Chapter 11
Solar Racer—Construction

11.1 Introduction

Emphasis has been placed herein on the main steps in the construction process. Within this domain, most of the material focuses on construction of the composite body shell and the solar cell array. These processes are probably the most unfamiliar to the reader. Remarks on chassis and moldless shell construction, the management of construction and the skills, facilities, and equipment needed to support it have also been included.

For details of composite fabrication, the reader should consult specialized publications. Constructors of homebuilt light aircraft and solar cars share some goals: the need to fabricate a streamlined, lightweight, but strong and stiff structure. Hence, the composite materials and the construction techniques used for homebuilt aircraft may also be used for solar cars. The solar car builder may therefore tap the wealth of technology and information accumulated by the homebuilt aircraft industry.

Books on steering, braking, and suspension construction have been published. Most of the key components of these systems, such as steering wheels, rack-and-pinion assemblies, rod-end bearings, hydraulic brake caliper units, master cylinders, and shock absorbers, can be purchased ready-made. Construction of these has therefore not been included.

11.2 Body Subassemblies

A solar racing car body provides aerodynamic streamlining, supports the solar array, and keeps the weather out of the car. The array is often detachable so it can be mounted on a moveable stand that points it at the sun when charging batteries. Figure 11.1 shows a three-subassembly car: array, canopy, and chassis during battery charging.

A chassis is a structure made of metal tubes, composite panels, or a combination of composite panels and molded shapes, to which are attached the suspension ele-

E. F. Thacher, *A Solar Car Primer,* DOI 10.1007/978-3-319-17494-5_11

Fig. 11.1 Body subassemblies. (Jules LeDuc)

ments, the steering system, the battery, motor, the aerodynamic shell, etc. Thus, the chassis carries the main structural loads.

11.3 Space Frame

If the chassis is a frame made of tubes, it is called a "space frame." The tubes of a "pure" space frame are only in compression or tension. Space frames are relatively easily and quickly constructed or modified (provided the team has the necessary skills) because they are assembled by cutting tubing elements to length, and welding or brazing the elements together. When a space frame is used, the body usually consists of a shell with the space frame inside it.

The frame materials are usually aluminum or steel tubes (6061-T6 aluminum and 4130 chrome–molybdenum aircraft tubing are frequently used) of well-known geometry and physical properties. Whereas composite components, especially those made with a wet layup process by relatively unskilled workers, can have quite variable structural properties, including built-in flaws. Thus, a prediction of where and how a composite will fail carries far less assurance than does a similar prediction for a space frame. Marshall (1998) strongly recommends load testing of sample composite pieces and finished articles.

The strength of aluminum is reduced about 50–80 % in the weld-affected zone. The designer must compensate for the weakening at the welds by using more, possibly thicker-walled, tubes or other reinforcements, such as gussets. These additions make the space frame heavier. Chrome–molybdenum tubing is more dense than

Table 11.1 Steel and aluminum properties

Material	4130 Chrome–molybdenum steel	6061-T6 aluminum
Property		
Property		
Density (pci)	0.284	0.094
Specific weight	7.9	2.6
Young's modulus (psi)	$29.0\ (10^6)$	$10.0\ (10^6)$
Ultimate tensile strength (psi)	207,000	42,000
Yield strength (psi)	197,000	35,000
Strength/specific wt. (ksi)	26	16

aluminum but far stronger, so that the space frame can have fewer members made with smaller tubing (see Fig. 11.3). Furthermore, the frame can be brazed together, thus avoiding the effects of welding on the joint's strength. Table 11.1 gives room-temperature properties for 6061-T6 aluminum and 4130 chrome–molybdenum steel.

It is easy to predict the space frame's weight during design, and to control it during construction, because it is made of elements of a known weight and geometry. Wet layup composites tend to be heavier than intended. (See the remarks on "prepreg" cloth in the Sect. 11.4 below.)

A space frame can be built independently of the shell. This means that a battery-powered, operable, but shell-less car can be finished before the shell and the solar array. Testing of the vehicle can begin. This is a very important advantage. Figures 11.2 and 11.3 show cars with aluminum and steel space frames, respectively. Contrast these with the chassis shown in Fig. 11.4 made of aluminum honeycomb composite sheets.

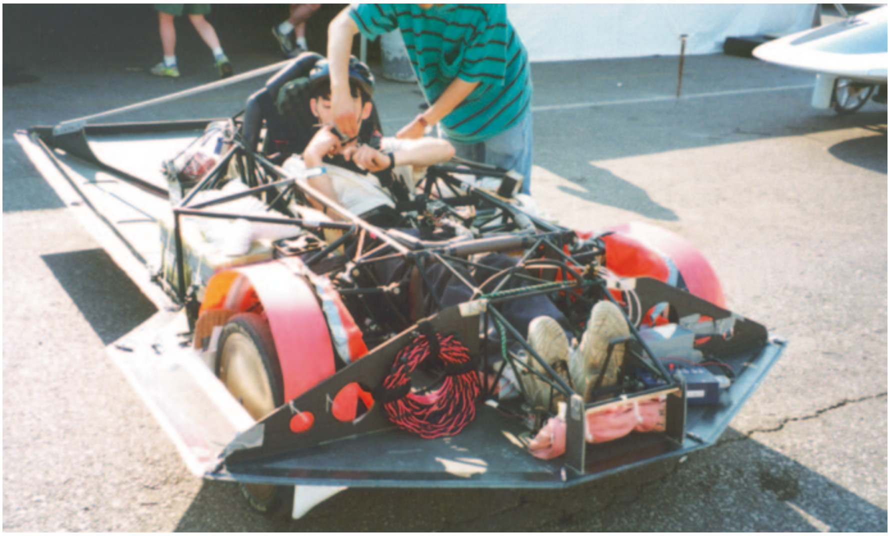

Fig. 11.2 Steel space frame—M.I.T. 1995. (Jules LeDuc)

Fig. 11.3 Aluminum space frame—Missouri-Rolla 1999

Mock-Up Mock-ups are temporary prototypes quickly constructed of cheap materials. Plastic tubing and duct tape were used to construct the mock-up shown in Fig. 11.5 made for checking the stiffness of the frame and its interface with other parts of the car. The figure shows the interface with the lower shell being assessed.

Fig. 11.4 Aluminum honeycomb chassis—Minnesota 1995. (Jules LeDuc)

Fig. 11.5 Space frame mock-up. (Brian Lisiescki)

Mock-ups can be particularly helpful in the cockpit area. Helmeted drivers can sit in the mock-up's cockpit and evaluate the utility of the layout and clearance to the roll bar. Mock-ups are very helpful in planning the wiring and instrumentation layout.

Alignment Jig As the welded or brazed joints cool, the frame may twist or bend out of its intended alignment. To minimize this, a stiff fixture should be constructed to hold the members in alignment during joining. The frame will become rigid enough to hold its shape without the jig after a number of its members have been connected.

11.4 Shell Materials

Cloth Marshall (1998) defines a composite as an assembly of dissimilar materials combined to do a job that individually they cannot do. The composites used in solar cars are made from cloths woven from special yarns and wetted with a resin, sandwiching foam or honeycomb reinforcement. Table 11.2 shows some of the properties of three yarns commonly used in homebuilt aircraft and solar car composites. (Compare some of the properties given in Table 11.1). The cloths have been numerically ranked highest (1) to lowest (3) in the "impact resistance" and "toughness" characteristics. S-glass (the "S" denotes a higher silica content) is frequently used in homebuilt aircraft applications.

Table 11.2 Yarn comparison

Material Property	S-glass	Kevlar® 49	Carbon
Specific weight	2.49	1.48	1.78
Young's modulus (psi)	12.4 (10^6)	11.0 (10^6)	35.0 (10^6)
Ultimate tensile strength (psi)	665,000	525,000	500,000
Strength/sp. weight (ksi)	267	355	281
Cost, plain weave ($/yd)	5	19	29
Electrically conductive	No	No	Yes
Impact resistance	2	1	3
Toughness	2	1	3

The function of the cured resin is to bind the composite structure together so that the load is distributed over the reinforcing yarns. Thus, the strength of the structure also depends on the uniformity of the resin content, how well it has bonded to the cloth, and the strength of the resin. The resin also bonds the composite to surrounding or embedded structures.

Cloth already wetted (impregnated) with just the proper amount of resin, "pre-preg," may also be purchased. Pre-preg must be kept cool to prevent its resin from curing before the cloth is used. The wet layup process, described in great detail by Rutan (1983) and Marshall (1998), in which the builder adds resin to the cloth, tends to produce a heavier-than-intended car. The amount of resin added is difficult to control precisely, especially when the builders are inexperienced. Pre-preg cloth solves this problem. But pre-preg is much more expensive than the dry cloth.

Of the three fibers in Table 11.2, S-glass has the lowest strength-to-specific-weight ratio and Kevlar® the highest. Therefore, solar car builders, in their quest for light-but-strong cars, tend to pass over glass in favor of Kevlar®. But this choice incurs about four times the cost of S-glass.

Flexing of the shell may crack the delicate solar cells on its surface, so the shell must be stiff. But it must also be light. Hence, carbon cloth-based composites are attractive because they offer the possibility of low weight, high strength, and greater stiffness. The stiffness of the carbon fibers is about twice that of Kevlar®, the next largest. However, the carbon fiber's cost is more than five times that of S-glass, and it is electrically conductive. If it is used in the construction of the shell, special care must be taken to make sure the final structure does not cause short circuits in the solar cell array. The electric conductivity of the cured structure will be lower than the cloth by itself. But the distribution of the resin may be nonuniform, especially if a wet layup is used, so that local areas of higher electrical conductivity may be present. Also, the fibers of the finished composite are quite stiff and can easily cut through the insulation on wires (and through flesh). Holes where wires from the array pass through the shell should be smooth and lined to prevent shorts. Having tried both Kevlar® and carbon, the author advocates making the shell of the former, nonconductive, material.

Table 11.3 Resin systems comparison

	Polyester	Vinylester	Epoxy
Strength	1	2	3
Cost ($/gal)	8	20	50
Shrinkage amount	1	2	1
Ease of use	2	2	1

11.5 Resins

A comparison of frequently used resin systems appears in Table 11.3. Except for the cost per gallon, the resins are rated 1, 2, or 3, indicating lowest to highest. For example, epoxy resin systems have the highest strength and cost, the least shrinkage during cure, and are the most difficult to use.

The entries are called "resin systems" because chemicals are available to mix with the basic resin to change its properties. For example, catalysts may be added to reduce the interval between mixing the resin with the catalyst and the onset of thickening of the mixture, the "gel" time. For any given mixture, the gel time varies inversely with temperature and directly with humidity. Marshall (1998) recommends cessation of resin mixing or fabric wetting below 60 °F and 60 % relative humidity.

The epoxy systems were rated lowest in "ease of use" because of the care that must be taken when mixing them. The cured strength of epoxy systems will be reduced considerably by small errors in the proportions of the mixture. Errors in mixing the other two systems will affect the cure time, but the cured composite will have the expected strength.

All the resin systems are toxic and subject to strength loss from exposure to ultraviolet radiation.

11.6 Core Materials

The salient characteristics of the core materials more frequently used in solar racing cars are discussed below. The material below was adapted from Marshall (1998). More details may be found therein.

Polystyrene Foam Two-lb/f^3 (pcf), large-cell type (not insulation-grade) Styrofoam was specified by Rutan (1983) for moldless construction of the wings and some other portions of a homebuilt light aircraft. It has adequate strength properties and can be smoothly cut by the hot-wire process into almost any required shape. It does not emit any toxic gases during hot-wire cutting as do urethane foams. However, it has the disadvantage of being soluble in Vinylester resins and polyester-based body filler materials and resins.

Do not use beaded styrene foam material. The bonds between the beads may be weak, making the strength of the foam unreliable.

Polyvinyl Chloride Foam Two common core materials based on polyvinyl chloride (PVC) are Klegecell® and Divinycell®. These materials are sold in densities as low as 2.5 pcf with good strength properties. They may also be purchased as "diced" sheets: sheets of small rectangular pieces of foam bonded to a fabric backing. These are intended for layups on curved surfaces.

Honeycomb Honeycomb cores are an array of small, open cells. Other cell shapes exist, but the hexagonal shape generally has the best strength. Honeycomb cores yield a composite structure of higher strength-to-weight ratio than do foam cores. Honeycomb cores made of aluminum and of Nomex® have been used in solar racing cars (see Fig. 11.4). Aluminum is cheaper, but Nomex® has better corrosion resistance and toughness.

11.7 Molded Shell Construction

The top shell section will support the solar array and be removable from the car so that it can be placed on a special stand for charging the batteries, as shown in Fig. 11.1. The two sections will each be made as a composite "sandwich" with outside and inside layers of Kevlar® cloth glued to a middle layer of structural foam or of a honeycomb structure such as Nomex®. To give this composite structure the proper shape, its two halves will be cured in female molds so that the outside layer of Kevlar® will have the shape and dimensions, and will approximate the smoothness desired, of the outside surface of the shell.

Plug In the process illustrated in Fig. 11.6, the interior surface of the female mold is first formed on a male mold called the *plug*. The plug must be made, as nearly as possible, to the exact exterior dimensions and shape of the shell. The surface of the plug must therefore be smooth; any defects in it will be reproduced in the mold and therefore in the shell. Figures 11.7–11.13 show a plug being constructed. The engineering drawings of the shell were used to produce templates of the cross-sectional shape of the shell at many stations along its length. The templates were used to cut these shapes from insulating foam. The shapes were mounted on rails, glued together, and smoothed. The surface thus formed was sealed,[1] coated with an automobile body filler material, and sanded smooth again. The smoothed surface was cleaned, spray-painted with a primer, wet-sanded, and then coated with a mold release compound.

Mold The top mold was created by spraying glass fiber onto the top half of the plug. The top of the assembly was then fitted with a stand and the assembly inverted. The original stand was removed and the bottom of the plug completed. Then the top part of the mold was constructed. Figure 11.14 shows the plug being loaded for shipment to make the top half of the mold. The mold was made as an in-kind donation by Empire Fibreglass Products, Inc., of Little Falls, New York.

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[1] To protect it from the polyester-based body filler.

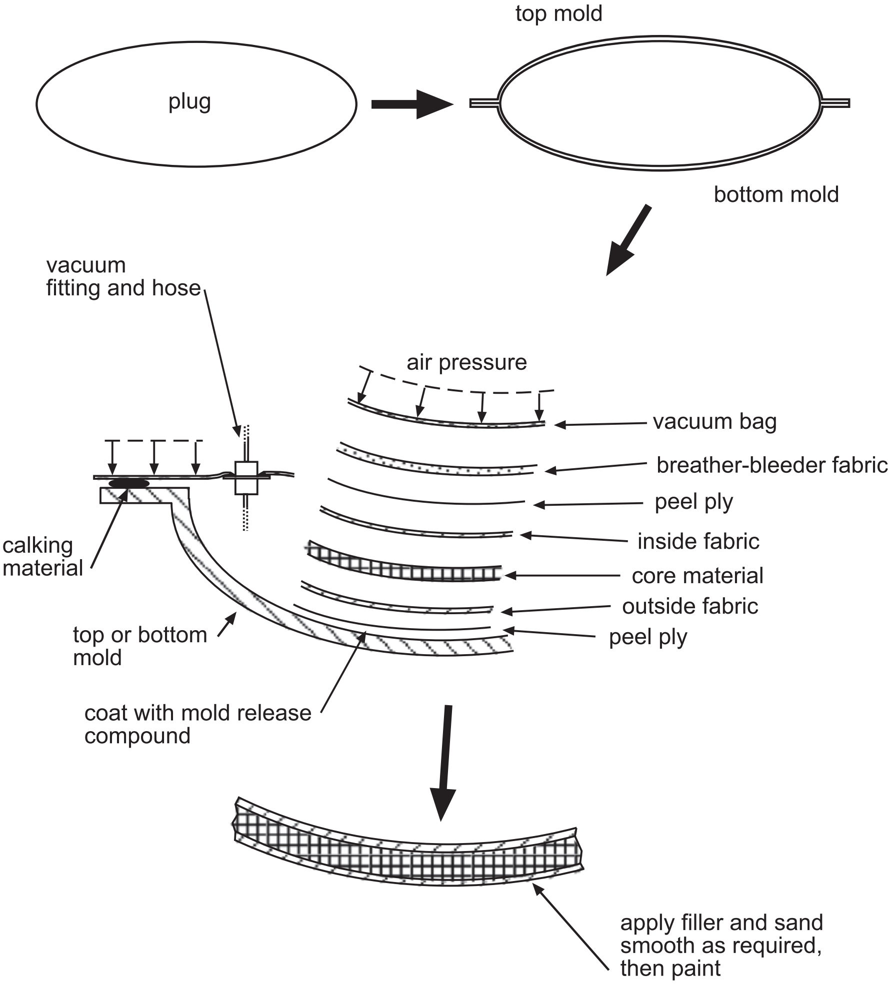

Fig. 11.6 Molded shell fabrication process

Figure 11.15 shows the finished molds prior to separation. The final steps in preparing the molds to make the shell were to thoroughly clean them and to coat them with three or four layers of a mold release compound. Figure 11.16 shows a mold being cleaned. After cleaning, the molds should be covered with a clean plastic sheet until used.

Layup Marshall (1998) and other practical books contain many layup details and suggestions. Before attempting to build a shell, obtain one of these books and perform some practice layups.

In Fig. 11.6, the first layer next to the mold is a release film that can pass through the curing process but not bond to the composite; it may be torn off without damag-

Fig. 11.7 Cutting plug foam segment. (Brian Lisiescki)

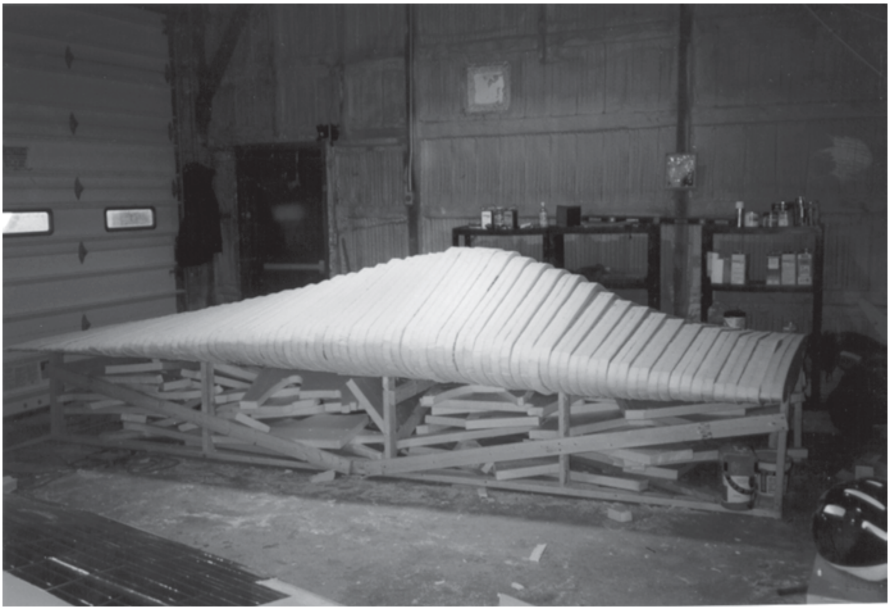

Fig. 11.8 Foam segments before sanding. (Brian Lisiecki)

Fig. 11.9 Shaped foam core. (Brian Lisiecki)

Fig. 11.10 Smoothing body filler. (Brian Lisiecki)

Fig. 11.11 Check flatness. (Brian Lisiecki)

Fig. 11.12 Spraying primer. (Brian Lisiecki)

Fig. 11.13 Wet-sanding plug. (Brian Lisiecki)

Fig. 11.14 Shipping plug. (Brian Lisiecki)

Fig. 11.15 Finished molds. (Brian Lisiecki)

Fig. 11.16 Smoothing a mold. (Brian Lisiecki)

Fig. 11.17 Laying down outer peel ply. (Brian Lisiecki)

ing the cured parts.[2] The outside layer of fabric may be positioned in the mold and wetted with resin; however, the mold side of the fabric will be hidden and consequently also any dry spots on that side. Marshall recommends placing the fabric on a plastic film on a table next to the mold. The fabric should then be wetted with the proper amount of resin and positioned in the mold using the plastic backing. This backing protects the fabric while it is worked into close contact with the mold. Then it is removed. The core material is then put in place, followed by the outer layer of fabric, then the outer peel ply and bleeder layers, and finally the vacuum bag itself.

If the mold is sufficiently smooth, the cured shell also will be. But if not, application and sanding of a body filler material may be necessary. The density of most conventional body filler materials is between 25 and 50 lb/f^3 (Marshall 1998). This will add some weight and increase the fabrication duration.

Figures 11.17–11.20 show the layup process. The fabric in this case was prepreg. It was cured at an elevated temperature in a large oven at Stafford Machining/ Cyclotherm Inc. of Watertown, New York.

Stiffeners Add stiffness by installing longitudinal ribs and transverse bulkheads inside the shell. These members are made by constructing flat composite panels, drawing the stiffeners' shapes on the panels, cutting the shapes out, and tabbing them in place with a resin-impregnated structural cloth. These reinforcements will of course add weight. Figure 11.21 shows stiffeners in the underside of a solar car shell.

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[2] Marshall (1998) recommends testing the release agent you have chosen with your resin system. He points out that the ability of each resin system to penetrate the release agent is different.

Fig. 11.18 Laying down bleeder cloth. (Brian Lisiecki)

Fig. 11.19 Vacuum-bag on layup. (Brian Lisiescki)

Fig. 11.20 Bottom half of shell. (Brian Lisiescki)

Fig. 11.21 Shell stiffening—Missouri-Columbia 1999

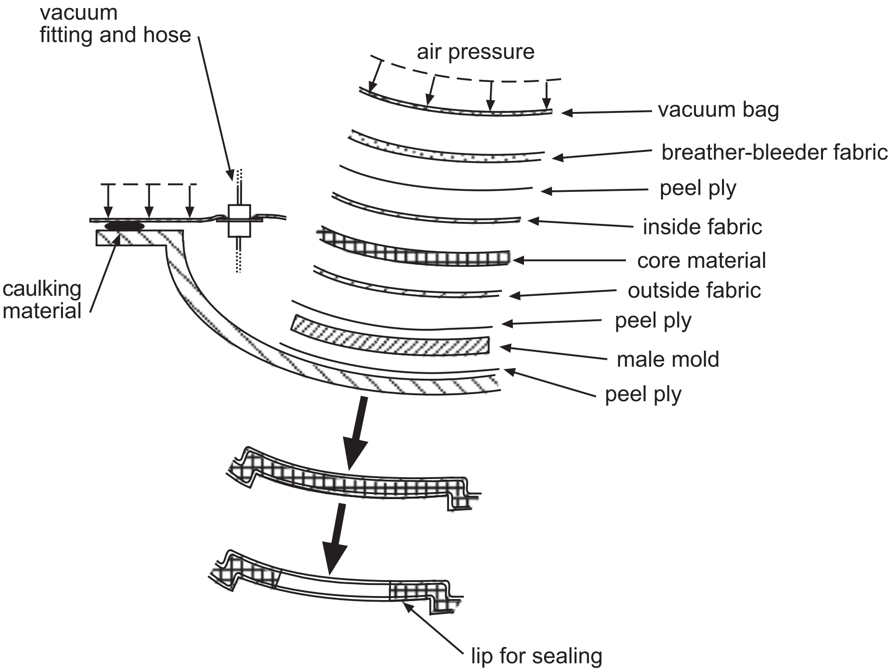

Fig. 11.22 Molding a flush-fit door

11.8 Doors and Windows

Figure 11.22 shows a method for making an opening in the shell for a flush-fit panel. The technique is the same as before except that a male mold slightly larger than the size (to provide clearance) and of the thickness of the door is placed as shown. Curing the shell in this manner produces a recessed area of the size and shape of the door. The center of this area is cut out to make the opening. A sealing lip around the opening remains.

11.9 Moldless Shell Construction

As the foregoing demonstrates, making a compound-curved shape using a female mold is an involved and therefore lengthy process. It may require 3 or 4 months, in an academic environment. Rutan (1983) describes the "moldless" construction process for homebuilt aircraft. The process has been successfully applied to solar racing cars. The essential idea is to form a surface of suitable lightweight foam that has been given the desired shape, but is smaller than the desired final dimensions. A "skin" of one of the cloths of Table 11.2 is resin-bonded to this core using a wet

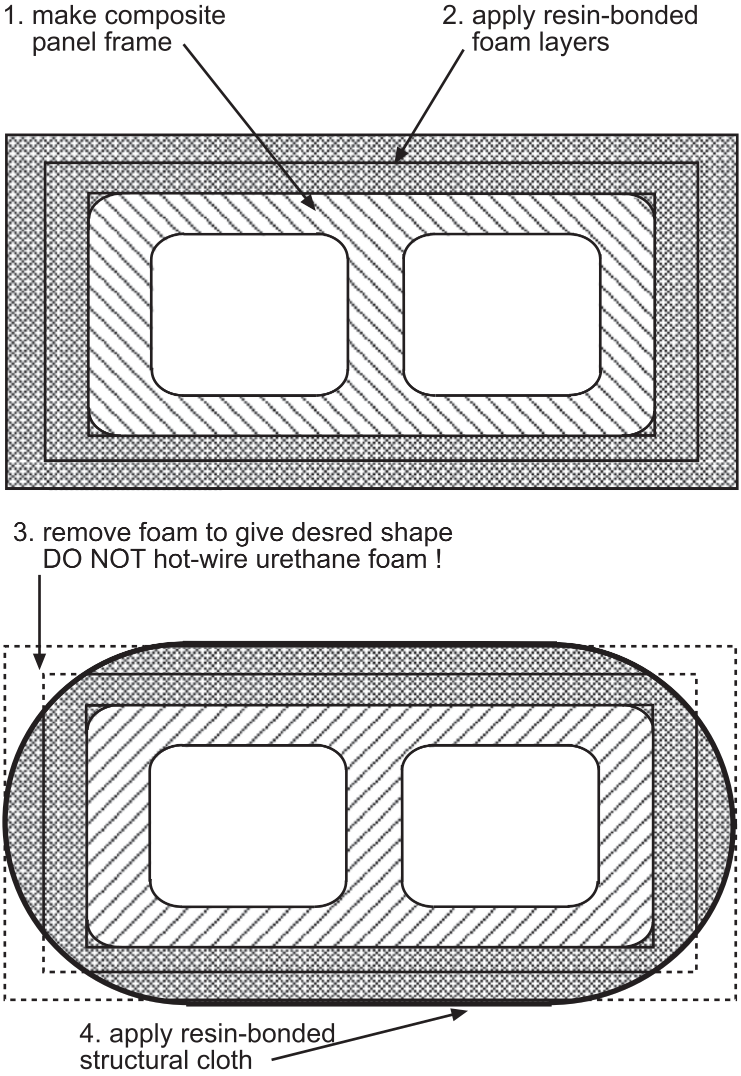

Fig. 11.23 Moldless construction process

layup process. This amounts to making a plug that becomes part of the car's structure. Finally, the outside surface of the final part is smoothed and finished. This may require much effort if insufficient attention has been paid to smoothing the plug's surface. The dimensions of solar cars must lie within certain limits and this must be allowed for when planning the dimensions of the core materials.

Figure 11.23 shows a simplified body frame constructed of composite panels. The panels would be made from one of the cloth–foam systems already described.

Foam is resin-bonded to the frame and sanded to the shape and dimensions required, less an allowance for the external cloth layers and other surface treatment. Then structural cloth is bonded to the foam and the surface finish applied.

11.10 Ultraviolet Protection

Resins decompose when exposed to ultraviolet (UV) light, causing a measurable loss in strength of unprotected composites over periods of a few weeks or months. UV inhibitors in the resin will slow the deterioration, not prevent it (Marshall 1998). Painting the car will block the UV light. Of course, painting will normally be done to improve the appearance. Until this is done, the body should be kept out of sunlight.

11.11 Solar Cell Array

Design and Layout The output of the design phase should be documents showing the number of cells required, the number of strings, their preliminary layout on the car, the wiring design (including the by-pass diodes), the encapsulant and underlayment materials, the cell-to-cell spacing, and the design area efficiency.

The final layout of the array, drawing the outlines of the parts of the array and the locations of wire holes directly on the shell's surface, should be done after the shell has been built and painted. Then account can be taken of the as-built dimensions, smoothness, and curvature.

Number of Cells An 8-m^2, rectangular, flat array may require 800, 10 × 10-cm cells. However, because solar cells are delicate, it is quite difficult to avoid breaking a number of them during array construction. Therefore, the quantity purchased should include extra cells to allow for this and also to provide replacements for cells damaged during operation of the car. The team may wish to practice tabbing, test sample modules, or try out methods of underlayment and encapsulation. Some cell suppliers furnish free sample cells that have defects and so could be used for experimenting with fabrication techniques. The need to replace broken cells in the array (see Fig. 11.1) or cells which were to be used in performance tests increases the quantity purchased by about 25 % for a total of 1000 cells.

Sub-arrays An array consists of a number of parallel-connected strings of series-connected cells. These will be called *sub-arrays*. The sub-arrays themselves are formed from subsets of series-connected cells, or *modules,* placed together on a particular part, or *facet,* of the shell's surface and connected in series with the other

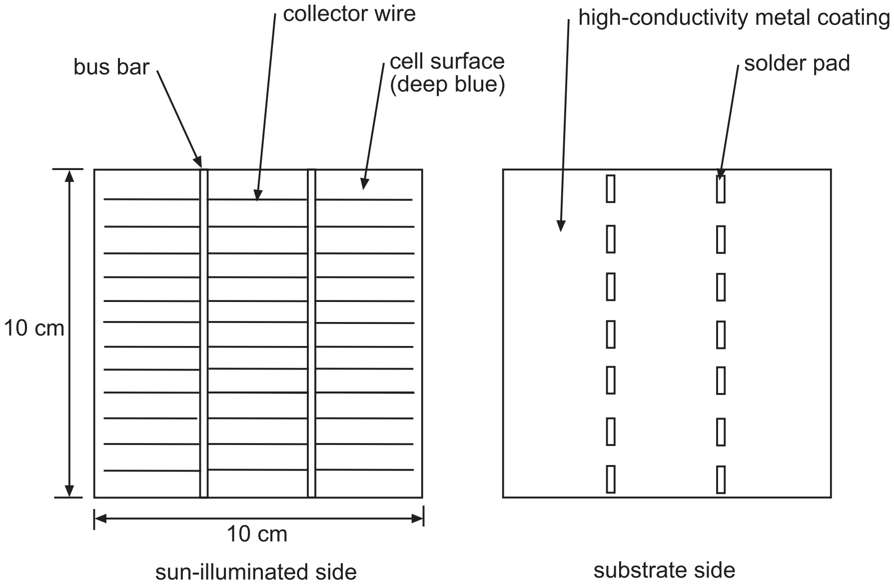

Fig. 11.24 Typical solar cell

modules of the sub-array. A facet is an approximately flat region molded into the shell's surface and designed to hold a particular module.

The cells in the modules should be connected together first. The team may stipulate in the purchase contract that this be done by the cell supplier.[3] This may save time and yield a better product; however, it will approximately double the cost of the array.

The first step in module construction will be *tabbing* the cells: soldering interconnect ribbon to the negative-side bus bars. Figure 11.24 shows the top, or illuminated negative side, and the bottom, or positive side, of a typical solar cell. Figure 11.25 shows a solar cell being tabbed. The worker is applying solder paste to the top bus bars. To save time, the tabbing operation should be done by several workers at once. The interconnect wires are flat, tinned (solder-coated), copper ribbons. Photon (1995) gives practical details about tabbing.

After tabbing, the cells are connected into strings. Figure 11.26 shows a cross section through part of a string. Consult Rauschenback (1980) for some variations on this standard "z-step" connection which were designed to reduce the thermal expansion between the cells in a string should be 1–1.5 mm to allow for thermal expansion. A fixture should be constructed to hold the cells at this spacing and to keep

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[3] The terms of this contract should describe the manufacturer's responsibility in case he damages the cells.

Fig. 11.25 Tabbing a cell. (Brian Lisiecki)

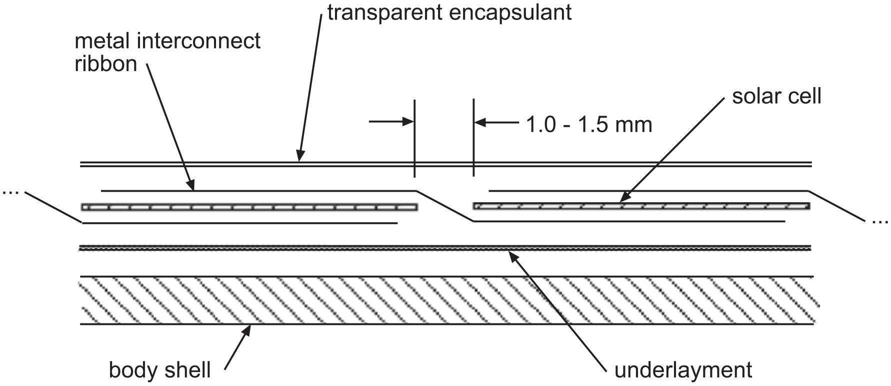


Fig. 11.26 Two cells in series

the edges of the cells in alignment while they are being connected. Figure 11.27 shows such a fixture; it was milled from a sheet of plastic.

Encapsulation The solar array must be protected from water, dust, and small stones that may be thrown against it in traffic. This may be done by applying an optically transparent encapsulant with a thermal expansion characteristic simi-

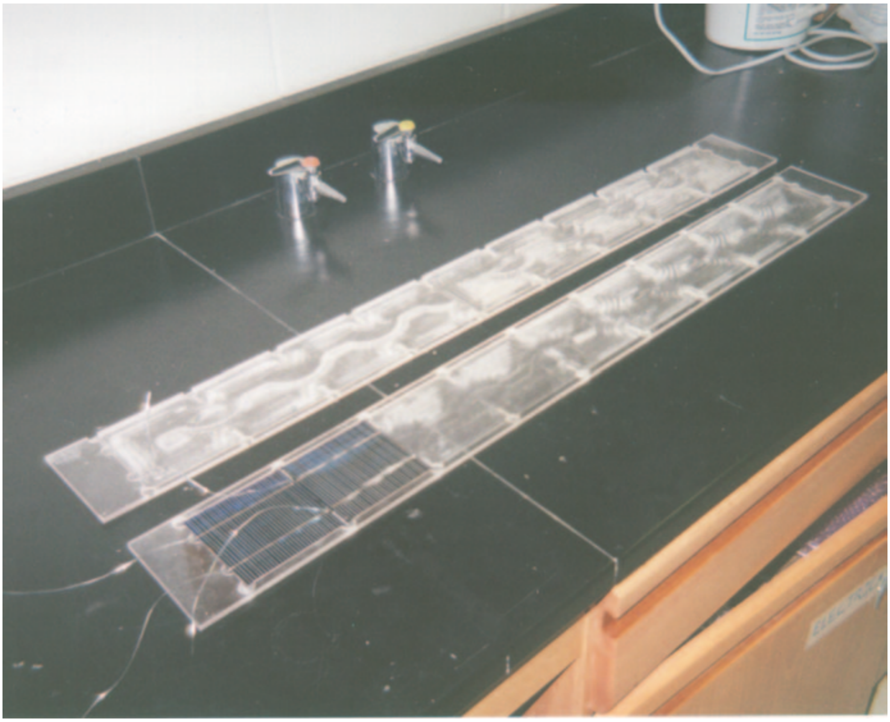


Fig. 11.27 Cell connection fixture

lar to that of the cells. Figure 11.28 shows workers brushing on a two-part silicone encapsulant to the back (foreground) and top (background) of modules. The two-part silicone materials will hold dust and are not washable. A one-part silicone that produces a washable surface is Dow-Corning 1-2577 Conformal Coating. Because the product cures by evaporating toluene solvent, it should be applied only while wearing solvent-rated breathing masks in well-ventilated spaces. Consult the materials safety data sheet and other instructions furnished by the manufacturer.

Each completed module should be tagged with a code indicating its place in the array, then stored and covered pending its installation on the solar car. The utmost care must be taken to prevent cracking of the cells when handling and transporting the modules.

Installation With the final layout of the array marked on the car, wiring holes drilled and lined, and the completed modules stored near the car, installation may begin. If access to the underside of the array substructure is not convenient when it is mounted on the car, place it in a fixture so that it is so.

Fig. 11.28 Applying encapsulant. (Brian Lisiescki)

Before applying its underlayment, give each module to be installed a final inspection. Then prepare and apply its underlayment, as shown in Fig. 11.29. The underlayment should be thick enough to fill in around the interconnect ribbon and solder joints on the backs of the cells. Also, if the depth is not elsewhere uniform, voids will form underneath the cells, leaving portions of the cells unsupported. These defects may result in cracked cells later. The underlayment depicted in Fig. 11.29 is “Tra-Bond 2151,” a two-part silicon adhesive manufactured by Tra-Con of Bedford, Massachusetts.

After application of the underlayment, remove the module from storage, pass the interconnecting ribbons through the wiring holes, lower the module onto the underlayment, and *gently* settle it into place, as shown in Fig. 11.30. This process must be done with care to preserve the intended alignment, avoid cracking, and ensure the backs of the cells are uniformly wetted by the underlayment, as mentioned above. Underlayment that may be squeezed onto the cells out of the gaps between them should be removed using the solvent recommended by the manufacturer.

Fig. 11.29 Applying underlayment. (Brian Lisiescki)

After the underlayment has cured, wiring may begin. The design should incorporate proper wire sizing to minimize power losses and voltage drops, color-coded insulation, and the construction of wire harnesses. McCarney et al. (1987) offer practical advice in these matters. The harnesses should be supported at frequent points from the underside of the shell so the electric connections do not bear mechanical loads and breaks do not occur from cold working.

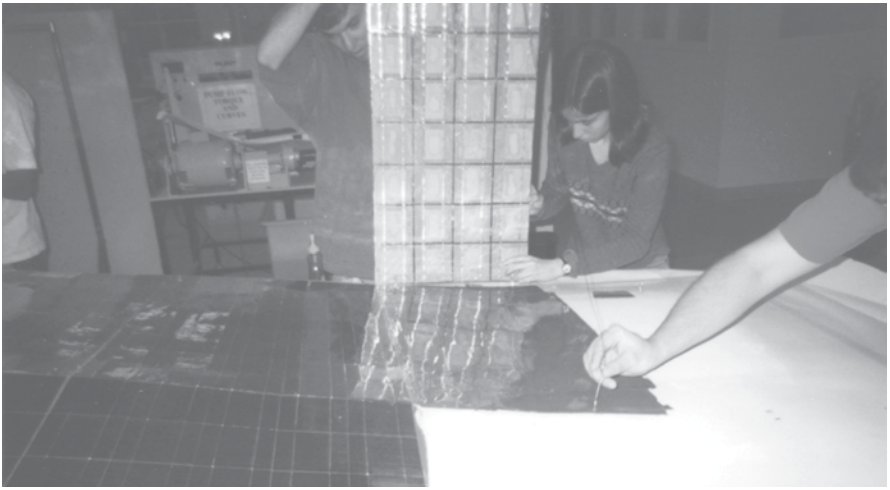
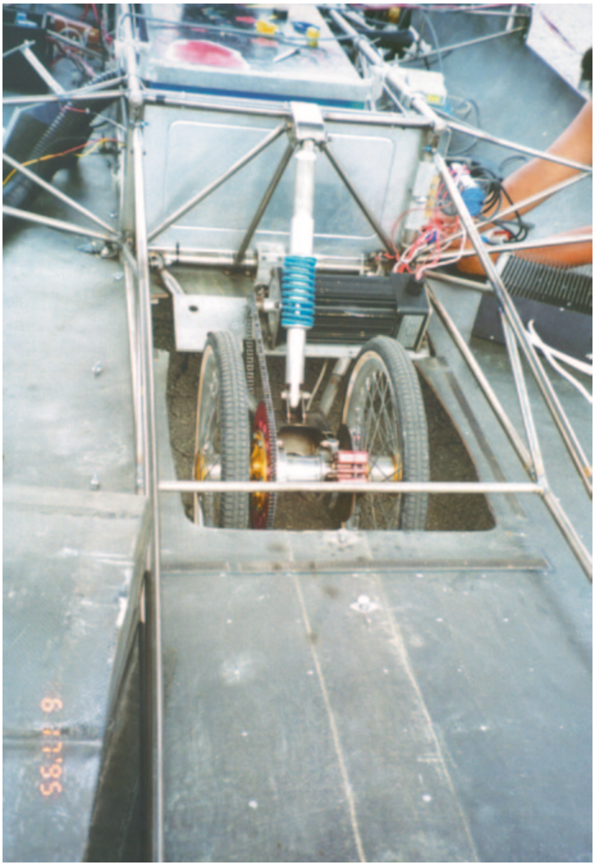


Fig. 11.30 Installing module

Fig. 11.31 A drive assembly



11.12 Electric System

Usually, the components of the electric system, from connecting wire to the propulsion motor and its controller, will have been purchased rather than fabricated from primary materials. The system will be built by mounting these components to the chassis or shell and connecting them according to the circuit design. During the design phase, thought should be given to the location and design of the mounts and the wiring layout.

It may be necessary to build mounts for certain components, such as the external lights, into the shell or the chassis during its manufacture, rather than add them afterward. Figure 11.31 shows a motor driving the rear axle through a chain drive. Kyle (1990) and Storey et al. (1993) show many examples of drive installations. Metal plates may be bonded into a composite structure to strengthen it for motor (or suspension) mounts. Marshall (1998) shows how to build such "hard points" from composite materials alone.

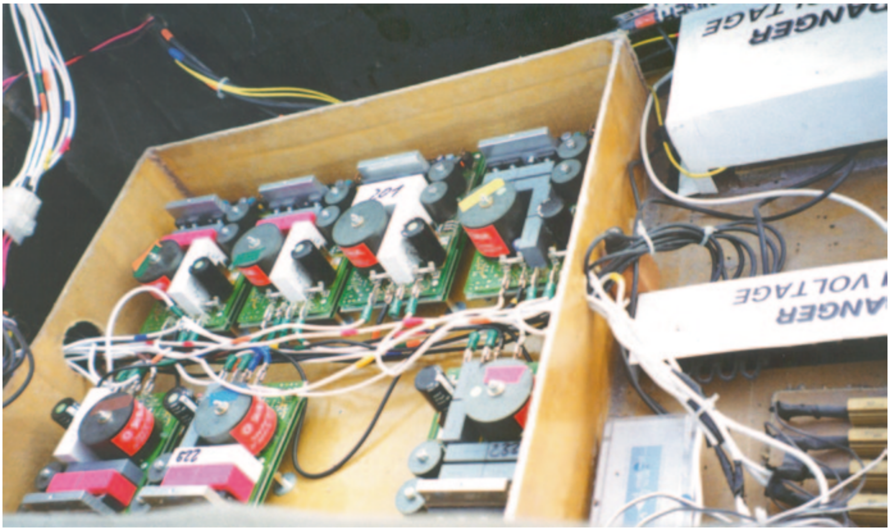


Fig. 11.32 Maximum power point trackers. (Jules LeDuc)

Short wire runs, low weight components, and ease of access should be guiding principles. Figure 11.32 shows maximum power point trackers conveniently mounted together in a Kevlar®-composite box.[4] A mock-up of the chassis will be very helpful in planning the electric system layout, as pointed out earlier.

Figure 11.33 shows a direct-current-to-direct-current (DC-DC) converter being connected to the circuit. Some of the circuit layout drawing can be seen.

11.13 Facilities

Central Office There should be a location near the car where the weight chart, a time line, and the engineering drawings can be displayed. Corrections to the time line, the chart, and to the engineering drawings to reflect any design changes found necessary combined with meetings of the construction crew serve to keep everyone informed, on schedule, and working together.

Array Construction, Composite Layup Figure 11.34 shows a fabrication facility. Ideally, the rooms in which these activities occur should be isolated from casual foot traffic, kept clean, and be well-ventilated. The depicted facility was shared with other student projects. But it was located next to a well-equipped machine shop, a great advantage.

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[4] However, the box was mounted on top of the battery compartment, making access to the batteries difficult.

Fig. 11.33 Wiring begins. (Brian Lisiescki)

Fig. 11.34 Assembly facility. (M. Griffin)

Encapsulates, underlayments, resins, and other chemicals associated with array and composite construction are hazardous chemicals. They are fire hazards, toxic, and give off noxious, and sometimes injurious, fumes during cure. Learn and follow the special precautions necessary when working with these substances. The manufacturers of hazardous substances send material safety data sheets with their products. Read these sheets and keep them on file.

Workers must be provided with protective clothing, such as rubber gloves with thin cotton gloves underneath (to absorb sweat) and breathing masks. (Notice the mask worn by the worker spraying primer on the plug shown in Fig. 11.12.) Wear a barrier cream. Do not clean skin with a solvent. Solvents absorb natural skin oils that prevent the resins from penetrating. Cleaning should be done instead with a waterless hand cleaner. Finish cleaning with soap and water.

The school must have a system in place for proper storage and disposal of hazardous wastes. Contact the individual designated as the school's health and radiation safety officer to learn the proper procedures and to obtain training in the use of these materials, and to have your workspaces inspected for compliance with regulations.

Electrical Electrical fabrication facilities are much easier to acquire. Circuit wiring does not require lots of space nor expensive machine tools. Soldering equipment, crimping tools, wire strippers, and the like are required instead. The solar cell array is the single most difficult and time-consuming component to make. It requires a clean and dust-free environment and table space to lay out cell-string soldering jigs and trial panels.

The major electrical safety issues are those associated with electric storage batteries. The project team must be trained in how to work around and with them, how to install them, how to charge and discharge them, and how to store them. Crompton (1996) (see page 98) is a handbook of battery technology. Manufacturers provide information on the proper installation, maintenance, and operation of their batteries. These instructions should be acquired, disseminated, and followed.

At some point during construction, the batteries must be placed in the car and wired. This must be carefully planned for because all subsequent work must account for the presence of the batteries. For example, no welding should take place once the batteries are present. Wiring the batteries should be done with insulated tools, and two persons should always be present. Once the batteries are installed, they must be covered. This will prevent metal objects from dropping into the battery box and causing a short. Figure 11.35 shows batteries being installed in a solar car.

People continually working around the batteries may become accustomed to them and consequently act carelessly. Supervisors must insure that the workers remain aware of the presence of the batteries and the potential hazard they represent.

11.14 Construction Management

Plan The construction plan should incorporate parallel effort. This implies that all the fabrication skill not be concentrated in a small number of persons. It also implies that the information on how the car is to be built be recorded on drawings, rather

Fig. 11.35 Installing batteries. (Brian Lisiecki)

than in the minds of one or two persons. The need to share information cannot be overstressed.

The construction crew will mostly be students. That means that the plan must account for their other commitments, such as job-interview trips, exams, and weekend trips home. However onerous it may seem, work must continue during holidays and the summer before the race. These times are precious: During them, the workers will be relatively free of other commitments. This means that arrangements must be made to house and feed them on-campus.

Construction generally seems to require more time than one anticipates. Therefore, the plan should incorporate allowances for this typical underestimate. A rule of thumb is to multiply one's original estimate by three.

The skills and equipment that must be available will become evident during design. If these are not present either within the team or within the school, then plans must be made for "outsourcing," that is, sending work to agencies outside the school. Businesses thus employed must of course be capable of doing the work and be able to meet the construction schedule. The construction plan must include ways to pay for outsourced work in cash or for donation of its services by the business.

Controlling Weight The design empty weight of the vehicle and a table giving the portion of this weight allocated to each system of the car should be available before construction begins. The engineering drawings will show the location of the various components. This sets the weight distribution, which is crucial to realizing the vehicle's intended stability characteristics.

Unless a careful watch is kept, the weight will tend to increase beyond the design value. As a means of controlling this, frequent weighing should take place

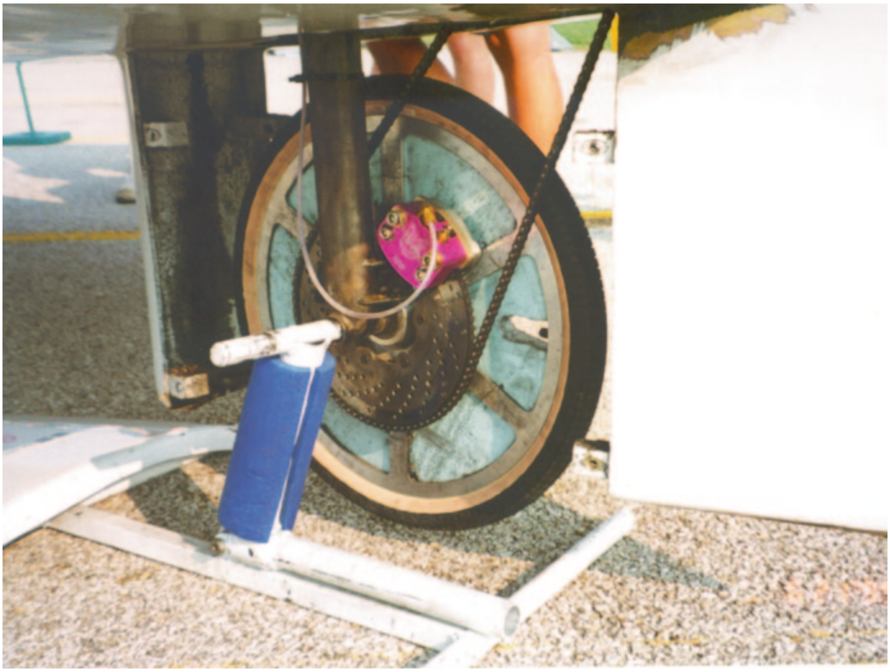

Fig. 11.36 A tire jack. (Jules LeDuc)

and be recorded on the table mentioned above. A cause of overweight is purchased components exceeding their manufacturer's advertised weight. Components should be weighed before they are installed to verify that their weight is as expected. Another cause is the accumulation of many small weights. Screws, nuts, washers, wire ties—a host of small parts must be installed. Often these small items are not planned for but installed at the whim of the workers. Their accumulated weight can add several pounds.

The weight chart should show the present weight and center-of-gravity coordinates of a system alongside its allocated weight and coordinates. This reveals where weight trades can be made and allows calculation of a trade's effect on the overall weight and the location of the center of gravity.

11.15 Tools

Three special tools should be designed and fabricated: an array stand to support the array during static charging (unless, as shown in Fig. 11.4, the array is hinged from one side of the car), a jack for changing tires, and a wheel chock. Making the latter is simple and could be done from plastic pipe, as is the chock under the right front wheel in Fig. 11.3, or wood. Figure 11.36 shows a jack in the "up" position. The bar at the top fitted into the socket built into each wheel strut. A lever placed into the horizontal tube was used to pivot the car up or down around the hinge at the bottom.

Fig. 11.37 Finished! (M. Griffin)

11.16 Completion

After many months of meetings, calculations, choices, spending, fund raising, planning, trips, public relations, attention to detail, missed holidays, arguments, and hours of devoted work, your car has been built—at last. Your team has learned a priceless lesson: the meaning of commitment. In this they have become professionals. Figure 11.37 shows the proud moment.

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