# Design, Build & Fly a Solar Powered Aircraft

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## Introduction

Development of manned and unmanned solar powered aircraft has attracted attention of several agencies over the past decade because of their promising potential in military and civilian applications. The most noteworthy examples are Dr. Paul MacCready's *Solar Challenger* [1, 2], that covered the English Channel on July 7th, 1981 on solar power alone, and NASA's *Helios* [3], which currently established a new altitude record of 96,500 ft and is seen as a possible alternative to communication satellites. A student project to 'Design, Build and Fly' a fully solar powered miniature aircraft at the Department of Aerospace Engineering can be challenging and can inject an awareness of this alternate source of energy among the students.

## The Design Problem

Top-level design problem, and constraints within which it has to be solved, is posed as follows. IIT Bombay has no experience or information regarding the design and manufacturing of a solar powered aircraft, hence the project aim is very modest. Project aim is to achieve sustained, controlled flight or hop of a Radio Controlled (R/C) model aircraft using only solar energy. No particular mission or flight profile is prescribed. No onboard energy storage is planned and hence the aircraft need fly only on a bright sunlit day.

Project will be termed a success only if the model is designed, built and flown within a 2-semester period extending from August 2001 to March 2002. Financial resources allocated for the project are Rs 30,000. The procurement process at IIT takes 45 to 60

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days for overseas purchase of items that are commercially (not requiring any clearances) available.

## Design Process

Because solar cells are to be used as the only source of energy, it was imperative that the model be electric powered. A rough estimate of the targeted size of the aircraft is required at this early stage of design. Large size of the aircraft translates into a higher weight and power requirement, which leads to an increase in the number of solar cells required and hence the cost of the project. Choice was thus on the smallest size. Micro Air Vehicle (MAV) sized aircraft is not feasible because the required micro hardware is costly and not easily available, and also the design data available within the department of Aerospace Engineering, IIT Bombay do not address these tiny sizes. A quick survey of commercially available miniature servos, electric motors and receivers revealed the weight, size, power requirements, cost and other specification of these components. Another search for R/C models that use these components led to Electric Slow-flyer aircraft. These R/C models have following broad specifications [4],

- Wing span of 0.5 m to1.0 m
- Weight: 100 gm to 150 gm
- Power requirement of 4 - 8 Watt
- Three channel control: One each for elevator and rudder control through servos (roll control is achieved through the rudder.) The third channel is for throttle control through an electronic speed controller.

The above data on electric slow flyer forms a base line design.

The hardware to be used for propulsion and control is mainly based on the R/C models supplied by WES Technik. The individual components are listed in the appendix and a detailed specification of each is available from the manufacturer [4]. The power requirements and weights of the components are given in Table 1.

## Solar Power for the Model

Use of solar energy as an alternative to fossil fuels has been widely studied for applications ranging from household appliances to aircraft. A single solar cell gives a voltage of 0.4 V to 0.5 V and several cells can be connected to make a photovoltaic (PV) module fulfilling the desired power requirement. Si based solar cells are the most popular and are available in three types: Amorphous, Polycrystalline and Mono-crystalline, with mono-crystalline cells being the most efficient with efficiencies of 12% to 25%. From typical commercially available solar cells, a rough estimate of the solar panel weight and power output is as follows [5],

- Area = 100 $cm^2$
- Wattage = 1 Watt
- Weight = 10 gm

Power requirement of 4.9 Watts thus requires solar cells area of 490 $cm^2$. and would weigh 49.0 gm. This assumes bright day with overhead sun and without cloud cover.

| **Component** | **Voltage (V)** | **Current (A)** | **Power (W)** | **Weight (gm)** |
|---|---|---|---|---|
| *Controls Unit* | | | | |
| Servo | 5 | 0.1 | 0.5 | 3 |
| | 5 | 0.1 | 0.5 | 3 |
| Speed controller | 7 | 0.05 | 0.35 | 1.9 |
| Receiver | 5 | 0.05 | 0.25 | 4.3 |
| *Propulsion Unit* | | | | |
| Motor and Gear | 6 | 0.55 | 3.3 | 14.2 |
| Propeller | | | | 3.4 |
| **Total** | | | **4.9** | **29.8** |

Table 1: Power break-up and weights for the hardware components

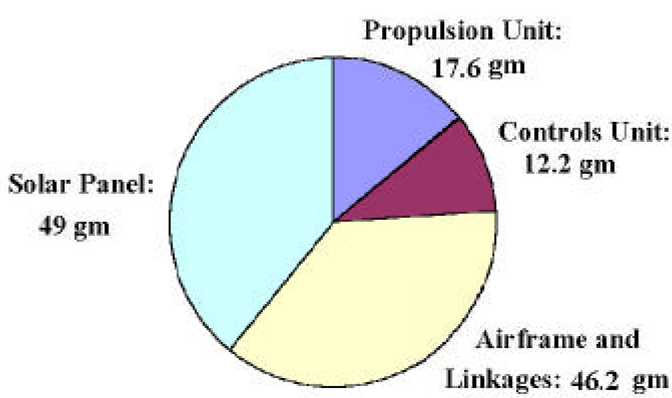


Figure 1: Weight break-up for the aircraft.

It can be seen from Table 1 that the hardware components for controls group weighs 12.2 gms and propulsion group weighs 17.6 gms; and both together weigh 29.8 gms. If an all up weight of 125 gms is targeted (this is the average weight of electric slow flyer aircraft) then airframe should weigh around 46.2 gms (= 125 – 29.8 - 49.0). Figure 1 gives the weight break up.

**Wing Design**

Wing loading of successfully flown R/C aircraft, $W/S_W$ = 0.183 gm/cm$^2$ = 6 oz/ft$^2$, was taken as a ballpark figure [4]. For a weight, W = 125 gm, the wing area, $S_W$ = 700 cm$^2$. Wing is the preferred location for mounting solar cells as it offers the flattest and contiguous surface and is naturally exposed to sun during normal flying condition. 500 cm$^2$ area of the wing should be as flat as possible to receive the solar cells. Several iterations later a wing layout at Figure 2 is arrived at. Note the 50 cm mid span area aft of front spar reserved for solar cells. Commercially available models have a full-length dihedral, which cannot be provided here because the central portion of the wing must be flat for the solar cells to get uniform sunlight. Wing tips over the last 16 cm are given a dihedral of 18.3 degrees (dihedral stability is essential for this model since lateral control is through rudder). The proposed wing has an Aspect Ratio of 7.

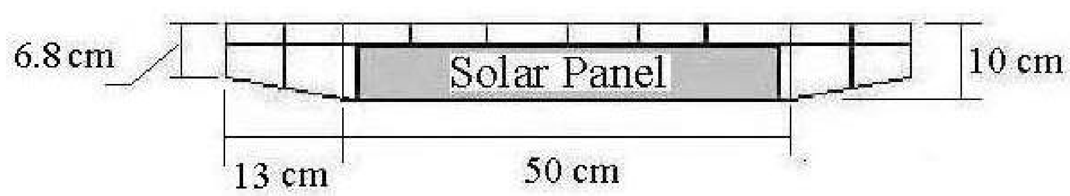


Figure 2: Proposed wing layout.

Wing has following specifications,

| | | |
|---|---|---|
| Span | = | 76 cm |
| Spanwise extent of constant chord | = | 50 cm |
| Constant chord | = | 10 cm |
| Tip chord | = | 6.8 cm |
| Dihedral angle of the tip | = | 18.3 $^o$ |
| Wing area, $S_W$ | = | 700 cm$^2$ |
| Aspect Ratio | = | 7 |

The wing has a box type construction consisting of ribs and spars covered by a thin Mylar skin. The flight speed for the aircraft is expected to be in the range of 2 to 5.4 m/s (for $C_L$ of 0.1 to 0.8). The Reynolds number range corresponding to this is 13,700 to 37,000. At low Reynolds number such as this, a curved plate with a sharp leading edge gives a better aerodynamic performance than normally used airfoil shapes [6, 7]. Presently, data of "8.7 % Gewolbren Platte" is available from literature [8] and hence it is decided to make the airfoil according to that contour. Figure 3 shows a proposed rib that will decide the shape of proposed single surface airfoil.


Figure 3: Proposed rib section.

**Empennage Sizing**

The tail surface area and tail moment arm are estimated using empirical relations, given by Andy Lennon [9], for typical R/C model aircraft. Recommended horizontal tail area, $S_{HTA} = 0.17\ S_W = 0.17 \times 700 = 119\ cm^2$. Tail moment arm, $L_{MA} = 31.76$ cm. The elevator area is taken as 0.40 $S_{HTA}$. Vertical tail area, $S_{VTA} = 0.08\ S_W = 0.08 \times 700 = 56\ cm^2$. Rudder area is taken as 0.35 $S_{VTA}$.

| **Horizontal Tail** | | **Vertical Tail** | |
|---|---|---|---|
| Area | 119 $cm^2$ | Area | 56 $cm^2$ |
| Span | 19 cm | Height | 9.5 cm |
| Root Chord | 6.8 cm | Root Chord | 6.8 cm |
| Tip Chord | 5.8 cm | Tip Chord | 5 cm |
| Aspect Ratio | 3 | Aspect Ratio | 2 |
| Tail Moment Arm | 31.76 cm | Tail Moment Arm | 31.76 cm |

Table 2: Empennage specifications

## Configuration

The aircraft will be conventional in design with a fixed main wing and tail surfaces and movable control surfaces in a tractor configuration. Two configurations shown in Figure 4 are considered. Twin boom configuration is expected to be structurally lighter and allow ease of aligning the horizontal tail with the wing. However, routing of control linkages in twin boom configurations is complex, and hence twin boom is not preferred. The single boom configuration is chosen.

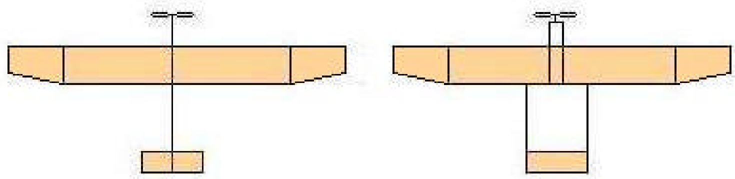

Figure 4: Configurations under consideration

## Glider Tests

An unpowered glider of specification given above is built and flown. Conventional balsa wood construction is used.

Figure 5: The Glider used for Initial Tests.

Glide tests have shown an L/D ratio of 7.5. The thrust required for level flight is hence found to be T = W x (T/W) = W x (D/L) = 125 / 7.5 = 17 gm. From the chosen propulsion unit, a thrust of 43 gm is available according to the manufacturer's information [4] and hence the power requirement can be satisfied. The glider weighs mere 31 gm and a margin of about 15.2 gm is still available for control linkages and reinforcements, which is adequate.

## Solar Panel Requirements Capture

Solar panel required for the present project are worked out as follows:

- The PV module should satisfy the power requirement of all the onboard components and the solar cells shall be highly efficient, preferably mono-crystalline Si cells.
- The panel should be modular in nature. This will ensure that the entire panel need not be replaced in the event of damage to a certain part of the panel.
- The panel should be lightweight, flexible and impact resistant.

Based on these requirements, Tata BP Solar India Ltd., a solar cell manufacturer in Bangalore has been contacted. The manufacturer has given an assurance of fulfilling the above requirements within the weight and size constraints. From the data available on the internet, it has been found that this is a feasible proposal for the solar cell manufacturer.

## Conclusions And Future Work

At the present stage of the project, the preliminary design of the model is complete. The design is tested as an unpowered glider. Battery powered flights are planned soon using the hardware components procured. This will assess the model for handling qualities in the presence of light winds. Requirements for the solar panel is arrived at and passed on to Tata BP Solar India Ltd. As soon as the solar panel is procured it will be integrated with the airframe and flights will commence. Expected date of first flight is March 2002.

## References


[1] Aerovironment Inc. Information on Unmanned Aerial Vehicles.
URL: http://www.aerovironment.com/area-aircraft/unmanned.html

[2] Cowley, M. (1981) "Wings in the Sun: the Evolution of Solar Challenger", *Flight International*. Vol. 13, pp. 1865-1868.

[3] NASA, Solar Powered Fact Sheet. "Solar-Power Research and Dryden"
URL: http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-054-DFRC.html

[4] M/s WES Technik: Model Aircraft and Accessories Suppliers.
URL: http://www.wes-technik.de

[5] M/s Plastecs Company: Solar cell and Panel Manufacturer, MA, USA
URL: http://www.plastecs.com/index.html

[6] Jones, R. T. (1990) *"Wing Theory"* Princeton, NJ.

[7] Laitone, E. V. (1996) "Aerodynamic Lift at Reynolds Numbers Below 7 x $10^6$", *AIAA Journal*, Vol. 34, pp. 1941-1942.

[8] Hageman A. (1980) *"Catalogue of Aerodynamic Characteristics of Airfoils in the Reynolds Number Range $10^4$ – $10^6$"*, Wind Energy Group, Technical University of Eindhoven, Netherlands. R443D, pp: 3-66.

[9] Lennon, A. (1999) *"Basics of R/C Model Aircraft Design"* Air Age Inc. CT, USA.

# Appendix

List of components and photographs:

| No. | Component | Product name | Remarks | Quantity required |
|---|---|---|---|---|
| 1 | Propulsion Unit | DC 5-2.4 | Motor + 11.8:1 gear | 1 |
| 2 | Propeller | 25 / 12 carbon fiber | Twin blade carbon fiber | 1 |
| 3 | Servo actuator | LS 3.0 | For elevator and rudder control | 2 |
| 4 | Receiver | R4P JST 72 MHz | Control input detection | 1 |
| 5 | Speed controller | JMP-HF9 | For throttle control | 1 |
| 6* | Transmitter | Futaba 72 MHz | To transmit the pilot's commands | 1 |

* Not shown in the photograph

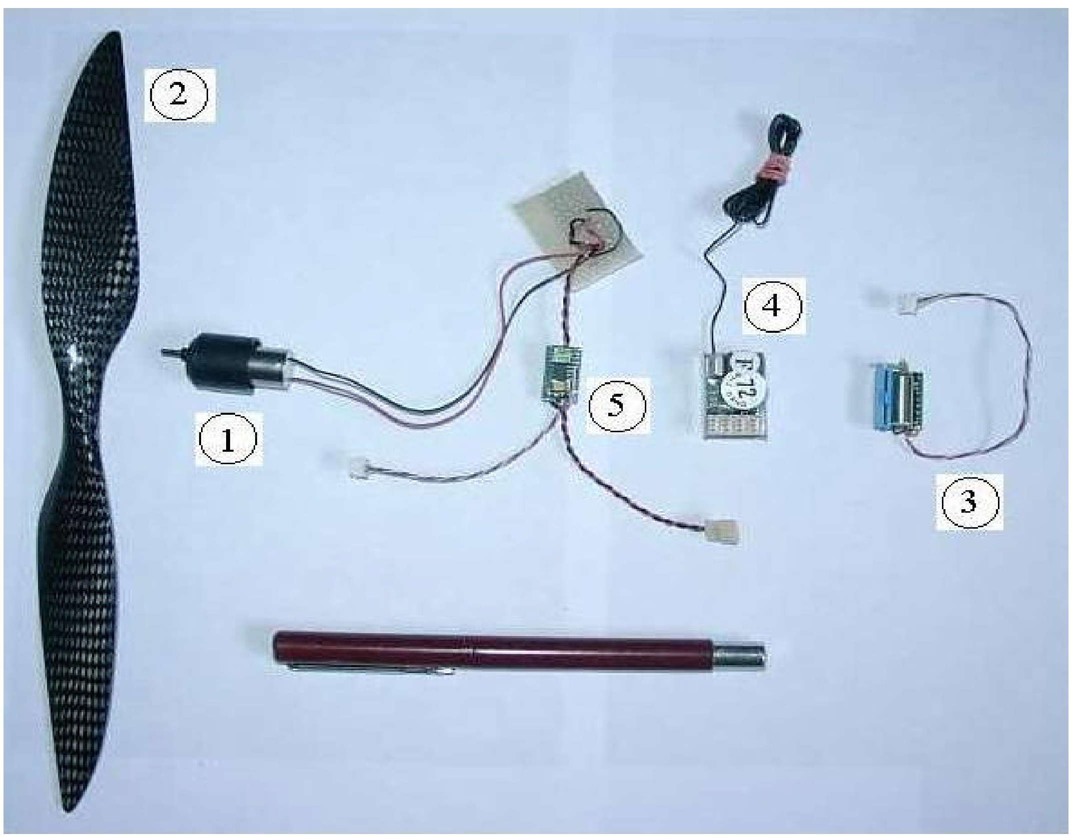


Figure A: Photograph showing the size of hardware components