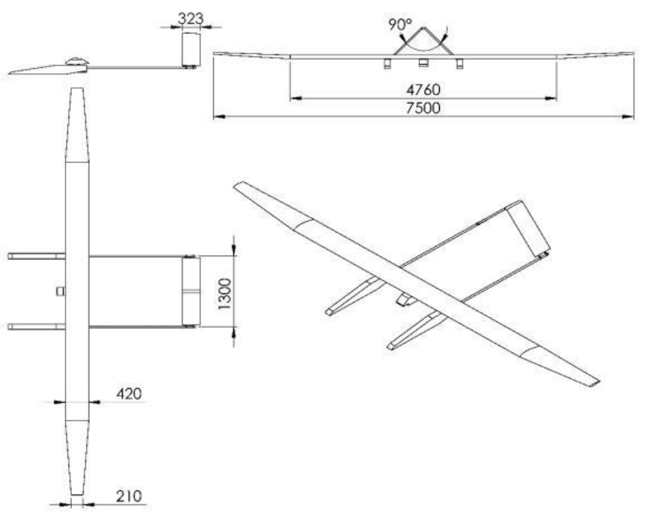

Figure 3: View of sun falcon 2 all dimension in mm.

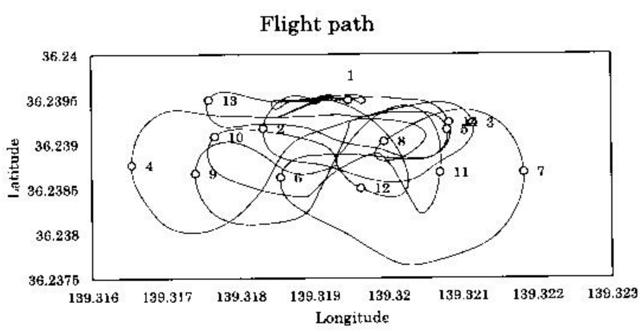

Figure 4: Flight path.

and other aerodynamic features of the final design are included in Table 1.

Loiter Control

The UAV was controlled to loiter within a specified airspace defined say by a number of prescribed boundary points identified by points 1 to 13 in the flight path as shown in Figure 4.

The stability and control feed-back system on board the UAV would manipulate the control surfaces to provide just the correct incremental acceleration at each step to advance it towards the next point on the trajectory. The incremental acceleration as discussed by Park et al. is obtained from the relationship:

$$\alpha_{scmd} = 2\frac{V^2}{L_1}\mathrm{Sin}\,\eta$$

With reference to the Figure 5.

The incremental distance to next location on the point is repeated step by step until the antire trajectory is completed bring the UAV back to the point of the origin. This entire flight path can be repeated many times over to maintain the craft within the permissible airspace for the entire duration of the many days of flight.

Figure 6 shows the photograph of the SUN Falcon 2 during its augrational flight in May 2015. The model was first flown under battery power and the UAV remained airborne for at least 30 minutes. It was controlled to fly within a specified airspace. After at least 30 minutes of flight, the UAV was flown singularly under power scooped up from the sunlight. It was able to fly without difficulty from the reserved power.

Conclusion

Sun Falcon 2 has been designed from the lessons learnt from the successful designs of Sun Falcon 1. Suitable temperature models have been used to assess the functions of the solar cells and their inevitable impact on the power /unit area distribution and the weight estimates. Meticulous design procedures with fast turnaround times, were devised to arrive at the most optimum design for the multi day operation of the Sun Falcon 2. The flight of the prototype Sun Falcon 2 demonstrated the successful design strategies adopted for the continuous flight vehicles. The first tests albeit for short duration of time demonstrated that the UAV could operate from the power reservoir recovered from the recharging of batteries from the power cells. The first flights were accomplished at Tokai University, Japan where the energy recovery source from a maritime climate is not as supportive as the more appropriate Jeddah desert climate.

Acknowledgment

This project was funded by the Deanship of Scientific Research (DSR) King Abdulaziz University, Jeddah, under the grand No. (431/009), the authors, therefore, acknowledge with thanks DSR technical and financial support, furthermore the

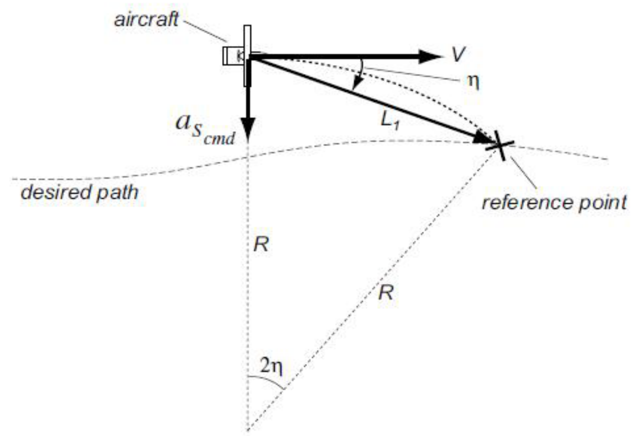

Figure 5: Trajectory incremental acceleration.

Figure 6: Sun Falcon 2 flight test.

authors would like to express their gratitude and appreciation to Tokai University for their technical help and support.

References

1. (2014) NASA Armstrong Fact Sheet. Solar Power Research.
2. Harasani W, Khalid , Arai N, Fakuda K, Hiroaka K (2014) Initial Design and Wing Aerodynamic Analysis of a Solar Powered UAV. The Aeronautical Journal.
3. Noth A, Siegwart R (2006) Design of Solar Powered Airplanes. Swiss Federal Institute of Technology.
4. Lyons CA, Boeren AP, Giguere P, Gopalarathnam A, Selig MS (1995) Summary of low speed airfoil data. University of Illionois at Urbana Champaign.
5. Park S, Deysr J, How P (2004) A New Nonlinear Guidance Logic for Trajectory Tracking AIAA - 4900.