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Feasibility Study of Solar Powered Unmanned Aerial Vehicle

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***Abstract*— High Altitude Long Endurance Unmanned Aerial Vehicles (HALE UAVs) could provide an improved service and/or flexibility at a reduced cost over existing systems for a vast number of civil patrol and surveillance applications. This document looks into the Feasibility and Conceptual Design of Solar Powered UAV for HALE applications. It mentions the advancements in technology of the components required to build an efficient solar powered UAV. It also provides a preliminary design methodology that can be adopted for the conceptual design of Solar Powered UAV. It also emphasizes the Aerodynamic difficulties that are faced in HALE configurations.**

Keywords—Design; HALE; Solar; UAV.

I. Introduction

Development of UAVs (Unmanned aerial vehicle) is one of the biggest boons to be introduced in the field of Aeronautics. Today, majority of the nations are developing and utilizing UAVs for various purposes.

Although these UAVs provide tremendous benefits, they fall short on performance due to their power restrictions. Hence for eternal flight conventional jet engines or IC engines cannot be used. If they are used for long duration missions such as for surveillance then they will have to carry a large amount of fuel that causes a drastic increase in weight and also the economy. Hence there is a necessity to design an air vehicle that can fly perpetually. To overcome this obstacle, use of solar power comes into picture.

With the implementation of solar cells, the UAV would be able to collect and store solar energy to be used for night time flight, and thus do not have to return for refueling or recharging. Thin- film solar cells have become vital for the endurance of HALE UAVs within the past decade. The major design aspect of a HALE UAV would be its ceiling altitude; it is vital for a HALE UAV to climb to a higher altitude to take advantage of the high amounts of solar radiation [4].

Electric motors powered by the electric power obtained from the solar panels will help keep the aircraft in the air during the day. The excess power generated during the day will be stored with the help of rechargeable batteries which will be used to fly the aircraft at night. Hence using a solar powered UAV we can fly longer than any conventional aircraft at present.

II. Objective

Communication is an important aspect in today's world, especially in the battlefield. A low altitude military satellite passes their intended focus area quickly, leaving the ground support with a smaller working window. If a HALE Solar powered Unmanned Aerial Vehicle (SPUAV) were to be implemented to be able to stay in a single location, it would dramatically increase the communication resolution. In order for a military UAV to exhibit complete dominance of the sky, it must have the endurance abilities of a solar HALE UAV.

A. *Mission Requirements*

The requirements of the HALE SPUAV shall be (but not limited) to the following:

- Stay aloft for 72 hours (3 days) minimum.
- Reach a maximum altitude of 21km during day time.
- Reach a minimum altitude of 17km during night time.
- Cruise speed of 40 m/s.
- Self-sustainable by solar energy
- Provide autonomous flight.

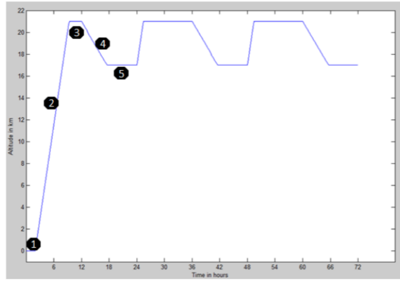


Fig. 1 Mission Profile

The Mission Profile as shown in the figure is as follows:-

1. Take-off.
2. Climb to an altitude of 21 km.
3. Day- time cruise at 21 km.
4. Descent to an altitude of 17 km.
5. Night-time cruise at 17 km.

III. SOLAR CELLS

A. Solar Radiation

Solar Radiation is radiation emitted energy by the Sun onto a given surface, like the Earth. The first solar cell was invented in 1954, and was a Silicon Photovoltaic (PV) cell. The efficiency of solar cells ranges from 18% - 40%. As performances of the cell increased, the prices decreased.

The average amount of solar radiation received at the edge of the Earth's atmosphere is approximately 12.8kW/m^2. This is reduced by almost 50% due to the Earth's atmosphere.

B. Solar Panel

Solar cells are usually made from semiconductors. Silicon is the material most commonly used, although it is very expensive. Owing to today's advancement in technology, solar cells are very light, and highly efficient.

Current solar cells are up to 45% efficient. There have been a lot of advancements in solar cell technology.

Specifications	
Standard Test Conditions	1000 W/m^2
Incident Radiation	25ºC
Open Circuit Voltage	0.67V
Short Circuit Current	5.9A
Maximum Power Voltage	0.56V
Maximum Power Current	5.54A
Rated Power	3.1W
Efficiency	21.5%

IV. PAYLOAD

The major module is the communication payload, which is made up of transponders. Transponder is capable of amplifying received radio signals, Sorting the input signals and directing the output signals through input/output signal multiplexers to the proper downlink antennas for retransmission to earth satellite receiving stations (antennas). The attributes of this is low cost, high capacity, exceptional coverage & reliability.

V. CONCEPTUAL DESIGN OF THE HALE UAV

As shown in Fig 1, the aircraft cycles every day between a cruising altitude of 17 km at night and 21 km at day to reduce the energy stored for the night flight. The initial UAV conceptual design is based on the method laid down for powered sail planes [1]. This method gives us the weights of the various sub systems of the UAV, which are, Payload, Avionics Solar Panel, Battery, Motor, Structure.

To obtain a better estimate of the weight distribution, we need to take into account the aerodynamic requirements of the solar powered UAV. Therefore, a method was developed to estimate the Profile Drag, Induced Drag and L/D at given Cl for different values of Aspect Ratio. Also, the variation of weight with aspect ratio of the aircraft is plotted. Using these we can obtain a much more detailed design of the solar powered UAV.

In order to provide the designer with a range of design variables to adapt for a specific design, new plots were plotted for the different design variables. The design variables considered are,

Power to Weight Ratio of the Aircraft.
Velocity.
Lift to Drag Ratio.
Energy Density of the Battery.
Power Density of the Solar Panel.
Battery Back-up Time.

The code was run for the following design values [1], and the result was obtained as follows

Payload Weight = 50 kg

Avionics Weight = 25 kg

Cruise Velocity = 40 m/s

Lift to drag ratio = 35

Battery Backup time = 8 hours

Energy density of the battery = 400 W-hr/kg

Solar Panel Power to Area Ratio = 150 W/m2

Weight per unit area of the Solar panel = 1 kg/m2

Power to weight ratio of the electric motor = 0.9 BHP/kg

The Estimated total weight of the aircraft assuming the aircraft to be a powered sail plane = 633.6 kg
The Estimated Power to Weight ratio of the aircraft required for cruise = 11.2 W/kg
The Estimated Area of Solar Panel required = 115.3 m^2

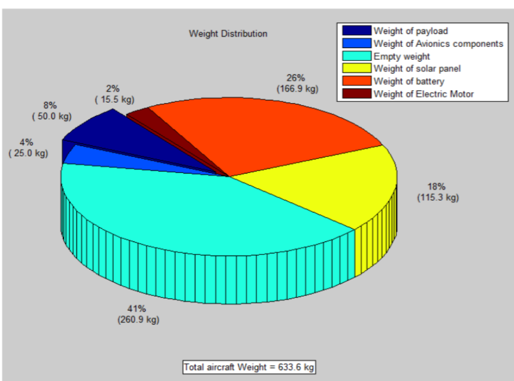


Fig. 2 Weight Distribution [1]

A. Weight Build up based on Aerodynamic Considerations

In the second iteration procedure, variation of Weight in accordance to Aspect Ratio is obtained.
For a constant value of C_l and Aspect Ratio, the drag estimate for tail, fuselage and wing is obtained based on the formulae [1]. Also, the Oswald Efficiency Factor (e) is obtained using the Shevell's Method. The Induced Drag, and hence the Total Drag can now be estimated. Further the required Lift to Drag Ratio and hence the Power to Weight Ratio of the aircraft is calculated. Using this, the total power required and hence the area of the solar panel is obtained. Finally we calculate the wing weight, battery weight, solar panel weight and motor weight.

This procedure is repeated for different aspect ratios; therefore we get the variation of weight of the components with aspect ratio. The corresponding codes are executed using .
Density at 21km altitude = 0.0842 kg/m3.
Dynamic viscosity co-efficient at 21km altitude = 1.6016e-05 kg/m-s.
Fuselage interference factor (q) = 1.
Thickness to chord ratio of wing = 0.15.
Position where t/c is maximum of wing = 0.3

Thickness to chord ratio of tail = 0.12.
Position where t/c is maximum of tail = 0.3
Chord of the tail = 2 m.
Span of tail = 5 m
Load factor = 3.
Taper ratio for wing = 0.45
Leading edge of the wing = 0 deg.
Length of the fuselage = 10 m.
Fuselage diameter = 0.75 m
Planform efficiency (u) = 0.99 usually $0.98<u<1$
Specific heat constant for air = 1.4.
Universal gas constant (R) = 287J/kg-K.
Temperature at 21 km altitude = 231 K.

B. Solar Powered UAV Performance Charts

Upto this point we have considered fixed values of battery energy density, solar panel power density, battery back-up time and aircraft power to weight ratio and lift to drag ratio. Now let us consider these parameters to vary within a specified range. Corresponding to these varying values the payload weight fraction is obtained. Hence the designer will be able to choose from a wide range of design parameters which best suits the mission.

This plot fig 8 gives the variation of Lift to Drag with Cruise Power to Weight Ratio for different Values of Velocity. A limit of 40 is mentioned for Lift to Drag ratio as it is difficult to design an aircraft with such high Aerodynamic efficiency. From the graph we can see that as Power to weight ratio of the aircraft increases for a given cruise velocity the L/D required decreases. Also as Velocity increases the Power to weight ratio increases if a fixed L/D is maintained.

The grpah fig 9 gives the variation payload weight fraction with Power to Weight ratio of the aircraft for different values battery energy density. As the battery energy density increases the Payload Weight fraction also increases for given value of Power to Weight ratio of the aircraft. Also it can be seen that the Payload Weight fraction increases with decrease in the Cruise Power to Weight ratio of the aircraft. However Decrease in Cruise Power to weight ratio will result in an increase in the Lift to Drag ratio.

The mission feasibility limit is set to 5% because it is not beneficial to conduct a mission in which the payload weight fraction is less than 5%.

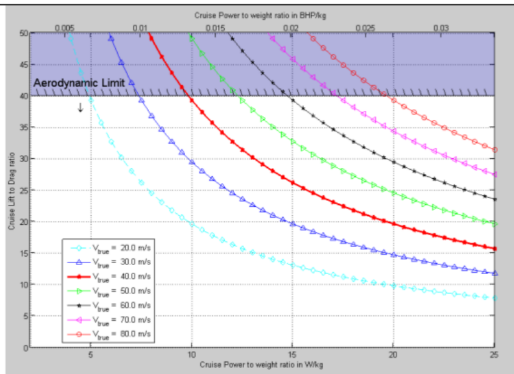
The plot fig 10 enables the designer to increase the battery backup time and determine the power to weight ratio required to maintain the same Payload Weight fraction. It is observed that as the Back-up time is increased the Cruise Power to Weight ratio required also increases to maintain a constant Payload Weight fraction.

Backup time atleast 6 hours is needed. Less than that is not of much use also P/W is less than 5 is not beneficial for the designs. Since low P/W results in less payload fraction weight.

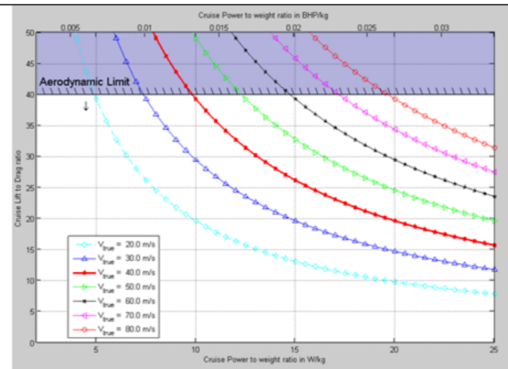
The plot shows the variation of Payload Weight fraction with the Solar Panel Power Density for different values of Cruise Power to Weight ratio. As the Power density of the Solar Panel increases the Payload Weight fraction increases for a given value of Cruise Power to Weight ratio. By increasing the Solar Panel Power Density and by increasing the Cruise Power to Weight ratio of the aircraft a constant value of Payload Weight fraction can be obtained.
Poor density of battery below 150 is not desirable as efficiency decreases.

B. Refined Weight Distribution

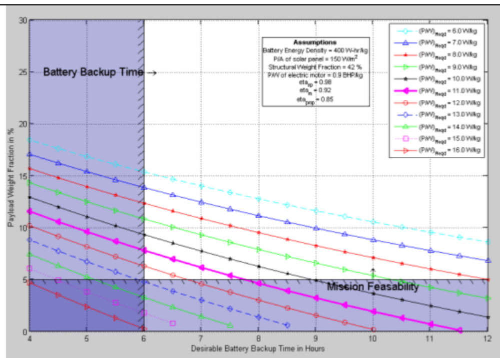
Based on the design steps performed and the Design variables obtained the final weight distribution is plotted. From the performance charts best suited values are used to get a redefined weight break up.



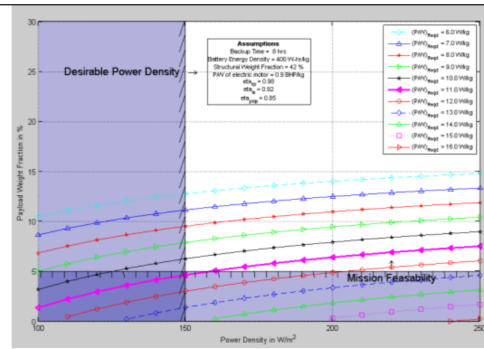
Plot Fig.1 Cruise P/W of aircraft vs L/D for different Cruise Velocities



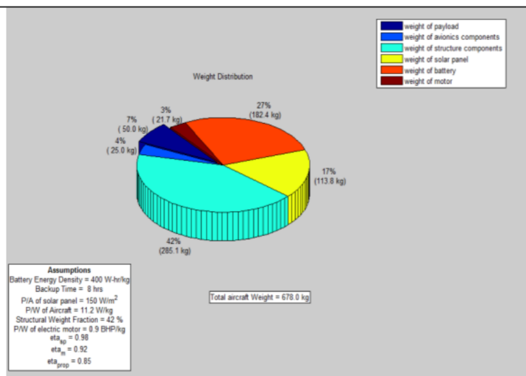
Plot Fig.2 Cruise P/W vs Payload Weight fraction for different Battery Energy Densities



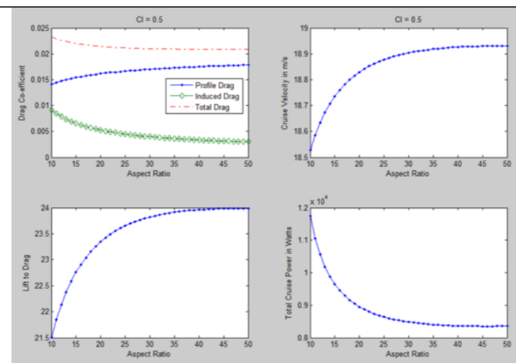
Plot Fig.3 Battery Back-up time vs Payload Weight fraction for different Cruise P/W



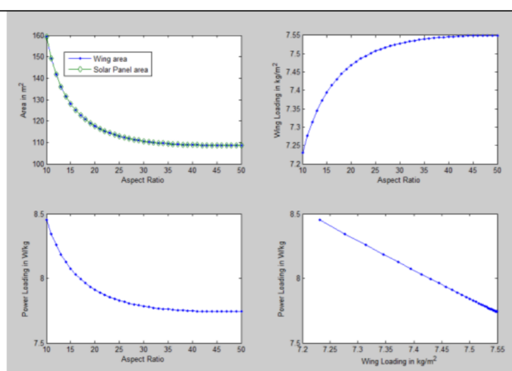
Plot Fig.4 Solar Panel Power Density vs Payload Weight fraction for different Cruise P/W



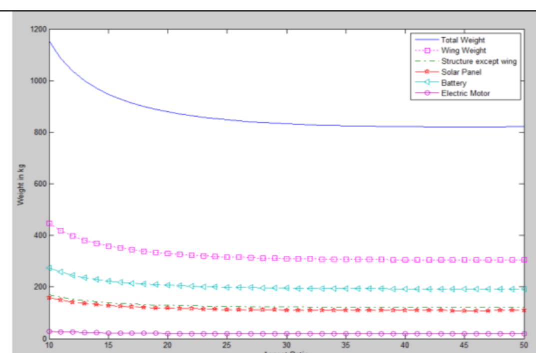
Plot Fig.5 Weight Break-up with the new Configuration



Plot Fig.6 Aerodynamic Coefficients



Plot Fig.7 Area, Wing loading and Power loading variation



Plot Fig.8 Variation of the Sub-System weights with respect to aspect ratio

Table 1: Details of UAV

Variables	Minimum Value	Maximum Value	Unit	Comment
Velocity	10	50	m/s	As velocity increases, L/D must also increase such that the ratio (V/(L/D)) is less than 1.35.
L/D	10	40	-	
P/W (of motor)	0.7	1.1	W/kg	From data of electric motors.
P/A (of solar panel)	150	250	W/m^2	Higher values of Power Density are not affordable.
W/A (of solar panel)	0.6	1.2	Kg/m^2	Currently available and affordable.
Back up Time	6	10	Hrs	Back up time to power the payload and avionics at night and also for a few hours of cruise.
Energy Density of the Battery	130	400	W-hr/kg	Higher energy density is more desirable if lower values of P/A and more power is required.

VI. CONCLUSION

The study emphasizes on the importance of choosing a right value of Cruise Power to Weight ratio of the aircraft (P/W = V*g/(L/D)). The Power to Weight ratio the aircraft is dependent on the Cruise Velocity and Lift to drag ratio. It is seen that a Power to Weight ratio of 15 W/kg or less has to be chosen. To achieve this low value of P/W ratio the Lift to drag ratio required is high, approx 30. For such high values of L/D the aspect ratio of the wing required is also high. This poses a problem from the structural point of view.

Higher L/D also means that the aircraft can cruise at low velocities of around 25 m/s. This in turn reduces the power needed to be produced by the motor for cruising and hence reduces the power needed to be generated by the solar Panel due to which the area of the solar panel required also reduces. Hence at higher aspect ratios the Total weight of the mission decreases.

The study also speaks about the importance of high energy density batteries. Battery is the only power source during night for sustaining flight and to provide power to the avionics and payload. High energy density batteries store more energy per kg of the battery. Hence higher the battery energy density more power will be available during the night for the aircraft if some maneuvers need to be performed. It also means that lesser weight of the battery is needed to store the same amount of energy needed for the mission. The Solar Powered UAV is beneficial for high altitude long endurance (HALE) missions. With the current technology it is difficult to achieve an efficient Solar Powered UAV. But with advancement in Solar Panel and Battery technology highly efficient UAV's can be built.

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