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Design of Solar Powered UAV

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ABSTRACT

This paper summarizes the final project of undergraduate student of the faculty of Mechanical Engineering at the DTU, New Delhi, India. The project's aim is to design, build, test and fly a solar powered Unmanned Aerial Vehicle. Integrating solar energy into modern aircraft technology has been a topic of interest and has received a lot of attention from researchers over the last two decades. A few among the many potential applications of this technology are the possibility of continuous self-sustained flight for purposes such as information relay, surveillance and monitoring. The use of UAS is increasing rapidly due to the reduced production and operating cost compared to the large conventional aircraft.

Keywords: *Solar Powered UAV; Solar Panel Area; UAV; Design*.

1.0 Introduction

Possible applications of the Unmanned Aerial Vehicle (UAV) include military and classified surveillance flights communication links. Solar powered UAV can be employed in many of the above mentioned missions as it is capable of long endurance flight and does not require much maintenance.

The Solar Powered UAVs use an unlimited power source for propulsion and other electrical systems. Using Photovoltaic (PV) cells, solar radiation is converted into electric power and then converted into kinetic energy by the electric motor.

The main difficulty as for today is the low efficiency of both PV cells and motors. This paper presents the design of the Flare, a Solar Powered UAV where small aircrafts are difficult to be detected by radars. Scientific applications include ozone monitoring, and collection of data for weather and global warming studies. Commercial applications include aerial surveying, geological and topographical mapping.

Table 1: Weight Estimation

Component	Weight (In Grams)
Wing	1410
Fuselage	330
Tail Boom	80
Tail Servos	78
Aileron Servos	70
Tail Servos	40
Autopilot	270
System Battery	360
Electric Motors	245
Speed Controller	40
Propeller + Spinner	20
PV cells	760
Wiring	200
TOTAL	3903 gm
Approx.	4kg

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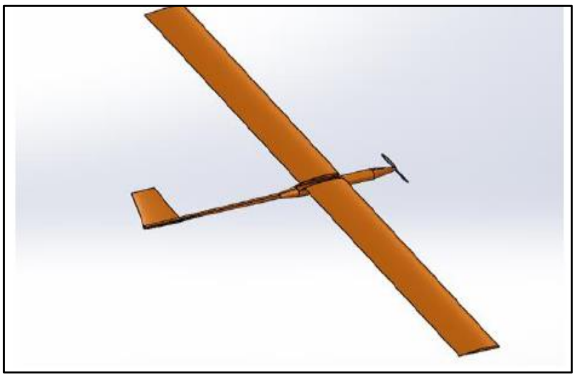
Fig 1: Solar Powered UAV



2.2 Airfoil selection

Airfoil Selection is one of the most crucial steps of aircraft designing. The desirable characteristics include high lift to drag ratio, low coefficient of moment and high stall angle. Different Low Reynolds number high lift airfoils were analysed in XFLR5 software and SD7032 was selected for high to drag ratio and high stall angle.

Fig 2: Coefficient of Lift Characteristics

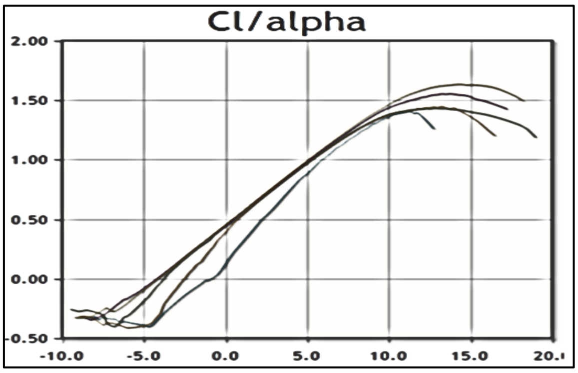


Fig 3: Coefficient of Drag Characteristics

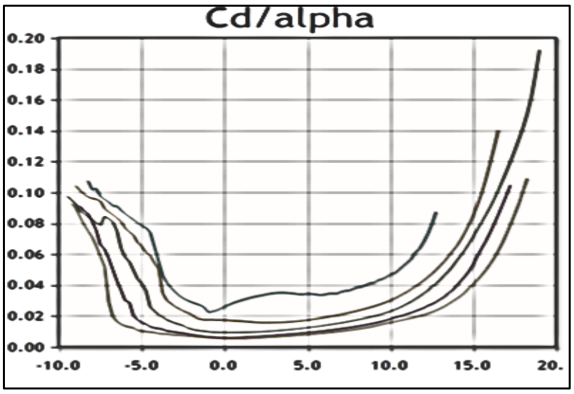
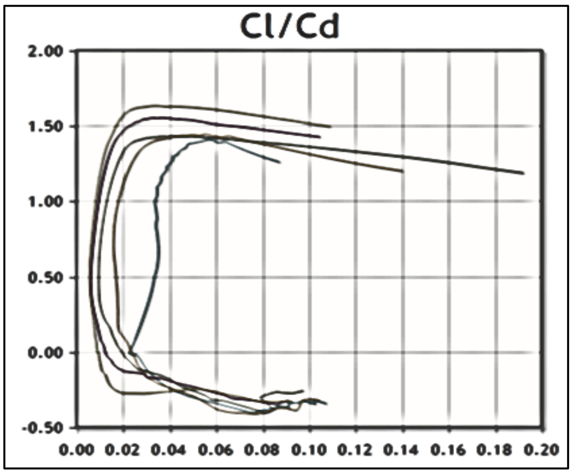


Fig 4: Coefficient of Lift and Drag Characteristics



2.3 Sizing of the plane

A GUI for calculating the dimensions of the UAV was made in MATLAB. The code takes airfoil parameters and design coefficients as its input and determines the dimensions of wing and tail based on standard sizing equations. The tail was calculated in a way to ensure that the derivative of coefficient of moment with respect to angle of attack is negative so that aircraft is longitudinally statically stable.

Fig 5: Spread Sheet

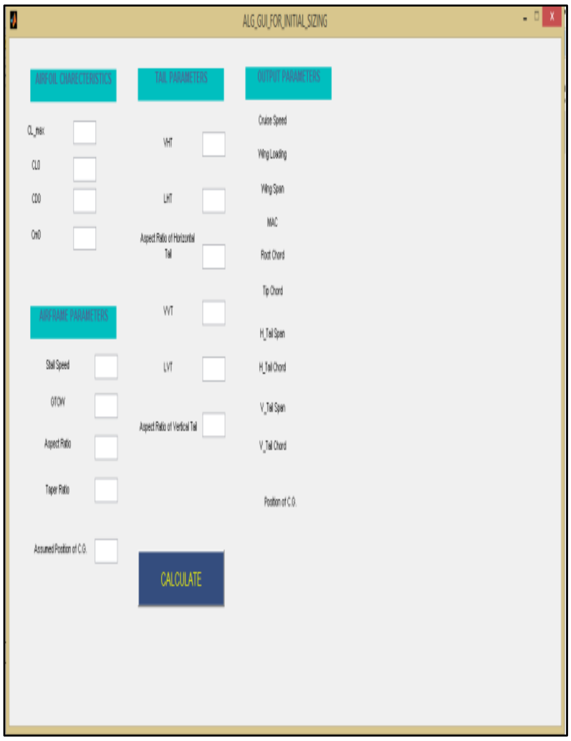


Table 2: The Final Dimensions

Parameter	Value
Maximum Take-Off weight	4 Kg
Length	2.4m
Wing Airfoil	SD7032
Aspect Ratio	13.20
Wing Area	1.34m2
Wing Dihedral	3.5o
Tail Airfoil	Naca0006

3.0 Power Calculations

3.1 Estimation of solar panel area

For the aircraft to be able to fly on any day of the year, it has to be designed on the coldest day of the year at a given location, which is defined by the latitude (/), and the common weather condition such as tropical, desert, or snow. The following procedure gives clear and straight forward methodology to estimate different parameters at given altitude and payload weight. The declination (d) is the angular position of the sun at solar noon with respect to the plane on the equator. The declination changes slightly each day and can be calculated using.

$$\partial = 23.45 \sin(360 \frac{284+n}{365}) \qquad (1)$$

The day of the year (n) has to be specified as part of a numeric sequence that starts with 1 for January 1st and 365 for December 31st. The hour angle of sunset (x) has to be estimated in order to evaluate the hours of sunlight for a given day. It is function of the latitude (/) and declination (d):

$$\omega_s = cos^{-1}(tan\emptyset * tan\partial) \qquad (2)$$

The exact hour angle of sunset can be taken as the answer obtained from Eq. (2), whereas the sunrise can be taken as the negative of the same answer. The collected energy, at each hour during the day per unit area at a certain location, changes dramatically with altitude. This is because near sea level there is a significant effect for the particulates and water vapor. On the other hand, at high altitudes, the cloud cover is negligible, thus there will be no daytime interruption of sun light.

For altitudes below 2.5 km, once the sunset hour angle has been found, the daily average total extraterrestrial irradiance (□□) availaible from the sun can be estimated using:

$$H_0 = \frac{24 \times 1367}{\pi}\left(1 + 0.033\, cos\frac{360n}{365}\right) * \left(cos\emptyset\, cos\partial\, sin\omega_s + \frac{\mu\omega_s}{180} sin\emptyset\, sin\partial\right) \qquad (3)$$

The total hours of the day can be found using:

$$N = \frac{2}{15} cos^{-1}(-tan\emptyset\, tan\partial) \qquad (4)$$

The average daily hours of bright sunshine (n) can be easily found from local weather stations. These data are based on Campell-Stokes instrument measurements. For this design, it was taken from India Meteorological Office

At the coldest month of the year in Delhi, this value is 7.4. Then, the monthly average daily radiation on a horizontal surface can be estimated using:

$$\frac{H}{H_0} = a + b\frac{n}{N} \qquad (5)$$

The above equation employs two empirical constants ‘a’ and ‘b’ which account for the local climate. A list of varies climates around the globe is given, from which the closest match was chosen for New Delhi. For New Delhi climate, a = 0.41, and b = 0.34. At each hour of the day (h), the instantaneous hour angle (x) can be estimated using

$$\omega = \frac{(15h - 180)\pi}{180} \qquad (6)$$

The hourly total radiation (I_b) per meter square at a certain hour, can be estimated using:

$$\frac{I_b}{H} = \frac{\pi}{24}(c + d\, cos\omega)\frac{cos\omega - cos\omega_s}{sinw_s \frac{\pi\omega_s}{180}} cos\omega_s \qquad (7)$$

The two constants in the above equation are given by:

$$c = 0.409 + 0.5016\sin(\omega_s - 60) \quad (8a)$$
$$d = 0.6609 - 0.4767\sin(\omega_s - 60) \quad (8b)$$

The radiation at each hour during the day has to be integrated to find the total energy from the sun in a day per meter squared.

$$\text{Calculated:} \quad I_b = 1181\frac{W}{m^2} \quad (9a)$$
$$\text{Experimental:} \quad I_b = 1117\frac{W}{m^2} \quad (9b)$$

3.2 Final results:

Estimated solar panel area = 1.1 m_2
Efficiency of solar array = 15%
Power Generated by Solar array ≅180 W

3.3 Electrical characteristics

At irradiance of 1000 W/m^2

Table 3: Power Used

Open circuit voltage	0.670V
Short circuit voltage	5.9A
Maximum power voltage	0.560V
Maximum Power Current	5.54A
Rated power	3.1W
Efficiency	20%
Temperature Coefficients	
Voltage	-1.9$\frac{mV}{°C}$
Power	-0.38$\frac{\%}{°C}$

3.4 Propulsion calculations:

3.4.1 Thrust and power requirement

Using the aerodynamic calculations and assuming a 4kg vehicle weight required thrust and power were calculated and then translated to Motor Input Required Power using motor, gearbox and propeller efficiencies.Minimum required power for cruise is 60 [W] at 8[m/s]. Maximum cruise velocity requires 75W

3.4.2 Propeller properties

The chosen propeller, a folder Aeronaut CAM, was selected using an electric propulsion system performance testing software, MotoCalc. After deciding on the belly landing concept a folding propeller was mandatory. Propeller diameters and pitches were checked for required thrust. The chosen propeller has a 15" diameter and 10" pitch.

3.4.3 Thrust required during level flight

Lift and Drag produced by vehicle at C_{al}=1.082 *and* C_{admax}=0.052 are summarized in table below:

$$Lift \quad : L = \frac{1}{2}\delta v^2 SC_{almax} \quad (8)$$
$$Drag \quad : D = \frac{1}{2}\delta v^2 SC_{admax} \quad (9)$$

Now, Thrust required by the aircraft is given by:

$$Thrust: \quad T = \frac{W}{\frac{L}{D}}$$
$$= 1.885\ \text{N} \cong 2\ N \quad (10)$$

3.4.4 Power for level flight

Power required by the aircraft is given by:

$$v_{cruise} = \sqrt{\frac{\frac{2W}{S}}{\partial C_{al}}} \quad (11)$$

$$P = Tv \quad (12)$$
$$Thrust: \ T = \frac{W}{\frac{C_l}{C_d}} \quad (13)$$
$$P = \frac{W^{\frac{3}{2}} * \sqrt{2AR} * C_d}{C_l^{\frac{3}{2}} * \sqrt{\partial S}} \quad (14)$$

Hence the total energy can be calculated by taking into account the efficiencies of the components as follows:

$$P_{elec_{total}} = \frac{1}{\eta_{(ctrl+motor+propeller+gearbox)}} P_{level} + \frac{1}{\eta_{tr}} (P_{av} + P_{pld}) \quad (15)$$

$$P_{elec_{total}} = 88\ W$$

So, to fly the aircraft we need minimum 90W power per hour.

Thrust Produced

$$T = \frac{\pi}{4} D^2 \partial v \Delta v \quad (16) \quad T = 14N$$

Propeller Efficiency

$$\eta_{prop} = 65\%$$

$$T_{act} = 0.65 * T \quad T_{act} = 8.8N$$

3.5 Power plant and solar array

The values of parameters have been given in the table 4 and table 5:

Fig 6: 15"x10" Propeller. Thrust Vs. Velocity

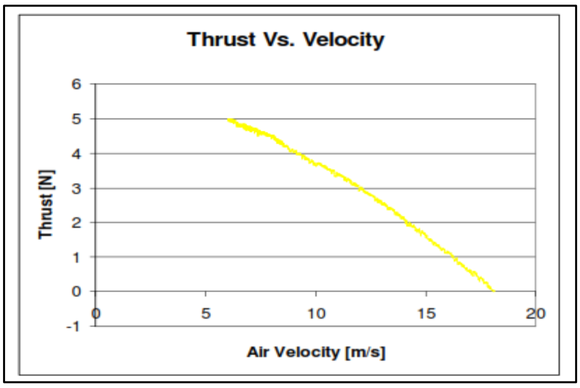


Table 4: Power Plant

Parameter	Value
Electric Motor	Hacker B50-13S
Speed Controller	Hacker X-30
Gear Ratio	6.7:1
Propeller	15"X10"

Table 5: Solar Array

Parameter	Value
PV's Area	1m2
PV's Efficiency	20%
PV's weight	0.76 Kg
PV's max power	160 W

3.7 Aircraft's final geometry

Fig 7: Aircraft Geometry

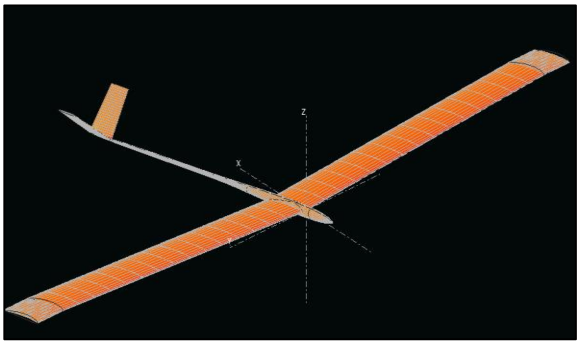


Fig 8: Aircraft Angular Variation

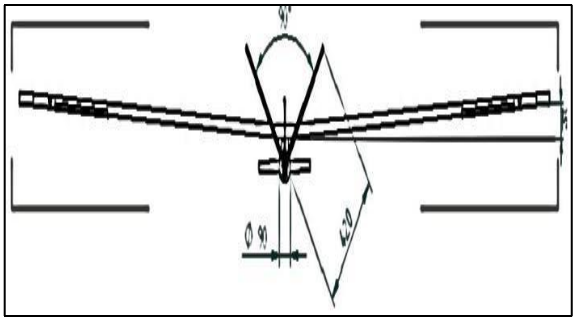


Fig 9: Aircraft Geometry for UAV

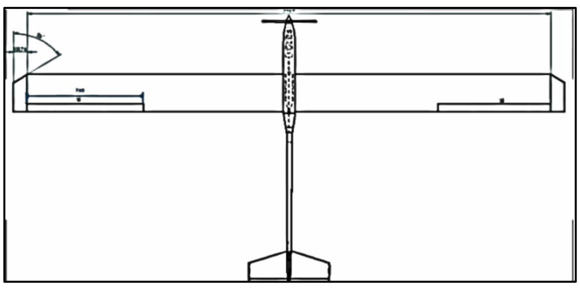
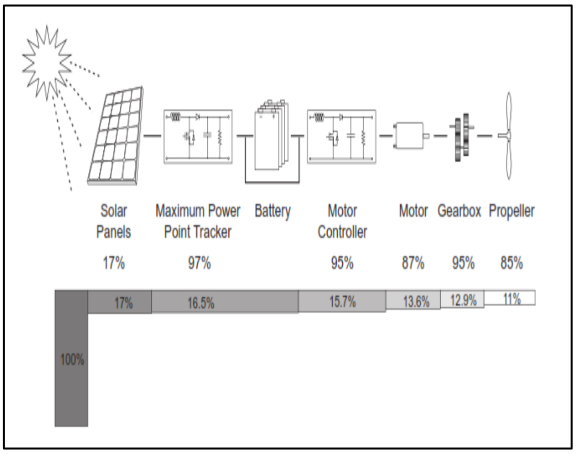


Fig 9: Line Diagram of Actual Working



3.8 Performance Parameters

Parameter	Value
Stall speed	6.6 m/s
Cruise Velocity	8 m/s
Take-Off Velocity	13 m/s
Power Required for Take-Off	80W
Max L/D	20.8
Aspect Ratio of Wing	13.2
Wing loading	28.98N/m2

4.0 Conclusions

This thesis presented a new methodology for the conceptual design of solar airplanes. It has the advantage to be very versatile and usable for a large range of dimension, from UAVs with less than one meter wingspan to manned airplanes. It is purely analytical and based on the concepts of energy and mass balances during one day using mathematical models that put the sizing of all elements on the airplane in relation. These models are used for efficiency or weight prediction and constitute a key part of such design method.

The methodology was used for the conceptual design of a prototype that would embed a small payload and with the objective to prove the feasibility of continuous flight on Earth. It also allowed emphasizing some general principles. For example, it was clearly demonstrated that the most limiting technology at this time is the energy storage. Even with the best lithium-ion batteries, the energy storage constitutes more than 40 % of the airplane's gross weight. For that reason, what is critical for a continuous solar flight is not the day that has to be the longest, but the night that has to be the shortest.

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Nomenclature

UAV – Unmanned Aerial Vehicle
MPPT – Maximum Power Point Tracker
AR – Aspect Ratio
AOA – Angle of Attack
C_l– Coefficient of lift
C_d– Coefficient of drag
C_m - Coefficient of momentum
b- Chord length
S- Wing surface area
P_{av}- Power consumed by avionics
$P_{electotal}$- Total electrical power needed by aircraft
P_{pld}- Power needed by payload
∂- Angle of declination
ω_s- Hour angle
H_0- Solar Irradiance
I_b- Hourly Total Radiation
T.O- Take Off
NACA- National Advisory Committee for Aeronautics
SD- Selig Donovan