R.V. College of Engineering, Bengaluru

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Department of Electrical and Electronics Engineering

8th Semester Technical Seminar Report on

Feasibility Study of Solar Powered Unmanned Arial Vehicles

Submitted by

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Feasibility Study of Solar Powered Unmanned Arial Vehicles

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***Abstract-* Unmanned Arial Vehicles (UAVs) are growing in relevance in the modern day. Their applications extend to crop monitoring, Surveying, Surveillance, reconnaissance, Search and Rescue and power line inspection to name a few. However, the most widespread form of UAV propulsion is using battery powered electric propulsion which gives limited endurance. Solar powered UAVs solve this problem of limited endurance since the sun act as a power source for a major part of the day. In this paper, different Solar UAVs developed prior are reviewed and its feasibility is discussed in the Indian context. In addition to this, the organization of the avionics and the fabrication processes are explored in brief. The budget breakdown and the challenges to the development are also discussed.**

Keywords- Solar Unmanned Arial Vehicles (UAVs) Feasibility Maximum Power Point Tracker (MPPT) Autopilot Pixhawk Power Calculations

I. Introduction

The UAV is short for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled aircraft i.e. flown by a pilot at a ground control station or can fly autonomously based on pre-programmed flight missions and other complex dynamic automation systems. UAVs are currently used for a number of missions, including reconnaissance and attack roles. A UAV is defined as being capable of controlled, sustained level flight and powered by a jet or reciprocating engine.. The acronym UAV has been expanded in some cases to UAVS (Unmanned Aircraft Vehicle System). The FAA has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other elements besides the actual air vehicles. Officially, the term 'Unmanned Aerial Vehicle' was changed to 'Unmanned Aircraft System' to reflect the fact that these complex systems include ground stations and other elements besides the actual air vehicles.

Unmanned Arial vehicles for civilian use generally make use of Lithium Polymer (Li-Po) batteries for the electric propulsion used in them. This severely limits the endurance of the UAV depending on the Battery capacity. Generally remote controlled aircraft flights last as long as 3 minutes to 1 hour at one stretch. In missions such as surveying vast stretches of land and Arial reconnaissance, minimal operator interference is advisable. However with limited endurance, the UAV has to be brought to ground to replenish power.

This procedure can be avoided by making use of solar cells as a power source to charge the batteries onboard. Earlier, solar cells were not feasible because of their low efficiencies and their fragile nature. However, with advances in modern day solar cell technology, solar cells with efficiencies as high as 21% and slight flexibilities are commercially available. These Solar cells can be integrated on surface of the Unmanned Arial Vehicles with limited difficulty and can serve as sources of power thus enabling UAVs to function for durations ranging from 6 hours to 1 day.

II. Methodology

A. Literature Review

Andre Noth [1] in his thesis provide a comprehensive overview of the design of Atlantik Solar. It was a 6.3Kg UAV capable of hand launch with a cruise velocity of 8.4 m/s. The wing span was 5.6m with 1.4 sq m available for solar panels. It was able to achieve 28 hours of day/Night flight without fuel

Further A Weiber Et al.[3] discussed about the first solar UAV Sunrise 1 which had a wingspan of 9.76m weighing 12.25 kg with 4096 cells giving a power output of 450W.The flight time was 3-4 hours

Xavier Mauclere[2] highlighted the process of optimization of the airfoils for the solar planes. Eun-Mi Kwon Et al.[12],Grant Wilkins[6] et al. brought out the design parameters to be considered while designing for a solar powered UAV.

T.V Ramachandra Et al.[4] provide the irradiation profile of Bangalore which helped in carrying out feasibility calculations.

Further, Scott Morton Et al. [10], proposed a short outlook into the design of solar UAVs. Every subsystem required for a solar plane was explained. Calculations for airframe design and propulsion parameters were conducted to verify the feasibility of the solar plane. The fabrication process for the solar plane and panel integration was also discussed. Further, the scheme of power conversion and electrical hardware were touched upon to give a comprehensive overview of the design of a solar plane. The main taking from this paper was that the design was able to pass experimental tests under various conditions for ex: the captured solar power was 300% of that required for the design, thus bringing out a robust design process for a solar UAV.

B.M Albaker [9], discussed about the architecture for a solar plane. For a UAV, especially a solar UAV, It is vital to know the health of the vehicle. In order to accomplish this it necessary to design a robust telemetry architecture and incorporate appropriate failsafe mechanisms. In [9] a model architecture for the same was extensively discussed.

Further Jaw-Kuen Shiau Et al.[7],Liu and Makaran[11] and Lee and Wolfs[5] discuss the structure of the maximum power point circuit for the solar cells.

B. *Description of Solar Cell*

Fig 1: Sunpower Maxeon Series Solar Cell

The Solar cell used to mount on top of curved surfaces should be flexible. Additionally, the cells should have high efficiency to reduce the surface area and weight of the solar panels. The best cells available in the market are the Sunpower Maxeon series of solar cells .The Specifications of the cell are as follows:

- Type – Monocrystalline
- Size - 5x5inch (125mm x 125mm)
- Efficiency - 21.8%
- Power - 3.34W
- Current (I_{mpp}) - 5.83A
- Voltage (U_{mpp}) - 0.574V
- Weight: 8 gram per cell
- Semi-flexible: up to 30 degrees

Further the Solar Cell is back connected which in turn allows more sunlight to incident per unit area. These cells are mounted on a suitable substrate and covered with an ETFE film to form solar panels. Overall efficiencies of about 18% can be obtained.

C. *UAV Fabrication and Panel Integration*

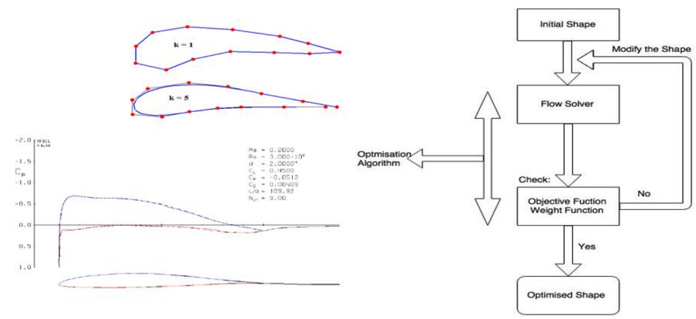


Fig.2: The Design Process for airfoil selection

The airfoil used for solar cells should have minimum camber. Though the cells are flexible, the performance of the cells are best when the natural shape is employed. In order to mount the cells in a straight fashion, the airfoil is optimized for minimum camber by setting lower bounds and upper bounds and running an optimization algorithm like Genetic Algorithm. The parameters are tested against a fitness function generated by evaluating the design in software packages like XFOIL or XFLR5. The design process is shown in Figure 2.The best generations are selected and can be further used. Alternatively airfoils of the Eppler Series can also be used for solar UAVs which can eliminate the before said procedure

Fig.3: Manufacturing Methods

The wings and tails of the plane are manufacture by using balsa wood with carbon fiber spars for additional strength. The airfoils are laser cut and placed along a carbon fiber rod. They covered by lightweight covering film like polypropylene or monokote .The use of Balsa contributes to making the plane lightweight. Carbon fiber landing gears can be prepared as they offer high strength to weight ratio. Figure 3 shows some of the manufacturing processes

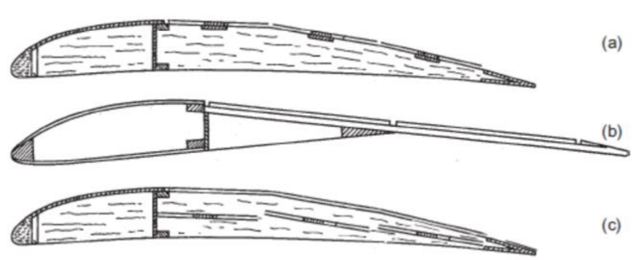


Fig 4: Solar Panel Mounting Methods

Slots are to made in the airfoil's upper surface with depth equal to thickness of the substrate upon which the panel is mounted, the solar cells and a covering film like ETFE as shown in Figure 4.This enables mounting the panel on the wings. Additionally airfoils can also be mounted on the fuse however, they tend to be inefficient in energy conversion. It is a common practice to utilize the wing and the tail for placement of solar panels.

D. Battery Management System-Structure and Arrangement

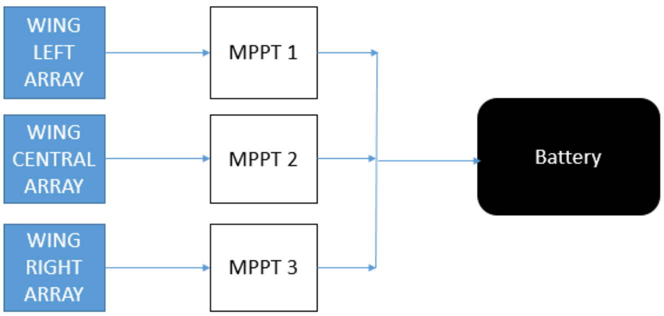


Fig 5: Arrangement of BMU

Figure 5 shows the proposed arrangement of the Battery Management unit on the plane. The use of separate MPPTs ensures that the solar charging system continues to function albeit at a lower capacity. It prevents complete system failure

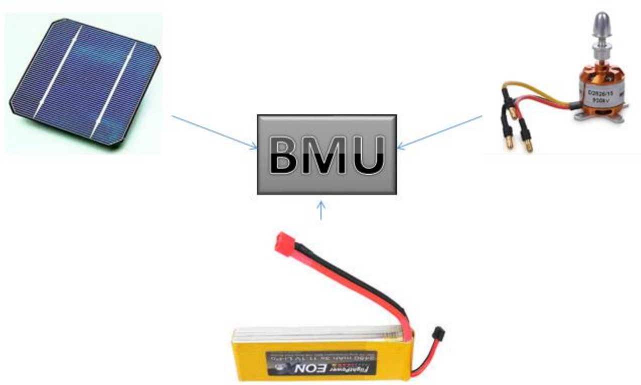


Fig 6: Arrangement of Power Systems

The Solar panel arrangement are connected directly to the Li-Po battery to charge them as shown in figure 6. The batteries are initially charged at constant current and then at constant voltage. In the presence of sunlight the panels function to charge the batteries. The terminals of the battery are connected to the ESC which drive the motor. The Li-Po must be operated within its charging and discharging curves

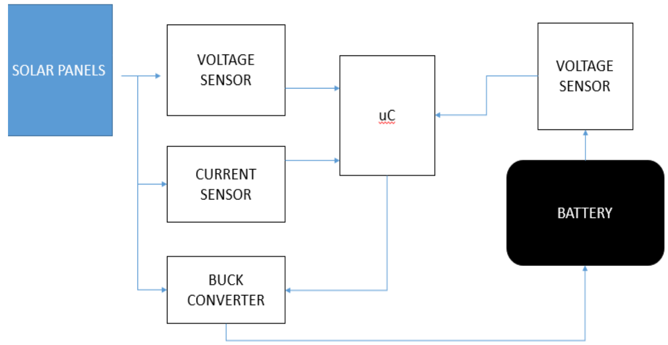


Fig 6: Structure of the MPPT Circuit

It is necessary to design the MPPT to extract maximum solar power from the panels and care is taken to see that it weighs as less as possible. Figure 6 shows the structure of an MPPT circuit. It consists of a DC-DC converter, voltage sensors, a current sensor and a microcontroller .The perturb and observe algorithm can be used to track the maximum power point. This makes use of the product of the voltage and current and compares with the previous value of product. Depending on the magnitude the duty cycle to the buck converter is varied by the microcontroller. High switching frequencies can be used to minimize losses and reduce the size of the circuit elements thus reducing weight of the MPPT .Alternatively, Linear Technology IC LT3652 as shown in figure 7 can be used to build a solar Li-Po battery charger which can accept input voltages of less than 40V from the solar panels and charge batteries of upto 4 cells at a constant rate of 2A.To increase the charging current multiple IC's can be connected in parallel. Slits can be made in the fuse to cool the avionics as the airflow is found enough to act as a coolant.

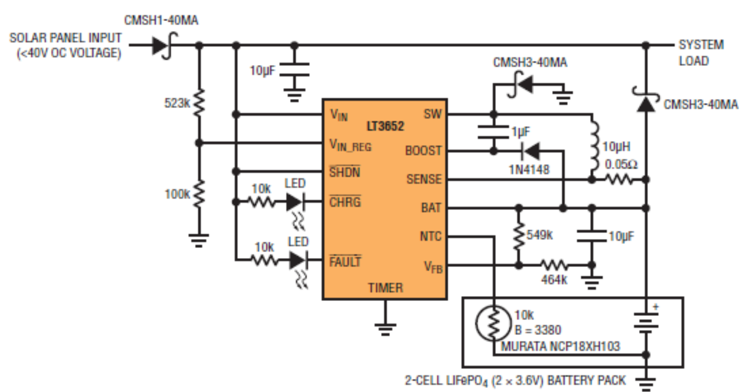


Figure 7: The Li-Po Battery Charger using LT 3652

E. Autonomous Capabilities

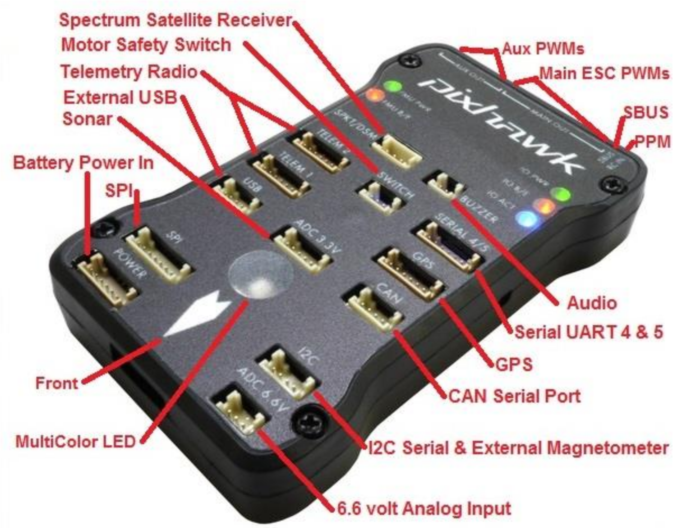


Fig 8:The Pixhawk Module

The Pixhawk platform is an autopilot system for unmanned Arial vehicles. The use of the autopilot provides stable flight in manual mode of operation. In the autonomous mode of operation, the operator involvement is minimal and the UAV can continuously monitor an area without any intervention.
The Pixhawk has 168 MHz Cortex M4F CPU (256 KB RAM, 2 MBFlash) and sensors like 3D Accelerometer / Gyroscope / Magnetometer / Barometer.It has Integrated backup, override and failsafe processor with mixing along with a MicroSD slot, 5 UARTs, CAN, I2C, SPI and ADC,.
The following Autonomous modes of operation of the solar UAV using Pixhawk can be achieved

- RTL: Return to launch i.e. hover around the home GPS location
- Loiter: Hover around the respective coordinate
- Mission: Navigation consisting of a set of waypoints

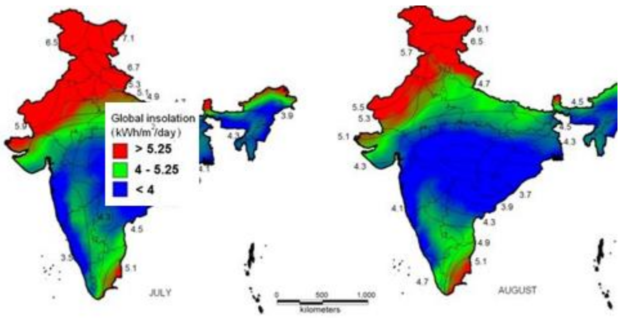
Any deviations from the required behaviour of the system like a higher battery discharge rate than charging rate can be detected using a simple comparator circuit connected to the Pixhawk analog read. Also, necessary action (like RTL, glide, land etc) can be programmed to the Pixhawk when the following fails might occur:

- Loss of GPS signal
- Low battery
- Loss of ground station communication

As the flight is in constant communication with the ground station, any fails or errors are be known immediately.

III. FEASIBILTY STUDIES

A. Power Calculations



Power input P_i		Maximum power output P_o		Actual on-site power output	
kWh/m²/day	W/m²	η=16%	η=20%	η=16%	η=20%
4	571	91	114	62	77
4.5	643	103	129	69	87
5	714	114	143	77	96

Fig 9: Irradiance profile [4]

The Irradiance is considered for the month of July. For the sake of calculations let Bangalore be considered. The least irradiance (avg.) – 4.5 kWh/m²/day gives 69 W/m² (@16% efficiency). This gives a output power of approximately 35 W.

For a wing area of about 0.7 m^2 and a 0.5 m^2 panel area from literature survey and previous experience designing UAVs the approximate weight is 2.5 kg. We have

$$P_{lev} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2ARg^3}{\rho}} \frac{m^{3/2}}{b}$$

The power required for level flight of this plane is 9.42W. Considering a rough reduction in efficiency of the propulsion system, about 14.2W is required. Adding power consumption of avionics gives a requirement of about 18W which is well within expected input of 35 W. Hence, it is possible to have pure solar powered flight.

B. Budget Breakdown

Tables 1 and 2 show the cost manufacturing and the cost of the solar cells. The cost of manufacturing does not take into account the addition costs incurred for reparation and restoration during manufacturing. The same is the case with Solar panel units since they involve handling and breakage costs which are unpredictable. Hence the cost of RS 31000 + 500*Number of Cells is the cost for the best case scenario.

Manufacturing

Particulars	Amount(Rs.)
Raw Material	12,000 – 14,000
Manufacturing Processes	8,000 - 10,000
Misc (Adhesives, Control mechs etc)	5,000
Total	27,000 – 31,000

Solar Panel Unit

Particulars	Amount(Rs.)
Panels	500 per cell
Installation and Integration and Handling	-

Tables 1:Manufacturing Costs and Table 2:Solar Panel Costs

Table 3 illustrates the cost of the avionic components.The avioncs are pretty much fixed and employed only after the design has been deemed airworthy.Hence the cost of avionics is mostly one time .

Thus the total cost of fabricating a fully functional Solar UAV can cometo about a sum of Rs 1,00,000 (1500$) in the best possible case.

Avionics

Particulars	Amount (Rs.)
Motor	5,000 – 8,000
ESC	8,000
Battery(40% off)	4,500 – 6,000
Propeller	400 – 800
Servos	5,000 – 6,000
MPPT and BMU	5,000
Pixhawk	16,000
Telemetry Unit	6,000
Misc Electronics	1,000
Total	51,000- 55,500

Table 3: Cost of Avionics

IV. Conclusion

In this paper, the feasibility of practical implementation of a solar UAV in the Indian context was discussed. It was seen that the UAV can be easily implemented with the current technological advances with a minimum budget as mentioned in the previous section. A solar powered UAV will serve to be a boon in situations like disaster response where the plane may have to cover large areas for long periods of time. With customizable payload the applications are manifold. Further, development of Solar UAVs serves as a means of research into vehicles incorporating clean energy.

However there exist various challenges to during the process of development. The involvement of high grade solar panels leads to the issue of cost escalation because breakage during handling. The integration of panels onto the wings is further a challenging process which uses manufacturing not commonly available. In addition to this, the electronics going onboard the plane must be as compact as possible to reduce the weight of avionics. Cooling methods must also be employed to reduce temperature and avoid failure of the onboard electronics due to continuous use. These challenges are not major obstacles but they escalate the difficulty of implementation of the project.

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