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THE CYPRUS INSTITUTE

Research Promotion Foundation

Solar Car Design Guide

&

Event Participation Requirements

Issue 2 - March 14th 2009

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Change Record - From Issue 1 to Issue 2

The following changes have been made from Issue 1 to Issue 2:

- Paragraph A3, Page 4: "TBD" replaced by "4th May 2009"
- New Paragraph A4 added to identify the funding procedure to be followed by the Participating Teams and by CyI.
- As a result of introducing the new Paragraph A4, the page numbers have been changed accordingly.

Introduction

The purpose of this document is to provide the potential participating teams with the following general information and guidance:

- Technical areas that need to be considered during the design phase of a Solar Car.
- Possible parts suppliers and associated costs.
- Project Management,
- Provide references to some Internet sites that are directly relevant to the Cyprus Institute Solar Car Challenge,
- Documentation required by CyI in order for teams to be accepted for participation in the event,
- Documentation required in order for the teams to be eligible for any financial support (funding) by the CyI.

This document must be read in conjunction with the event rules, “The Cyprus Institute Solar Car Challenge Rules”, document reference CyI/SVR/001.

CyI reserves the right to make any changes to this document and to the Rules as it deems necessary. Any changes made will be notified to the potential participating teams through the web page which is to be set up by CyI. It is the team’s responsibility to ensure that they become aware of any changes by frequent visits to the relevant web pages.

It should be noted that this document is not intended to be a complete guide as to how to design a Solar Car but it is merely intended to provide a general guide during the initial design and costing phase.

A1. Technical areas to be considered during the design phase

1. **Read the Rules** - The Cyprus Institute Solar Car Challenge 2009 Rules

2. **Background reading** -
Dell Winston Solar Car challenge, (www.winstonsolar.org/challenge/)
The Dell Winston Solar Car Challenge is a very useful Internet site and contains a wide range of very relevant information including the following:
• how to build a solar car,
• technical schematics,
• parts suppliers and approximate costs,
• a wide range of solar cars with their dimensions, weight, motor type, solar array type etc.

3. **Background reading -** Appendix A of this document provides general information on the following:
• Simplified block diagram of Pascal Solar Car and motor characteristics,
• Maximum theoretical speed, thrust force and climbing angle calculations,
• Aerodynamic design aspects of a solar powered car
• Various solar car designs
• Measurement of Drag Coefficient, Cd in a school laboratory

4. **Wheel configuration and suspension -** three or four wheels and type of suspension?

5. **Tyre dimensions -** diameter, thickness and pressure?

6. **Battery bank** - voltage, capacity, mass?

7. **Drive system** - hub or chain/belt driven?

8. **Maximum design speed** - wheel radius and corresponding rpm?

9. **Motor selection** - brushed or brushless, power rating, rpm, torque, efficiency?

10. **Motor controller selection** - suitability for chosen motor and maximum speed?

11. **Solar cells or solar panels** - power requirement and configuration?

12. **Solar panel/cells** - Dimensions, area and power?

13. **Solar charge controller** - number to be used, standard or MPPT, efficiency?

14. **Auxiliary electronics -** speedometer, odometer, lights, turn indicators, voltage, power, step-down DC to DC converter?

15. **Array and battery disconnect -** electrical high current disconnect switches/circuit breakers?

16. **Chassis mechanical structure** - dimensions, materials, solar panels/cells support.

A1. Technical areas to be considered during the design phase continued

17. **Chassis and solar panels/cells arrangement -** unified body and panel or separate cab and panel (see Appendix A)

18 **Breaking system-** hydraulic or mechanical?

19. **Parts salvage -** are there any individual parts from broken down cars, scooters etc. that can be potentially used in certain areas?

20. **Solar car weight -** estimated mass, acceleration, climbing capability?

21. **Regenerative braking -** what would be the benefits in this event and is it important to incorporate?

A2. Project Management

Among other aspects of managing the overall project by the various teams, the following areas need to be considered:

1. **Team structure -** how many people and their responsibilities (task allocation)?

2. **Race registration -** how and what information is needed to register for the Cyprus Institute Solar Car Challenge? See Paragraph A.3 on the next page.

3. **Team training -** how can the team members be made familiar with the design process and the technical/practical skills required?

4. **Location -** Where will the construction take place?

5. **Pricing of parts and datasheet collection -** cost breakdown and manufacturers technical documentation for the various parts (motor, batteries, charge controller/MPPT, motor controller, solar panels/cells, other items or services).

6. **Lead time of various parts -** how long will it take to have the various parts available?

7. **Time Plan -** produce a time plan of the time required to complete the various activities until the completion of the project.

8. **Testing -** at what stages will extensive tests be carried out and how much time should be allocated?

9. **Driver training -** when and how?

10. **Planning for the race -** transportation of solar car etc.?

11. **Safety -** What safety steps need to be taken at each stage of testing and manufacturing? Who would act as the safety officer and how would they be trained?

A3. Design Phase - Documents and drawings to be produced and submitted to CyI

In order to be considered for participation in the Cyprus Institute Solar Car Challenge, each team must submit the following information to CyI not later than 4th May 2009.

1. **Data Sheets** – Each team must submit data sheets for the following major parts:
   (a) Motor
   (b) Motor controller
   (c) Charge controller/MPPT
   (d) Batteries
   (e) Solar panels/cells

2. **Drawings -**
   (a) Complete, detailed drawing(s) showing the mechanical structure of the vehicle. These should be drawn with a drafting program such as AutoCAD or Corel Draw. The drawing(s) must include crush zones, frame structure, and overall dimensions in three views (front, side, top).
   (b) A complete, detailed schematic wiring diagram showing the electrical layout of the vehicle. This schematic must include but does not need to be limited to all the wiring for the propulsion, instrumentation, and battery systems.

3. **Solar car specification -** the specification should include the following:
   (a) estimated weight and maximum speed
   (b) dimensions including solar panel
   (c) number of motors
   (d) number of charge contollers/MPPTs
   (e) number of solar cells/solar panels
   (f) total number solar cells/solar panel area
   (g) total mass and number of batteries.
   (h) solar car body type, unified airfoil body and panel or separate cab and panel

4. **Cost breakdown of the following items:**
   (a) Motor
   (b) Motor controller
   (c) Charge controller
   (d) Batteries
   (e) Solar panels/cells
   (f) Estimated cost of all other items

5. **Schedule for major activities until completion and testing of the finished design.**

All the above documents will form the basis for event participation acceptance and for the possible provision of team funding. The funding procedure to be used is explained in Paragraph A4 of the following page.

Updated drawings/schematics must be submitted if there have been any design changes since the first drawing was submitted.

A4. Funding Procedure

By 4th May 2009 all the documents listed in Paragraph A3 should have been received by CyI from the various participating teams. Upon approval of these documents by 30th June 2009, the procedure to be followed by CyI and the participating teams is as follows:

Stage 1

A sum of 3000 (three thousand) Eu will be issued to each of the approved teams Supervisor in order to purchase some of the long lead items. The Team Supervisor will be required to sign a receipt which will also indicate the team's commitment to participate in the event.

Stage 2

Each team shall provide the following:
(a) Receipts for their initial 3000 Eu expenditure.
(b) A formal letter stating that the sum of 3500 Eu has been raised and briefly explaining how this was achieved.

Upon acceptance of the above, CyI will issue a sum of 3500 (three thousand five hundred) Eu to the respective Team Supervisor. The Team Supervisor will be required to sign a receipt which will also indicate that no major problems have been encountered in their activities.

Stage 3

Each team shall provide the following:
(a) Receipts for their previous 3500 Eu expenditure.
(b) Formal progress report based on their initial schedule.
(c) A formal letter stating the amount of funds raised and briefly explaining how this was achieved.

Upon acceptance of the above, CyI will issue to the Team Supervisor a sum equal to the funds raised during this stage but not exceeding 3500 (three thousand five hundred) Eu. The Team Supervisor will be required to sign a receipt which will also indicate that no major problems have been encountered and that the total expenditure for the project will not exceed 20K Eu.

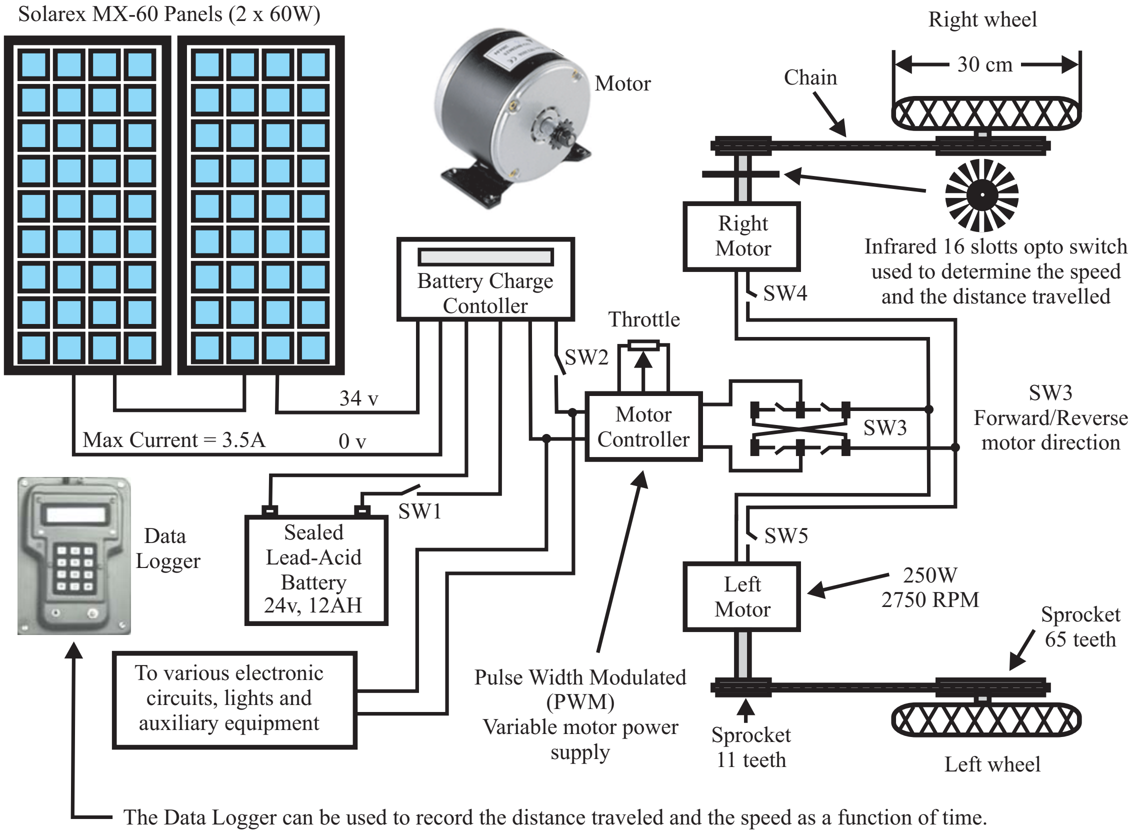
Stage 4

The Team Supervisor will be required to submit receipts based on the previous 3500 Eu expenditure.

IMPORTANT NOTE:
All cheques issued by CyI will be made payable to the Supervisor's Organization.

APPENDIX A

Simplified Block Diagram of Pascal Solar Car



Motor Characteristics (All parameters ± 5%)

Condition	Torque/Nm	Speed/rpm	Pout/W	Volt/V	Current/A	Pin/W	Efficiency/%
No load	0.03	3320	9.39	24.02	1.91	45.81	20.49
Maximum Efficiency	0.61	2932	188.86	24.07	9.64	231.97	81.42
Rated Load	0.87	2767	250.82	24.09	12.93	311.50	80.52
Maximum Torque	1.10	2610	302.00	24.11	16.08	387.69	77.90

APPENDIX A

Maximum theoretical speed, thrust force and climbing angle

The maximum theoretical speed v_{max} is give by,

$$v_{max} = (\text{motor rpm at rated load}) \times (\text{gear reduction}) \times (\text{wheel circumference})$$

$$= 2767 \times \frac{11}{65} \times \frac{\pi \times 0.30}{60} = 7.4\ ms^{-1} \text{ or } 26.6\ kmh^{-1}$$

The maximum driving or thrust force F_{max} is given by,

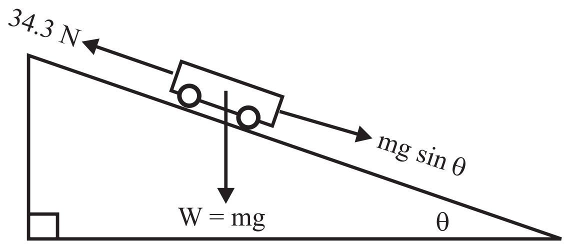
$$\text{Torque} = F_{max} \times \text{gear reduction} \times \text{perpendicular distance}$$

$$0.87 = F_{max} \times \frac{11}{65} \times 0.15$$

Solving for F_{max},

$$F_{max} = 34.3\ N$$

The situation on the right shows the solar car attempting to climb up a slope. If the available driving force is 34.3 N, then the angle θ must be such that the component of the weight acting down the slope is less than 34.3 N. As given in the Solar car specification, its mass is 73 kg. If the mass of the driver is also assumed to be 73 kg, then,



$$mg \sin\theta < 34.3$$

$$146 \times 9.81 \times \sin\theta < 34.3$$

solving for θ, gives that $\theta < 1.31°$

In all the cases above, the values obtained correspond with only one motor operating. The effect of having two motors operating in parallel needs to considered separately.Also, any resistive forces such as rolling resistance aerodynamic drag and friction would need to be taken into consideration. These aspects may be considered separately.

APPENDIX A

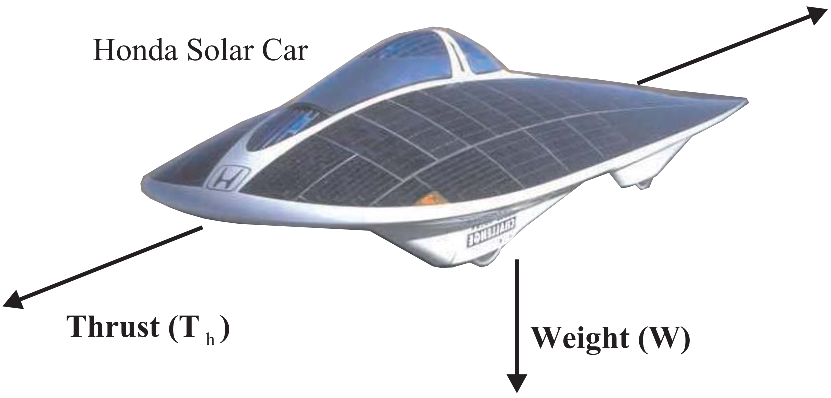
Aerodynamic design aspects of a solar powered car

The **drag force** experienced by an object moving through air can be determined by the use of the **drag equation** which is expressed as,

$$F_d = \frac{1}{2} \times C_d \times A \times \rho \times v^2$$

where, C_d is the drag coefficient (a dimensionless constant)
A is the projected frontal area
ρ is the density of air = 1.2 kg/m^3 at 20° C
v is the speed of the object relative to the air

The forces acting on a moving car are shown below.



Forces opposing motion

1) $F_d = \frac{1}{2} \times C_d \times A \times \rho \times v^2$

2) Frictional force F_r
(rolling resistance)

The sum of the resistive forces acting are,

$$F_{resistive} = \left(\frac{1}{2} \times C_d \times A \times \rho \times v^2\right) + (F_r)$$

The power P required to overcome all the resistive forces is,

$$P = F \times v = \left(\frac{1}{2} \times C_d \times A \times \rho \times v^3\right) + (F_r \times v)$$

It is clear that the shape of the car plays a very important role in establishing the power required to attain the maximum possible speed from a given source of power. In particular, the following parameters must be reduced to the maximum extend possible:

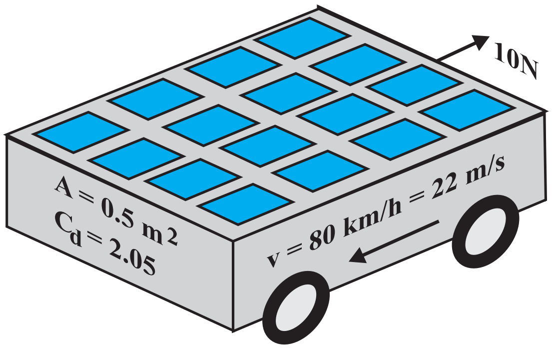
- drag coefficient, C_d
- frontal area, A
- rolling resistance, F_r

The drag coefficient of various shapes/objects is shown on page 10.

APPENDIX A

Aerodynamic design aspects of a solar powered car continued

As an example of the use of the previous equation, the simple case below shows that 7 KW of power would be needed to be able to attain a maximum speed of 80 km/h (22 ms^{-1}).



$$P = \left(\frac{1}{2} \text{ x } C_d \text{ x } A \text{ x } \rho \text{ x } v^3\right) + (F_r \text{ x } v)$$

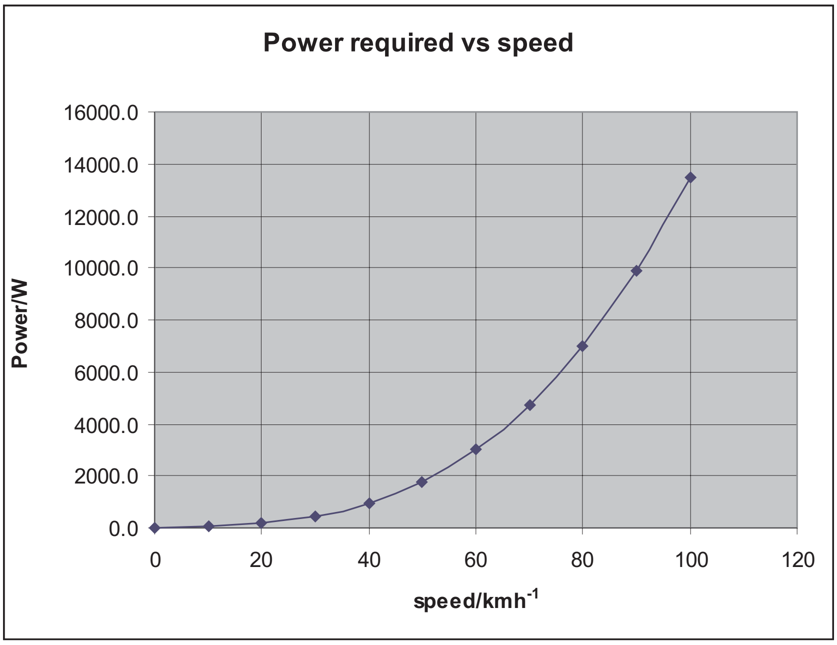
$$= \left(\frac{1}{2} \text{ x } 2.05 \text{ x } 0.5 \text{ x } 1.2 \text{ x } v^3\right) + (10.0 \text{ x } v)$$

$$= 0.615\, v^3 + 10.0\, v$$

$$\approx 7 \text{ KW}$$

In the above calculations, it is assumed that the frictional forces (rolling resistance) is approximately 10N.

The graph and table of power versus speed for the simple case considered above is shown below.

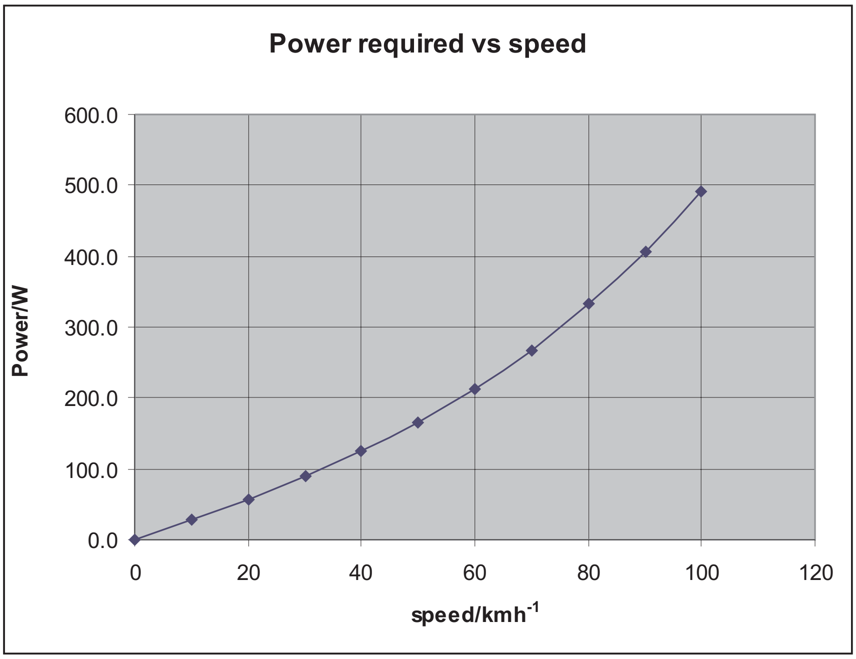


Speed /kmh^{-1}	Speed ms^{-1}	Power /W
0.00	0.00	0.00
10.0	2.80	41.0
20.0	5.60	161.0
30.0	8.30	439.0
40.0	11.1	954.7
50.0	13.9	1787
60.0	16.7	3014
70.0	19.4	4716
80.0	22.2	6970
90.0	25.0	9860
100.0	27.8	13460

APPENDIX A

Aerodynamic design aspects of a solar powered car continued

Repeating the previous calculations for a three dimensional object with a C_d = 0.04 (teardrop/airfoil shape), the graph below is obtained.



It is clear that that the shape of the vehicle plays a very important role in establishing the power required to attain the maximum possible speed from a given source of power. In particular, as previously stated, the following parameters must be reduced to the maximum extend possible:

- drag coefficient, C_d
- frontal area, A

Considering the analysis performed so far, it is not surprising that the Honda Solar Car shown earlier has the shape that closely resembles the shape considered here.

Solar Panel Considerations

Solar panel orientation and maximum power

The energy arriving on the Earth on a clear summer's day is approximately 1000 Wm^{-2}. If the photovoltaic cells have an efficiency of 15% and they are directly pointing at the Sun, then the maximum electrical power output that can be produced by 1 m^2 solar panel is:

$$P_{max} = (P_{in} \times 15)/100 = (1000 \times 15/100) = 150 \text{ W}$$

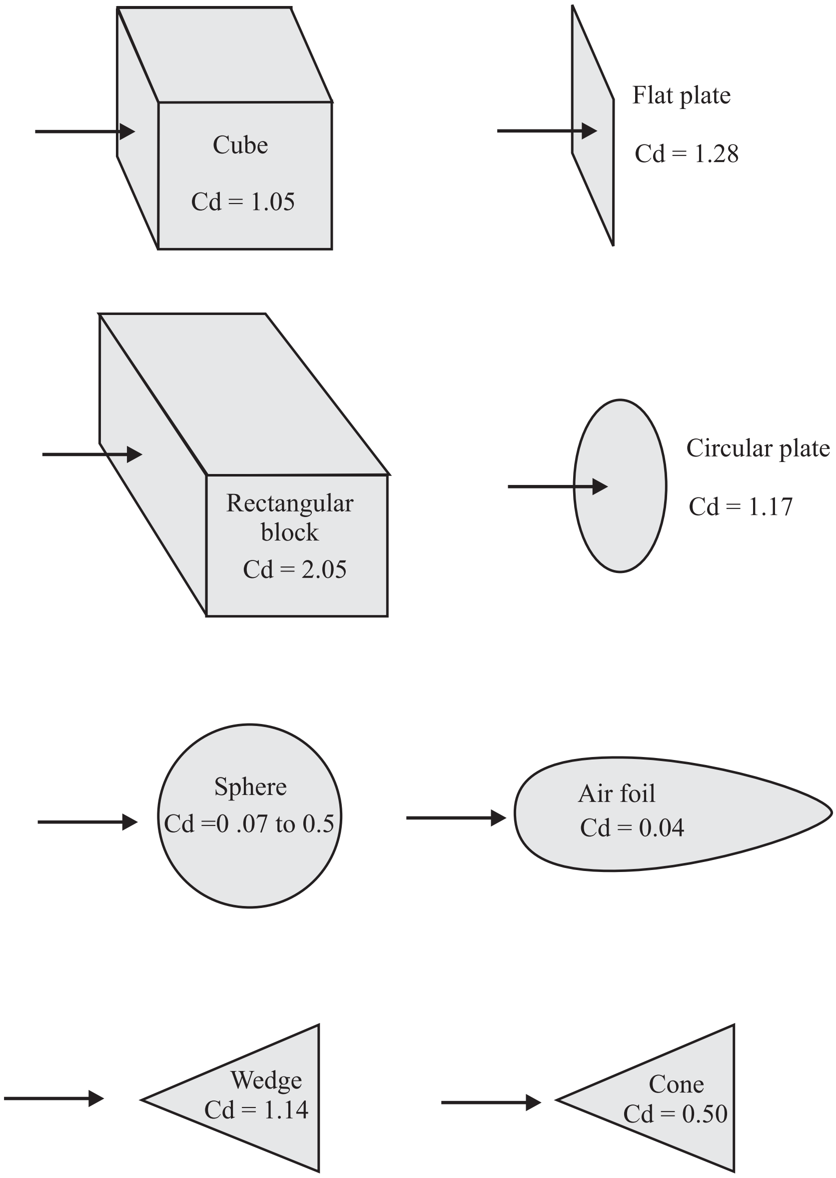
If the solar panel area used is 9 m^2, then the total maximum power output = 9 x 150 = 1350 W

In practice, the solar panel would not be pointing continuously directly at the Sun but its angle would be changing during the day. Therefore, the ultimate power available would vary between some minimum value (zero in worst case) and the possible maximum of 1350 W during the day.

APPENDIX A

The drag coefficients of various shapes are shown below.

References: 1) http://www-mdp.eng.cam.ac.uk
2) http://www.grc.nasa.gov
3) http://www.aerospaceweb.org
4) http://aerodyn.org/Drag/tables.html



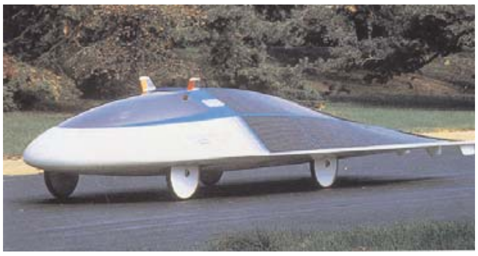
Further examples:

Object	**Cd**
Sports car	0.2 - 0.3
Typical car	0.5
Motorcyclist	1.5
Trailer alone	0.9

Object	**Cd**
Racing car	0.65 - 1.10
Man (upright position)	1.0 - 1.3
Wires and cables	1.0 - 1.3

APPENDIX A

Various solar car designs (unified airfoil body and panel)









Various solar car designs (separate cab and panel)


APPENDIX A

Measurement of Drag Coefficient, Cd in a school laboratory

The drag coefficient of a specific shape can be determined by making a scaled model of the proposed design and then testing this in a small wind tunnel. Using the drag equation

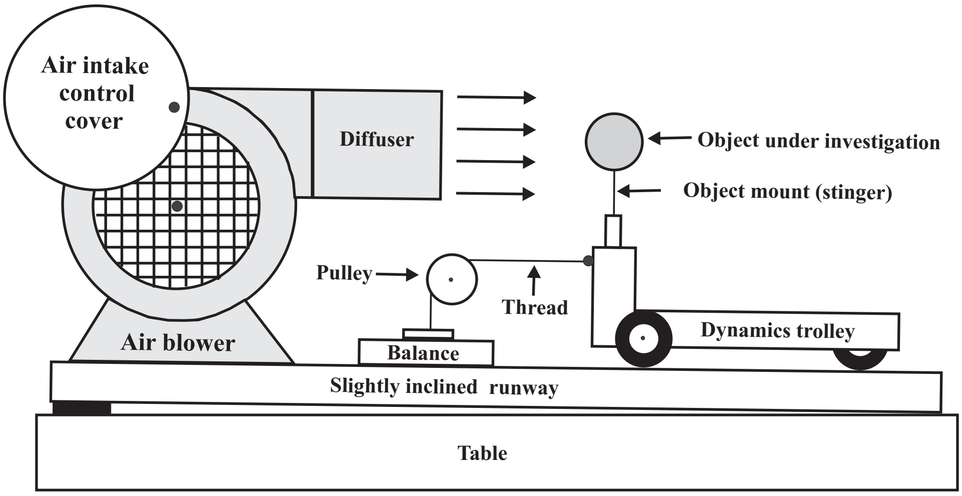
$$F_d = \frac{1}{2} \times C_d \times A \times \rho \times v^2 \quad \text{and rearranging,}$$

$$C_d = \frac{2 \times F_d}{A \times \rho \times v^2}$$

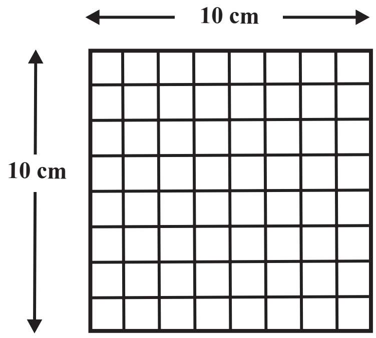
By measuring F_d, A, and v, the drag coefficient C_d can then be calculated.

Wind tunnel description

The wind tunnel with some smooth standard shapes can be bought commercially. The standard shapes are, a sphere, a teardrop and two circular plates of different diameters. The other equipment shown on the diagram should be readily available in a Physics Lab. The speed of the air at a specific distance from the end of the wind tunnel can be measured by using a digital anemometer.



Front view of Diffuser
(air outlet)



Standard shapes available