# 2011 World Solar Challenge

# Solar Vehicle Structural Report

This document comprises the Structural Report required by General regulation 2.6.2

The check lists provide guidance to the minimum requirements needed to certify that sound engineering practice has been applied to the construction and use of the components and systems of the vehicle. The checklists may be supplemented with any supporting drawings or diagrams deemed necessary.

A copy of this document, comprising check sheet and certificate, must be completed by a suitable qualified engineer and submitted to the Road Transport Authority at the time of scrutineering. It will also be required to support any application for pre-event on road testing permit made to an Australian Road Transport Authority. *(General Regulation 3.4.3 and footnote refers).*

**Entrants are strongly advised to submit a copy of this document, to the Organisers, prior to shipping their vehicle to Australia.**

| | |
|---|---|
| **Vehicle Details** | |
| Team Name | MIT SOLAR ELECTRIC VEHICLE TEAM |
| Vehicle Name | CHOPPER DEL SOL |
| Vehicle Builder | MIT SOLAR ELECTRIC VEHICLE TEAM |
| Competition number | 4 |
| Vehicle Identification Number (VIN) | |
| Proposed Gross Vehicle Mass (GVM)* | 225 kg |
| Tyre manufacturer/type | HUTCHINSON GPI |
| Tyre size / quantity | 16" x 2.75" x3 |
| * GVM is total mass of vehicle including driver and ballast. | |

This document contains five (5) pages.

Team name: MIT SEVT Car name: CHOPPER DEL SOL No. 4

| **Braking System** | Confirmed |
|---|---|
| Are all components within the braking system suitable for their application? | ✓ |
| Does the vehicle have a balanced, dual mechanical braking system fitted to at least two of the vehicles wheels so that if one system should fail, the vehicle can still be stopped? | ✓ |
| Is the braking system in its entirety suitable for the application and fit for purpose? | ✓ |

| **Wheel Rims** | Confirmed |
|---|---|
| Are the rims of a suitable strength with relation to the vehicle's GVM? | ✓ |
| Are the rims of a suitable strength to adequately sustain the lateral, horizontal and braking forces expected in the event (including at Hidden Valley Raceway)? | ✓ |
| Are the rims of dimensions recommended by the tyre manufacturer? | ✓ |
| Are the rims, and their attachment to the vehicle, suitable for the application and fit for purpose? | ✓ |

| **Suspension** | Confirmed |
|---|---|
| Are all components of the vehicle's suspension systems suitable for their application? | ✓ |
| Are the vehicle's suspension systems suitable for the vehicle's GVM? | ✓ |
| Are the vehicle's suspension components of adequate strength to sustain the lateral, horizontal and braking forces expected in the event (including at Hidden Valley Raceway)? | ✓ |
| Are the vehicle's suspension systems, and their attachment to the vehicle, suitable for the application and fit for purpose? | ✓ |

Team name: MIT SEVT Car name: CHOPPER DEL SOL No. 4

| **Steering** | Confirmed |
|---|---|
| Are all components within the vehicle's steering system suitable for their application? | ✓ |
| Are all critical steering components (such as tie rod ends) retained with fasteners that cannot come loose through vibration (i.e. by use of nyloc fasteners, cotter pins etc) | ✓ |
| Is the vehicle's steering system suitable for the application and fit for purpose? | ✓ |

| **Chassis** | Confirmed |
|---|---|
| Is the vehicle's chassis suitable for the vehicle's GVM? | ✓ |
| Is the vehicle's chassis of an adequate strength to sustain the lateral, horizontal and braking forces expected in the event (including at Hidden Valley Raceway)? | ✓ |
| Is the vehicle's chassis suitable for the application and fit for purpose? | ✓ |

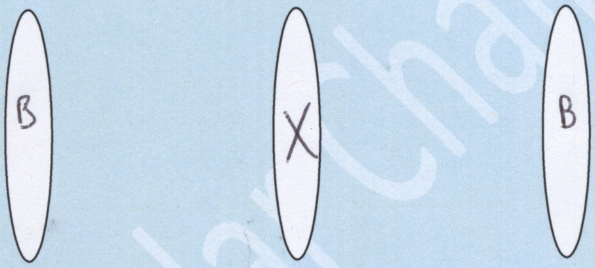
| **Occupant Restraint** | Confirmed |
|---|---|
| Are all components within the vehicle's occupant restraint system suitable for their application? | ✓ |
| Are the vehicle's occupant restraints of an appropriate standard? (meet or exceed AS/NZS 2596:2003 or UNECE Regulation 16 or equivalent) | ✓ |
| Are the vehicle's occupant restraint anchorage points of a suitable size, strength and location to withstand the deceleration forces expected in the application (ie at least 20g deceleration forces)? | ✓. |
| **Continued on next page** | |

Team name: MIT SEVT    Car name: CHOPPER DEL
SOL    No. 4

| **Occupant Restraint (cont…)** | Confirmed |
|---|---|
| Are the vehicle's seat belts and anchorage points, and the area in which they are located, free from any sharp edges or chafing risk? | ✓ |
| Are the vehicle's occupant restraints, and their attachment to the vehicle (anchorages), suitable for the application and fit for purpose? | ✓ |

VEHICLE CONFIGURATION

FRONT OF VEHICLE

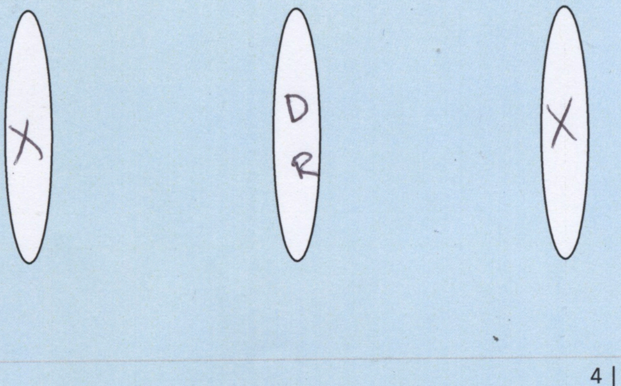


**Indicate wheel configuration by marking wheels not fitted with: X**

**Indicate wheels with mechanical brakes with: B**

**Indicate drive wheel/s with: D**

**Indicate wheels with regenerative braking with: R**



## Structural Integrity Certificate

**The vehicle described on page one of this document has been inspected in accordance with checklists, has been constructed in accordance with sound engineering practice and, and in my professional opinion, is suitable to be driven on public roads as a participant in the 2011 World Solar Challenge.**

| | |
|---|---|
| Name of certifier | MICHAEL / P / ROBERTS |
| Qualifications held by certifier | MIT MECHANICAL ENGINEERING BS.<br>MIT SOLAR ELECTRIC VEHICLE TEAM DESIGN LEAD |
| Signature | Michael Roberts |
| Date of certification | 5/28/2011 |

Comments……………………………………………………………………………………………………

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**MIT Solar Electric Vehicle Team**

**Massachusetts Institute of Technology**
77 Massachusetts Avenue, Building 4-405
Cambridge, Massachusetts 02139–4307

Phone 408-375-1604
mitsolar.com

May 28, 2011

Team: MIT Solar Electric Vehicle Team
Vehicle: *Chopper Del Sol*
Number: 4

Deflection Modeling Report

Chopper Del Sol has two main components that pose a threat to the driver in an impact: the chassis and body. The chassis is a robust steel space frame constructed of aircraft alloy 4130 steel tubing of diameter ranging from 0.5 to 1 inch and thickness ranging from 0.035 to 0.058 inches as appropriate. The seat belt, and thus the occupant, is affixed to the chassis. The body is primarily constructed using kevlar and carbon fiber cloth laid up over nomex honeycomb core in the traditional sandwich panel construction method. The body forms the exterior shell of the solar car to which the array is mounted. All other components of the solar car are mounted to either the body or chassis in such a way as to remain attached during any collision, such that they will not pose a threat to the vehicle occupant.

Frontal, side, and rear impact, rollover, typical and maximum road loading situations were modeled for the chassis using Solidworks Simulation FEA package for forces appropriate to a solar car of GVM 270kg, traveling at ~100km/hr. These estimates represent a generous increase over the actual mass (225kg) and expected speed of the vehicle (90km/hr) in race configuration. The chassis was designed such that no tube should yield under the maximum foreseeable road loading, and that no tube should exceed its ultimate Mises-equivalent tensile strength or deflect more than 2.5cm under any impact loading. The design of the passenger compartment is such that these deflections would not pose a threat to the occupant.

Modeling of the body in a collision is more difficult. By nature, it will experience large deflections by bucking during any significant collision. The design of the car is such that, in the event of a frontal collision, parts of the body near the occupant will remain fixed to the chassis, while parts of the body near the nose will form a "crumple zone" until contact is made with the chassis. This keeps the body intact around the driver while providing the necessary deflection for the chassis to absorb the energy of an impact.

Michael Roberts

Michael Roberts

Mechanical Engineer
MIT SEVT Design Lead

## Chemical Safety Plan for Battery Pack

All batteries are fully sealed in a box whose walls are made of honeycomb laminated with kevlar. Kevlar was chosen due to being electrically non-conductive. The joints at the walls are sealed with epoxy and further covered on the outside of the box with strips of carbon fiber. The holes that allow the wires into and out of the battery box are sealed with a spill-proof mixture of microglass and epoxy. The fans blowing air through the box are also fully sealed to direct air, and in the event of a spill, the chemicals, away from the driver and other electrical components of the car.

The box itself is strapped to an aluminium frame on the chassis of the car via two 1-inch velcro straps.

# MIT SEVT Safety Plan

MIT Solar Electric Vehicle Team

Name of Safety Officer: Thomas Villalon

Contact Details for Safety Officer:

Address:
Telephone (mobile): 1-210-649-0649
Email: villalon@mit.edu

## DUTIES OF TEAM SAFETY OFFICER

- To ensure the whole team is safety conscious, and understand their responsibilities.
- Appoint a qualified first-aid officer as a team member.
- To ensure hardcopies of Material Safety Data Sheets (MSDS) for the relevant battery technologies utilised are available in English and, for non-English speaking teams, also in the native language of the team. Note: A copy of the MSDS (in English) must be provided for each vehicle's Log Book.
- To identify hazards and control procedures associated with battery pack and spares:
- Document safe handling, storage and transport *Document first aid procedures and emergency responses.
- Document procedures for dealing with spill or leakage containment - safe transport to authorised disposal company.
- Develop and document an Emergency Action Plan for support team and driver in the form of a flow diagram.
- Document procedures for dealing with overcharge and overheating conditions, e.g., emergency fire-fighting procedures.
- Note: Fire extinguishers and procedures must be specific to the battery technology used in the vehicle.
- To ensure all members of the team (especially drivers) are trained to execute the Emergency Action Plan.
- To ensure storage containers used for transport of cells/modules carry appropriate warning labels.

### *TEAM MANAGERS DECLARATION*

I have read and understood the contents of this section and the duties of my Safety Officer. My Safety Officer understands the roles and responsibilities required.

Name: ALEJANDRO ARAMBULA

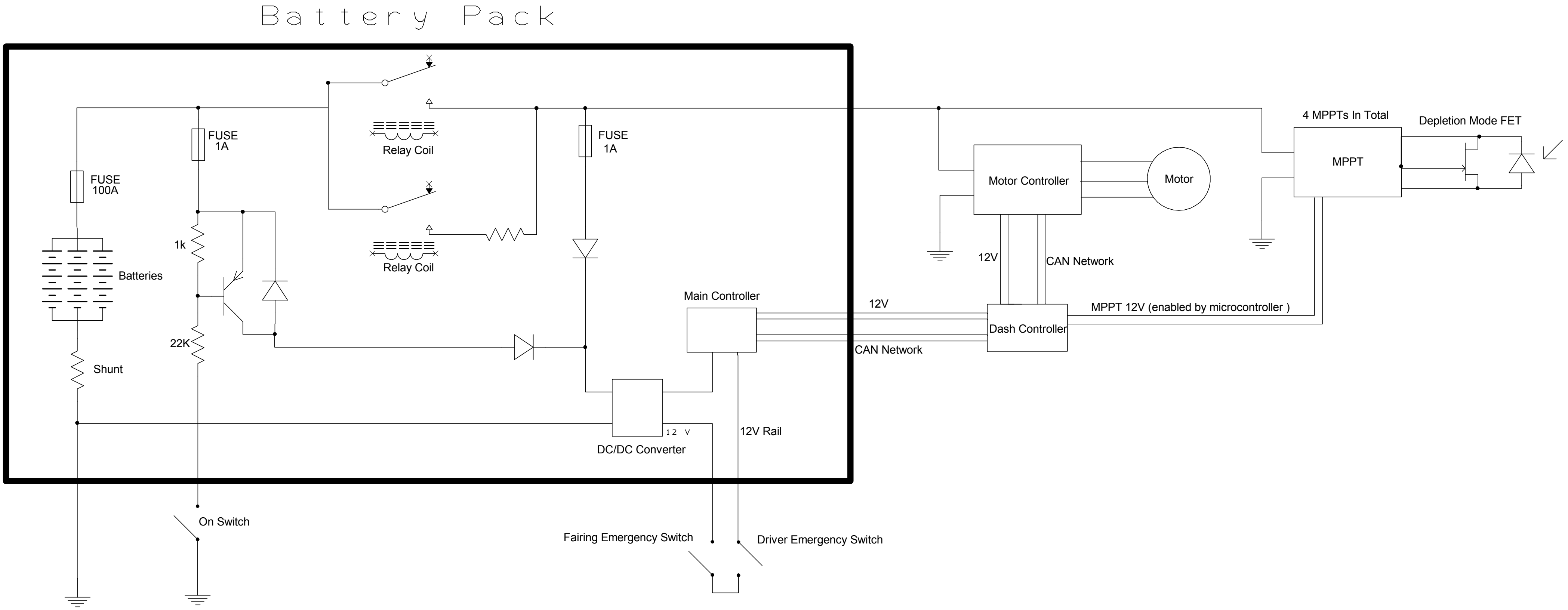
Signed Alejandro Arambula Date 5-29-11

## Observer Arrangements

The Observer will be seated in the passenger seat of the vehicle immediately following the solar vehicle. The Observer's seat and view will not be obstructed by equipments, computers or materials of any kind.

The Observer will be provided with the same meals as are given to team members, three times a day, for breakfast, lunch and dinner. This will change from day to day, but should constitute an entire meal. At the observer's request, more food can be provided.

Sleeping arrangements (tent, sleeping bag, sleeping pad, etc) should be arranged by the Observer ahead of time.


Battery Pack
FUSE 100A
Batteries
Shunt
FUSE 1A
1k
22K
On Switch
Relay Coil
Relay Coil
FUSE 1A
Main Controller
DC/DC Converter
12 V
12V Rail
Fairing Emergency Switch
Driver Emergency Switch
12V
CAN Network
Motor Controller
Motor
12V
CAN Network
Dash Controller
MPPT 12V (enabled by microcontroller )
4 MPPTs In Total
MPPT
Depletion Mode FET

## BATTERY PACK INFORMATION FORM

(In addition to submitting this form and its attachments as part of your documentation package, Dr Rand has requested a separate email copy by the due date. Please email a copy of the same matierial to Dr David Rand david.rand@csiro.au

**Please print in block letters**

TEAM NAME: **MIT Solar Electric Vehicle Team**

CAR NO: **4** Car Name: **Chopper del Sol**

TEAM CONTACT: **Alejandro Arambula**

TEAM ADDRESS:
**77 Massachusetts Avenue**
**Room 4-405**
**Cambridge, MA 02139**

TEL: **1-408-375-1604**

FAX:

EMAIL: **gosolar@mit.edu**

**BATTERY PACK DESCRIPTION:** * Delete as applicable

| | | |
|---|---|---|
| Type of cell/module* | **NCR18650A** | |
| Manufacturer of cell | **Panasonic** | |
| Voltage cell | **3.6V nominal** | V |
| Capacity (20-h rate) cell | **3100mAh nominal** | Ah |
| Weight fully-charged cell | **45.5g** | kg |
| Total No. cells | **459** | |
| System layout | **27 series 17 parallel** | |
| Total battery pack energy | **5.12kWh** | kWh |
| Total battery pack weight | **20.88kg** | To nearest 0.01 of a kg |
| Manufacturers Specification Sheet attached | | [✓ Y] / N |
| Description of Battery Pack Management System attached | | [✓ Y] / N |
| Diagram of Battery Pack Configuration attached | | [✓ Y] / N |

Team Managers Declaration:
*I certify the submitted information is true and correct*

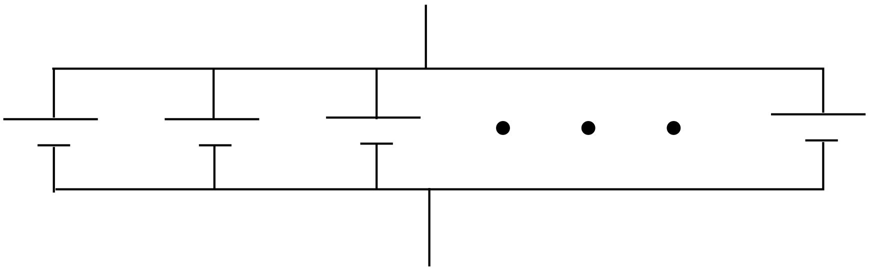
Signed: Alejandro Arambula

Print name: ALEJANDRO ARAMBULA Date: 5-29-11

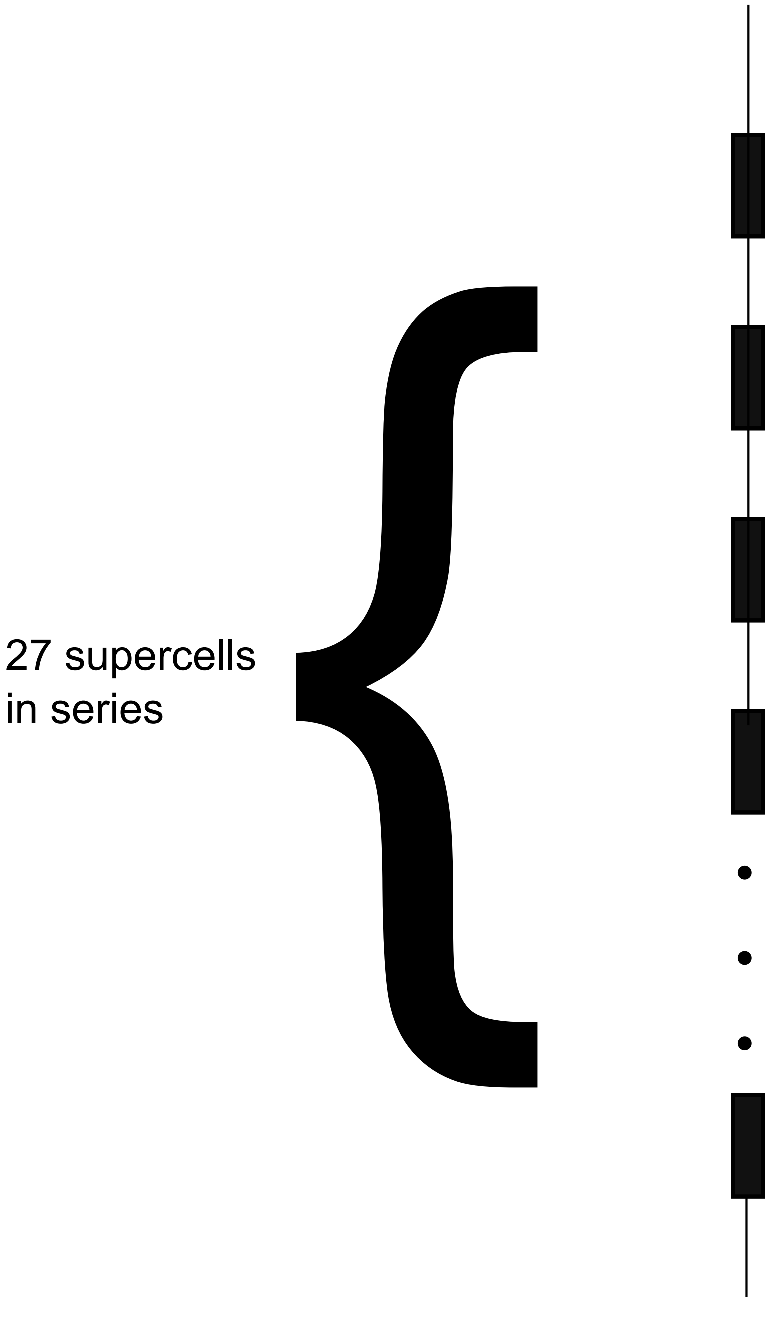
This form and its attachments must be emailed to Dr Rand AND submitted in hard copy as part of the pre-event documentation by 31 May 2011.

*Auth D Rand 31 March 11*

MIT SEVT Battery Pack Configuration: 27 series, 17 parallel



17 parallel = supercell



**Tyre Information**

Number on solar vehicle: 3 tyres

Number in support vehicles: ~40

Size: 16” x 2.75”

Type: To be determined. Currently, SEVT cannot commit to a type of tyre, since there is currently no formal arrangement between WSC and tyre suppliers, namely Michelin and Dunlop.

Once an agreement has been reached and tyres are available, SEVT will then acquire and forward the necessary documentation.

# 1 Array information for MIT Solar Electric Vehicle Team

## 1.1 Specifications

**Make** SunPower

**Type** unmodified C50 monocrystalline N-doped silicon, back-contact, back-junction.

**Size** 14,857.99 square millimeters

**Quantity** 403

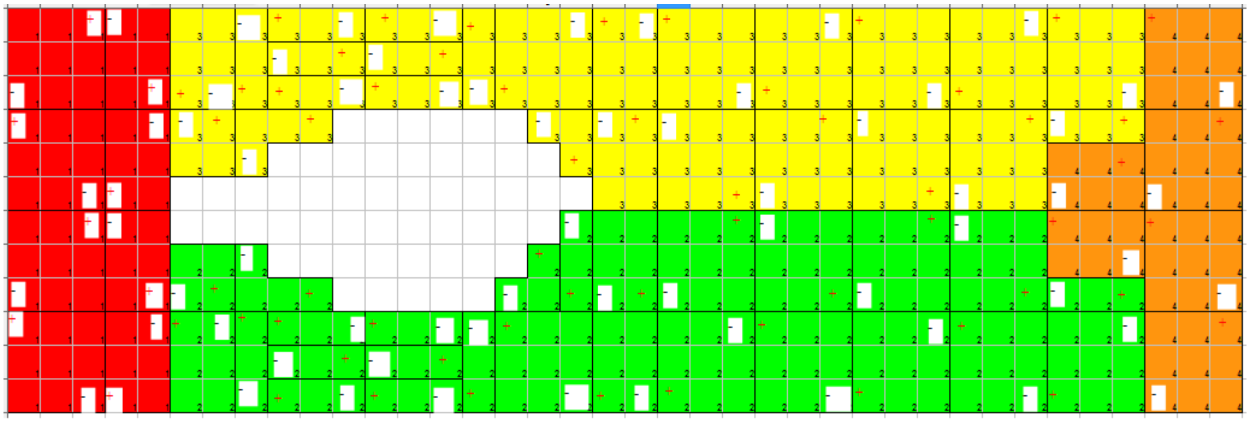
**Output power (nominal)** 1250 watts

## 1.2 Total area calculation

For the calculation of total area, we follow the derivation from the WSC FAQ regarding the SunPower A300 cell, as the cells are identically sized and manufactured from the same type of wafer. Thus, the WSC board itself is the independent authority. Though the error propagation as performed by WSC is incorrect[1], 403 is the approved number of C50/A300 sized cells. Excerpting:

> The data-sheet states the cell dimensions as “150mm diameter with 125mm × 125mm square edges.” As they have written 125mm (not 124 mm or 126 mm) we can assume a manufacturing tolerance (uncertainty) of ± 0.5 mm. These linear uncertainties, when multiplied together provide an area uncertainty of ± 0.25 $\text{mm}^2$.
>
> The data-sheet does not give the overall cell area, but mathematically (OK, we used AutoDesks 3-D modeller) the cell area is 14,857.99 $\text{mm}^2$ to which we must apply our uncertainty of ± 0.25 $\text{mm}^2$.
>
> If we assume the tolerance is always in our favour we can calculate the cell area at 14,857.74 $\text{mm}^2$.
>
> Regulation D.5 states the total surface area of the solar array be no greater than 6.000 $\text{m}^2$. As 403 × 14,857.74 $\text{mm}^2$ gives us 5.987 $\text{m}^2$, the answer to the question is: 403.

## 1.3 Array diagram



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[1] See Appendix A

# A Error propagation in cell area

WSC states error in side measurements of the C50/A300 cell as 0.5 $\mathrm{mm}^2$ so we continue to use this figure. WSC multiplies these linear uncertainties by each other to find the total uncertainty in the area of the cell, and then assumes the minimum cell area to calculate the largest possible number of cells permissible. The stated area uncertainty of the cells is 0.25 $\mathrm{mm}^2$, which is the result of an incorrect calculation. The general formula for error propagation in a function $f(x_1, x_2, \ldots, x_n)$ of random variables $x_n$ each with finite variance $\sigma_n^2$ and assuming zero covariance is as follows:

$$\sigma_f^2 = \sum_n \left(\frac{\partial f}{\partial x_n}\right)^2 \sigma_n^2 \tag{1}$$

As calculation of area is based on length × width, $f = f(l, w) = l \times w$. Thus,

$$\begin{aligned} \sigma_f^2 &= 125^2 \times (0.5)^2 + 125^2 \times (0.5)^2 && (2) \\ &= 7812.5\mathrm{mm}^4 && (3) \\ \sigma_f &= 88.3883\mathrm{mm}^2 && (4) \end{aligned}$$

Thus 88.3883 $\mathrm{mm}^2$ is the true area uncertainty of the cell. Thus the minimum area of the cell is 14769.60 $\mathrm{mm}^2$, which by WSC's standard would permit up to 406 C50/A300 cells (area 5.9965 $\mathrm{m}^2$). We suggest WSC permit no more than 403 C50/A300 cells for the 2011 race as this was the standard posted on their website for the past several years, though it should change for the 2013 race to reflect correct error propagation.

**Team Information**

Team Name: MIT Solar Electric Vehicle Team

Country of Origin: United States of America

Key Members:

Kojo Acquah; Electrical Engineering/Computer Science 2014
Alejandro Arambula, Captain; Aerospace Engineering 2012
Rachel Batzer; Mechanical Engineering 2011
Michael Buchman; Mechanical Engineering 2013
Kai Cao, EE Lead; Electrical Engineering/Computer Science & Physics 2011
Lauren Chai; Mechanical Engineering 2012
George Hansel, Aero Lead; Physics 2012
Alexander Hayman; Electrical Engineering 2008
Alix de Monts; Mechanical Engineering 2013
Chris Pentacoff; Aerospace Engineering 2006
Kelly Ran; Electrical Engineering 2012
Michael Roberts, MechE Lead; Mechanical Engineering & Mathematics 2011
Tom Villalon; Mechanical Engineering 2014

Design Inspiration:

Our 2011 vehicle had its design inspired by data. Data collection and processing during the 2009 race was performed on an immense scale relative to previous races. This data permitted a comprehensive design process, from aerodynamics to array development, in which major design decisions were not based on assumptions but on valid estimates of conditions during the racing state. Further design inspiration was motivated by the Manta series of vehicles, raced by MIT in the late 1990s and early 2000s. These vehicles inspired the long sloping wheel fairings, flattened sides to the vehicle, and a return to the MIT SEVT traditional black-on-white color scheme.

Technical Specification:

Class Entered: Challenge Class
Type of Cells: SunPower C50
Type of Battery: Panasonic NCR 18650A
Type of Motor: NGM SCM150
Cruising Speed: 50mph
Maximum Speed: 70mph

Team Website: www.mitsolar.com

Photos:

Key Contact: gosolar@mit.edu