MODEL SOLAR BOAT HELP DOCUMENT

Revision 5 July 2007

By: Ian Gardner for MSV Committee

This document is the composite of a number of documents which were produced for workshops conducted for various schools.
It is intended to give a basic understanding of the critical features involved in building a boat that functions. It is hoped that it will better guide supervisors and students to produce a functioning model solar boat.

CAUTION: Test results in this document were obtained using standard production Solar panels, motors and propellers available at the time of testing. Some will no longer be in production. Typically the power output of solar cells is increasing constantly as production processes improve. Consequently any new solar panels, even if apparently identical to older ones, will probably perform better than the test results here indicate.
The combination of components tested was somewhat random and not intended to be the combination to give best results. Neither was it intended to suggest which components are the best or which you should use. The only purpose of this whole exercise was to show how easily a boat that would actually function is to build.

ADDITIONAL RESOURCES:

Model Solar Boat Guide - By Wayne Young
Competition rules and regulations are available from the Tasmanian Website.

INDEX

MODEL SOLAR BOAT
BASIC DESIGN POINTS TO CONSIDER

- Hull should be stable, have good hydrodynamic shape to minimise drag and have sufficient buoyancy to support solar panel & motor.
- Keep weight as low as possible.
- Do NOT shade any part of your solar panel. If only one cell in a string of cells that are connected in series is shaded, the power output from that string of cells will be reduced to near zero.
- Solar cells will produce their maximum power when directly facing the Sun that is when the Sunlight strikes them at 90 Degrees. There will be a power increase just by pointing the cells directly at the Sun compared to when they are laying flat.
  Caution: If you tilt a large single panel up at an angle it will act like a sail, any gains in power output may be lost due to increased air drag as the boat moves. In a strong wind the boat may even be blown backwards.
- Test your boat to determine which solar panel configuration and propeller choice is best in different light conditions. By solar panel configuration we mean do you run with all the cells in series or perhaps two groups of half your cells per in series and these two groups parallelled. Or any other configuration. Refer to sections on SOLAR CELLS for details. Overloading the motor with too large a propeller or one with too much pitch for the power available from your panel will significantly reduce performance.
- Make certain that the propeller shaft and motor shaft are in alignment and remain so at all times, misalignment will waste a lot of power and significantly degrade boat performance. Pay attention to your coupling as power can be lost here. A **SOFT** plastic tube is in common use and is superior to hard couplings.
- Ensure your boats guides are free running on the guide wire.
- Keep the propeller shaft angle as low as possible to maximise the forward thrust component and minimise the lifting effect. A propeller facing directly down will not push the boat along but just push it upwards.
  Do not have the propeller too close to the water surface or it will suck air down (ventilation) which will significantly reduce the thrust. A plate parallel to the water surface above the propeller and below the water surface will help in reducing or eliminating ventilation. Obviously running the propeller deeper in the water will also help but the shaft angle may become an issue.

HULL:

- Must float. It is required to carry motor and solar cells.
- Be constructed from water resistant materials or if not the material used must be sealed.
- Be stable not roll over, remember wind effects.
- Shape. Should have a low drag shape and slip easily through the water.

POSSIBLE TESTING:

Test buoyancy of hull.
Test roll over stability.
Tow hull in tank and record the force required, compare various different hull shapes and choose the best for your boat.

GUIDING:

- Normally a wire with a hook bent in the top that hooks over the fishing line guide is used.
  CAUTION: Make your guide hook long enough so your boat will not "HANG" on the line.

PROPULSION:

- Can be any method you like except using the guide wire. Some possibilities are:

  - Rowing/oars
  - Paddle wheels
  - Airscrew
  - Conventional water propeller is by far the most common, in fact almost universally used. **Select a propeller that transfers all the solar panel power available to the water to drive your boat. Keep the shaft angle low to maximise the forward thrust component and minimise the vertical thrust component.**
    Use a good quality shaft and stern tube to minimise friction losses. Lubrication of the shaft in the support bearings will also help reduce friction losses.
    In order to understand how a propeller functions in driving a boat we can take the simplified view of a screw advancing in a nut as it is turned and see the propeller doing this in the water. The distance the propeller would advance in one revolution with no slip is the pitch, increasing the pitch increases the load on the motor. Conversely decreasing the pitch decreases the load on the motor.
    An alternative is to look at momentum. The propeller pushes a column of water rearwards at high velocity the reaction force pushes the boat forwards.

Be cautious a very small propeller can easily use all the power available from your panel. It is also common for boats to be fitted with large propellers that overload the motor and pull the solar panel down into a low power operating point - SIGNIFICANTLY DEGRADING PERFORMANCE
See the test results section for propeller details and thrust produced.

PROPELLER TESTING CAUTION:

The only way that propeller testing results can be considered accurate is when tests are carried out on a free running boat. The very act of holding the boat stationary during testing increases the load on the motor thus introducing errors which can be significant. Consider a full size boat powered by a 140 HP motor and capable of 80 KPH. With the boat held stationary in the water and the motor at full throttle it can only manage 3000 RPM. However with the boat running free the full throttle RPM increases to 5000.

POSSIBLE TESTING:
Different sized propellers at different Sun levels. Measure thrust obtained or time taken to run the length of a pool. (A different size propeller need not be a propeller of different diameter it could be propeller of the same diameter but different pitch.
Repeat these tests with your solar panel configured differently (eg. series–parallel)

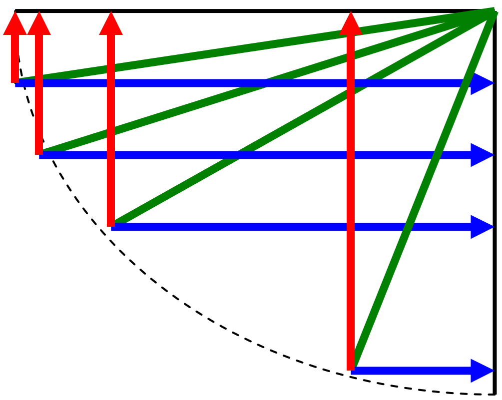
HINT: With the boat running free in a pool measure the voltage output from the solar panel. A voltage output from your solar panel lower than 0.4 volts per cell in series would indicate an overload condition. When overloaded the power available from your solar panel is reduced below the power it could potentially provide.
A voltage higher than this 0.4 volts per cell in series would indicate an underloaded condition where all the power potentially available from the solar panel is not being used. Refer to SOLAR CELLS section later in this document for details.

PROPELLER FORWARD THRUST VARIATION WITH SHAFT ANGLE:

The diagram below represents the forward thrust in BLUE and the Vertical thrust in RED at various shaft angles.
This diagram is to scale so the relative magnitude of the forces is depicted by the line length. The GREEN line represents the propeller shaft angle and magnitude of the propeller thrust. Thrust direction is towards the intersection point.

Note how at relatively low shaft angles (near parallel to the water surface) the forward component of the thrust (BLUE) only reduces slightly as angle is increased. However as the shaft angle exceeds 20 degrees, reduction of the forward thrust component becomes significant.
More importantly the vertical component of the thrust (RED) increases rapidly as the shaft angle is increased. This can have a significant effect on boat performance as it lifts the stern and changes the balance of the boat, consequently influencing the way the boat moves through the water.

Diagram 1. Thrust Variation with Shaft Angle



GREEN LINE REPRESENTS MAGNITUDE AND DIRECTION OF PROPELLER THRUST
BLUE LINE REPRESRNTS MAGNITUDE AND DIRECTION OF FORWARD COMPONENT OF PROPELLER THRUST (DRIVE PORTION)
RED LINE REPRESENTS MAGNITUDE AND DIRECTION OF VERTICAL COMPONENT OF PROPELLER THRUST (NON DRIVE THRUST)

SOLAR CELLS:

There are many solar cells available that can be used for model boats and will fall within the area requirements of the regulations.
How do they work? Simplistically, light falling on an atom in the semiconductor solar cell material imparts its energy to an electron in an outer orbit of this atom. This gives the electron sufficient energy to break free and become an electric current capable of doing work.

SOME SOLAR CELL BASICS:

- Connecting cells in series adds the voltages of the cells. Silicon cells have about 0.5 Volts per cell so 3 cells in series will give about 1.5 Volts.
- Connecting cells in parallel adds the current. If each cell can deliver say 1 Amp at a particular Sun level 2 cells in parallel will deliver 2 Amps at the same Sun level. (More surface area = more current)
- The Open Circuit (or no load) Voltage of each cell varies only slightly with Sun level but the maximum current available (Amps) varies directly with Sun level. The brighter the Sun the more current is available.
- The maximum power will be obtained when the Sun strikes the cells at 90 degrees. (See test results later for an indication to effect of tilting panel.)
- Shading only one cell in a series array will reduce the power output significantly.
- Power = Volts x Amps (in watts)
- **Solar cells can only deliver current up to the limit imposed by the prevailing light level. If the electrical load (your motor) has a resistance so low that it wants more current than is available (ohms law applies V = R x I) the voltage of the cells will drop rapidly to near zero. Consequently the power delivered to the load (your motor) will be near zero.**
  FOR BEST RESULTS (maximum power transfer from panel to motor). IT IS CRITICAL TO MATCH THE LOAD TO THE SOLAR PANEL OUTPUT AVAILABLE AT THE PARTICULAR LIGHT LEVEL PREVAILING.

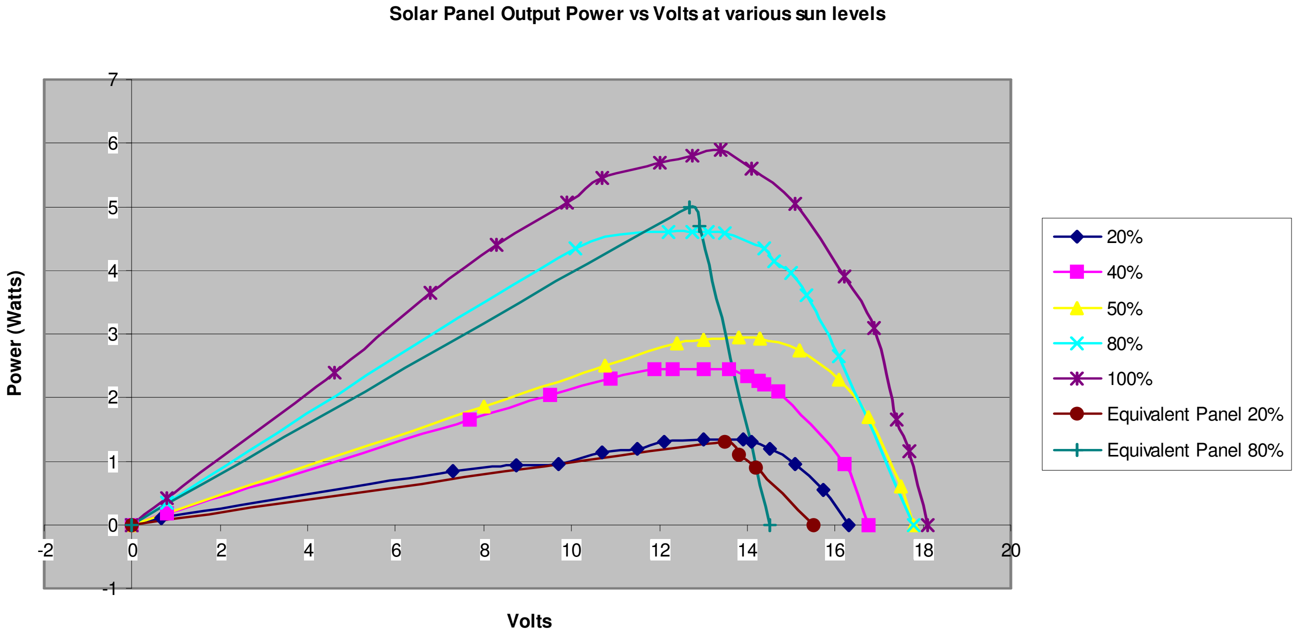
  TO IMPROVE THE LOAD MATCH, CHANGING THE MOTOR, PROPELLER OR THE SOLAR PANEL CONFIGURATION ARE THE ONLY OPTIONS IN A DIRECT DRIVE CONFIGURATION.

SOLAR PANEL CONFIGURATION COULD BE:

- **All cells in series.**
- **All cells in parallel**
- **A combination of series and parallel.**

REMEMBER:
FREE RUNNING ON WATER TESTING OF THE COMPLETE BOAT IS THE ONLY ACCURATE WAY TO TEST.

The graph below shows the power output vs. volts for a panel constructed from 12 Dick Smith segments each of 3 cells all wired in series. Note how the power peaks then drops off rapidly on both sides of the peak.
On the right hand side of the peak it is underloaded. A larger propeller or a propeller with more pitch is needed to increase the load and take advantage of the extra power available.
On the left hand side of the peak it is overloaded and a smaller propeller or a propeller with less pitch is needed to reduce the load and obtain more of the available power to drive the boat.

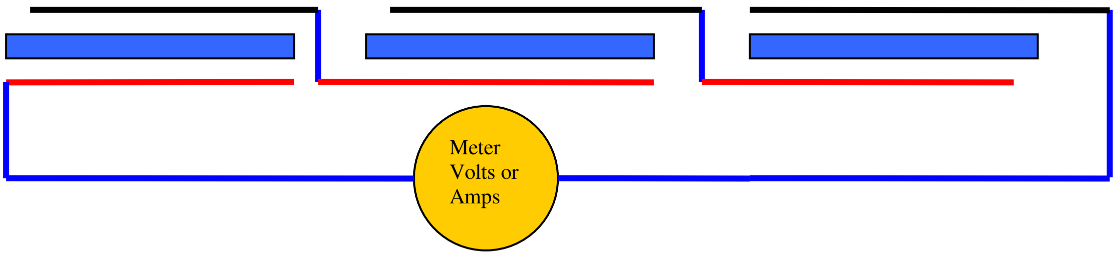


Changing the panel configuration to reduce the voltage and increase the current has a significant effect, as lower voltage reduces motor RPM which significantly drops the propeller load on the motor whilst the increase in current increases the available torque. Both these effects combine together to significantly change the operating parameters.

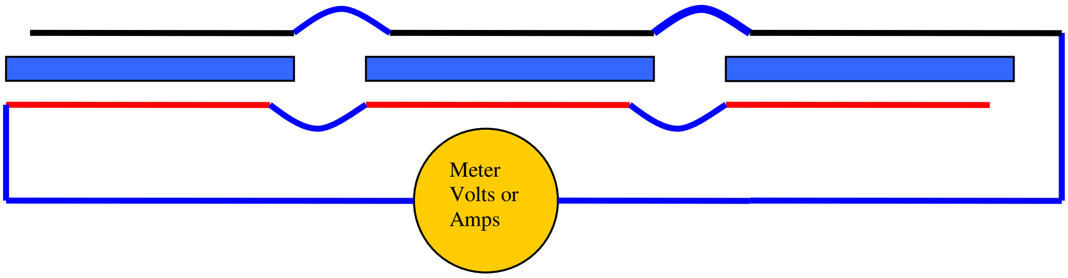
To help you in determining the load condition on your boat panel consider the following: The maximum power voltage for a silicon cell occurs at about 0.4 volt per cell. Using this figure the panel above with 30 cells in series would have maximum power occurring at about 12 volts. Examining the graph this is a fair average for all the sun levels.
Consequently if you measure the voltage of your solar panel while the boat is running free in a pool (take care the leads from panel to voltmeter do not load the boat and tend to either pull it faster or slow it down) you can easily tell if the panel is under or over loaded and consequently what actions you should take to improve the situation.

WIRING DETAILS & HINTS for SOLAR CELLS & MODULES

Cells connected in series and parallel



Series: cells connected positive to negative



Parallel: all cell positives connected together and all cell negatives connected together.

When cells are connected in series that is the +ve of one cell connected to the –ve of the next forming a "string" of cells, the voltages add. So two cells connected in series would have an output voltage twice the voltage of each cell alone. The current (amps) available remains the same as that available from individual cells.

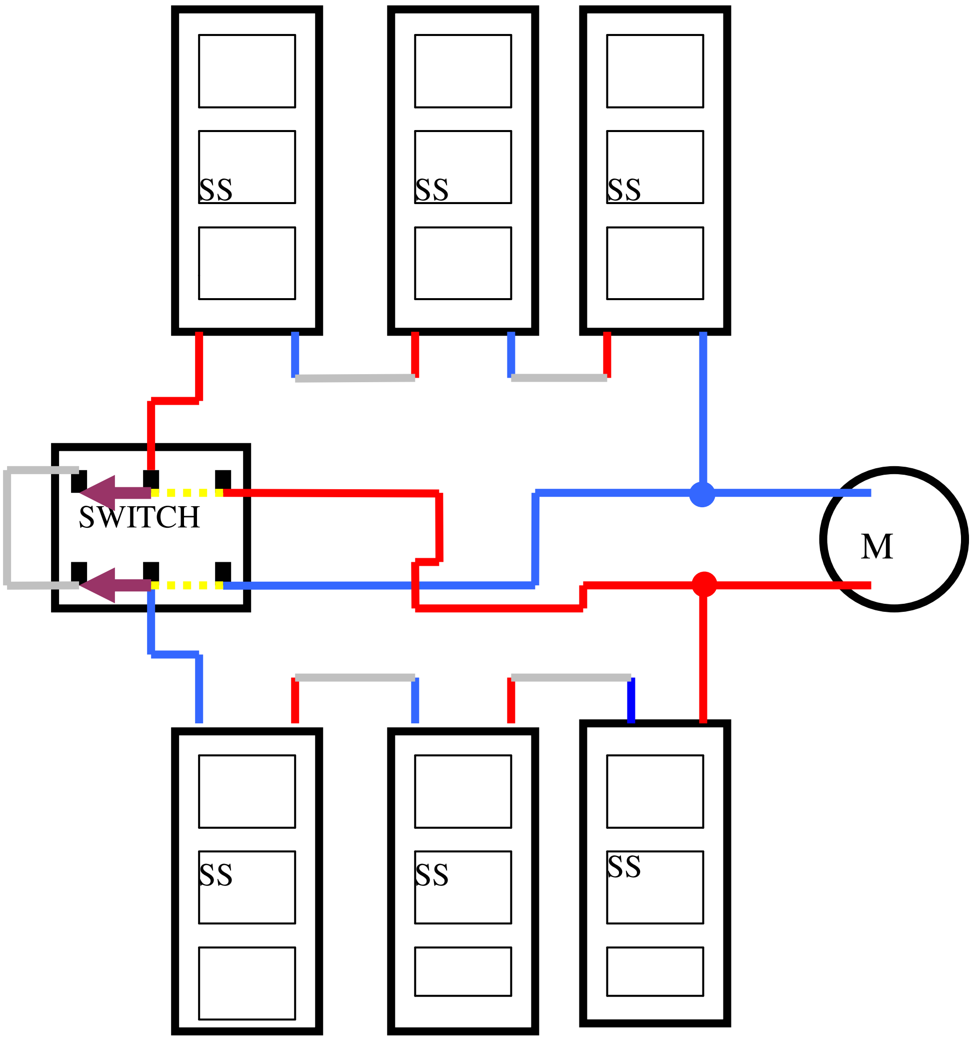
When cells are connected in parallel that is all cell positives connected together and all cell negatives connected together the current available adds. So three identical cells connected in parallel would be able to deliver three times the current that each cell alone could deliver. The voltage however will remain the same at the voltage available from each cell.

CIRCUIT TO CONNECT 6 DICK SMITH MODULES IN:

A ALL SERIES

B 2 GROUPS OF 3 MODULES IN SERIES THEN PARALLELED

A circuit to achieve this by simple switching is shown below.



DRAWING LEGEND:

SWITCH: Three Position double Pole Centre OFF

NOTE: SWITCH DRAWN in position to have all cells in series. The brown arrows show the connections made within the switch. The yellow dotted line shows the alternate connections made within the switch when it is switched to have the 2 groups of cells in parallel. When the switch is in centre position it is off and no connections are made within the switch.

To change motor direction of rotation, reverse the positions of the wires on the motor terminals.

M is MOTOR

SS Solar Modules Dick Smith Cat. O 2015

POSITIVE WIRES in RED, NEGATIVE WIRES in BLUE

OTHER interconnecting wires in GREY

POWER VARIATION WITH PANEL ANGLE:

Below is a table of power increase measured at different times of day (16/1/07 Daylight Saving Time) with the panel laying flat on the ground and then tilted 35 Degrees and rotated to directly face the Sun.
As the conditions were hazy due to high level smoke (bushfires) causing the available power to be variable the % increase in power has been used so as to give us a useful measure of any improvement.

TIME	PANEL FLAT	PANEL TILTED	
	ISC mA	ISC mA	%
9.30 am	225	320	42
11.00 am	350	425	21
12.00 noon	390	450	15
1.00 pm	400	420	5
2.00 pm	420	440	5
3.00 pm	370	425	15
4.00 pm	340	420	23
5.00 pm	300	420	40

Examination of these results shows that around the middle of the day there is some power gain to be had by facing the panel to the Sun. The gains increase significantly the further away we get from midday.
Most racing occurs in the time span of 11.00 am to 3.30 pm. At either end of this time span a 20% increase in power is possible by facing the panel to the Sun.
Many competitors already do this. **CAN YOU AFFORD NOT TO?**
CAUTION: A Panel at an angle acts like a sail it will increase air drag and in a strong head wind your boat may even be blown backwards.

POSSIBLE TESTING:

- Check the short circuit current available from a cell at various Sun levels (use a multimeter on the current or amps range)
- Check the short circuit current variation from a cell as you face it towards the sun and then slowly turn it away from the Sun.
- Connect cells in series and measure the open circuit Voltage as more cells are added.
- Connect cells in parallel and measure the short circuit current as cells are added.
- Shade one cell in an array and observe the reduction in short circuit current.

WIRING:

- Keep wiring neat and well laid out.
- Colour code wiring, the convention is Black for Negative and Red for Positive.
- Insulate any bare wires that could touch and short circuit.
- Secure wires that could move and fracture either themselves or other components such as switch or motor terminals.
- Make certain all connections are tight making good electrical contact and cannot work loose during operation.

MOTOR:

This type of DC motor is essentially driven by magnetic attraction and repulsion between the permanent magnets in the motor stator (case) and the rotor which is an electromagnet powered by your solar panel.

- Motor RPM (revolutions per minute) varies directly with Voltage.
- Torque (twisting force on the motor shaft) varies directly with current (Amps)
- **The slower a motor is turning (lower RPM) the lower will be its electrical resistance, and consequently the chance of overloading the solar panel is increased. SEE DESCRIPTION IN SOLAR CELLS. To overcome this problem we can reduce the motor load and let it speed up by switching to a smaller propeller or make more current available by changing the solar panel configuration to series and parallel.** (This change of panel configuration reduces voltage which slows the motor. A slower propeller speed significantly reduces power required to drive it. So we tend to see a double effect from only this one change)
- **Matching the motor load to the available panel output is critical for best performance.**

COUPLING:

Connecting the motor to the propeller is essential if the boat is to function. This area has the potential for high loss of power if not done correctly.
Alignment of the motor and propeller shaft is critical if losses are to be minimised, once obtained this alignment must be maintained at all times.
Testing has shown that a soft silicon rubber tube coupling tolerated slight alignment errors without measurable power loss, but a harder PVC tube coupling had higher losses.

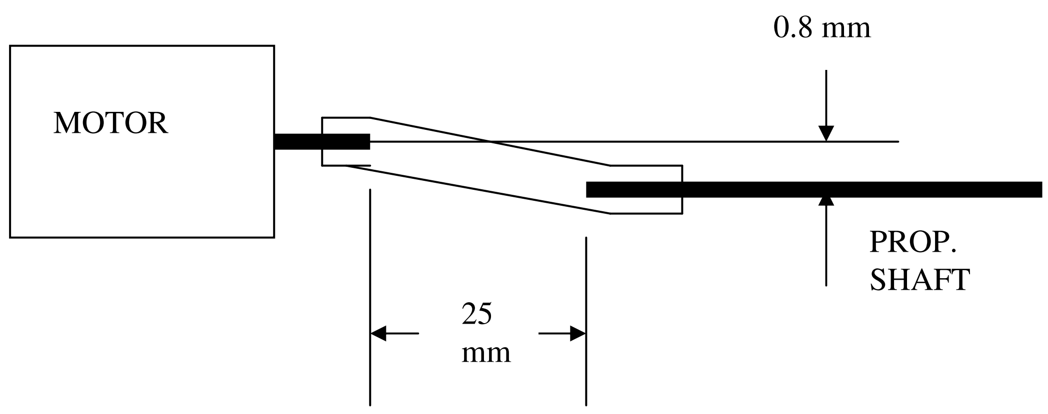
COUPLING:

POSSIBLE TESTING:

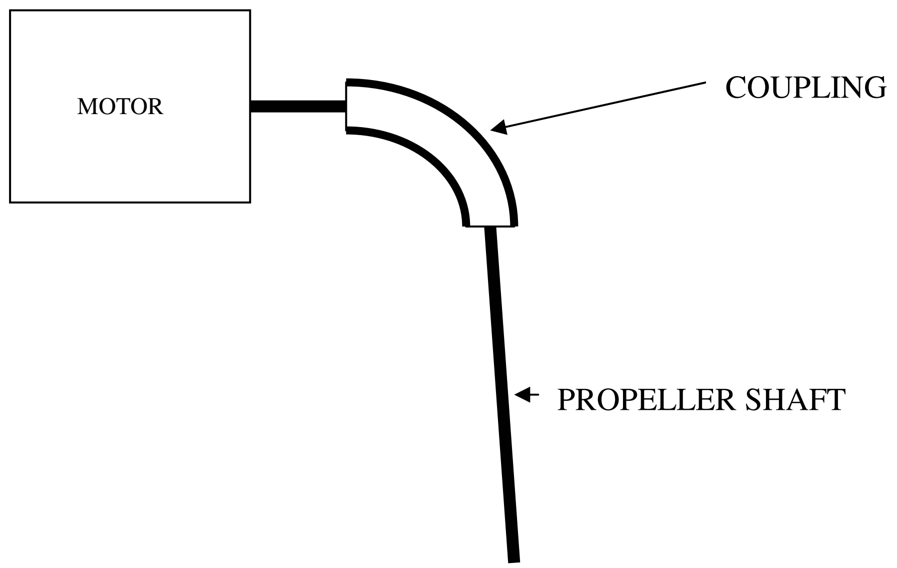
To determine the difference between couplings when alignment of motor and propeller shaft is not "perfect"

Two misalignment cases are suggested.

Case one, motor and propeller shaft parallel but vertically shifted by 0.8mm



Case Two: The motor and propeller shafts at an angle to each other but extensions of the shaft lines would intersect. I suggest testing up to 90 Degrees out of alignment.



Test by running the motor from a battery supply using 2 cells in series giving 3 Volts and note the current required by the motor. This is an indication of the power required. You can test both the soft and hard tube coupling as well as the effect of alignment.

COMPLETE BOAT:

TESTING:

Test boat in pool with different propellers, motor and solar panel configuration. I.e. all cells in series and a combination of series and parallel at different Sun levels.
Record the results of time taken to travel a set distance and the Sun level. From these results decide the best configuration for different Sun levels. Use this data to set your boat up on race day.

Note: Test with boat running free if possible as static testing loads the Motor more than free running. Free running tests will give more relevant data.

APPENDIX 1: MEASURING SUN LEVELS

Many references are made in this document about Sun levels. Your ability to measure them is critical to making sense of any testing.
DO NOT USE AN ORDINARY LIGHT METER these are typically set up to respond to the light frequencies the human eye is sensitive to.
Silicon solar cells respond to different frequencies so readings taken on an ordinary light meter will not be relevant to their performance.

It is suggested that you construct a meter for your own use. It is very simply done only one solar segment Dick Smith Cat. No O 2015 and any multimeter capable of measuring from 0 to 100ma is required.

The solar segments output terminals are connected directly to the multimeter test leads, positive to positive and negative to negative.
The meter is switched to the milliamp range and the output of the solar segment adjusted to 100 ma in full Sun by partially covering it with tape or any material that stops sunlight reaching the cells.
We now have a meter that reads Sun level in %. It responds exactly the same as our silicon solar panel as it is a silicon solar cell.

Calibration is the most difficult thing about this meter. **WHEN IS IT 100% SUN??**
Around midday when the sky is clear between November and February is best.
Make sure to point the solar segment directly at the sun (angle of incidence 90 degrees)
However for your testing it does not matter if the meter is not calibrated to exactly 100% Sun so long as you conduct all tests using the same meter and do all set ups on race day using the same meter everything will be ok.

The photograph below shows how to set up such a meter to record sun %.

On the left is a standard solar segment for comparison. In the centre is the partly covered segment which has been mounted on a piece of timber for convenience. On the right is the multimeter

APPENDIX 2:

MOTOR, PROPELLER & SOLAR PANEL TESTS

For students the building of a boat that does not run is disappointing and sends a negative message. For this reason the following document has been prepared to give you a starting point for a drive system that will function.

The components listed here are just a few of the many that have been tested. They were chosen for inclusion here as they are readily available and have given good results.

DETAILS OF TESTING:

Testing was conducted by placing the solar panel being tested on a light box and varying the light intensity to simulate different sun levels.

MOTORS TESTED:

SCORPIO - See SCORPIO SOLAR RACING CATALOGUE
DICK SMITH Cat. No. P 8980

SOLAR PANELS TESTED:

SCORPIO - See SCORPIO SOLAR RACING CATALOGUE
This unit was tested in two configurations.
All cells in series shown as **SCORPIO SER** in results table.
Two groups of 5 cells in series and these two groups paralleled together shown as **SCORPIO//** in results table.
The solar panel used in these tests was tested in full sunlight and gave the following power reading 4.6 Watts at 4.68 Volts and 0.98 Amps when all cells were in series.

DICK SMITH Cat. O 2015 (1.5 Volt 500 mA)
6 of these segments fall within the area allowed in the boat regulations.
They have been tested in 3 different configurations.
All segments in series shown as **DS ALL IN SER** in results table.
2 groups of 3 segments in series, these 2 groups then paralleled shown as **DS 3 IN SER//** in results table.
3 groups of 2 segments in series, these 3 groups then paralleled shown as **DS 2 IN SER//** in results table.
The solar panel used in these tests was tested in full sunlight and gave the following power reading 3.8 Watts at 8.35 Volts and 0.45 Amps when all cells were in series.

PROPELLERS TESTED:
Of all the propellers tested one gave much better overall results. Unless otherwise noted all the results detailed here were obtained using this propeller.
This propeller was from Radio Active 81 Font Lane Cranham Essex 1XL England.
It was a 30 mm Diameter 3 blade propeller Cat. No. RAD-MA3045/A.
For an assembly of this propeller together with shaft and 153 mm long tube the Cat. No. is RAD-MA3046
This same propeller as an assembly with a 203 mm long tube has the Cat. No. RAD-MA3048.

CAUTION: Take great care if you use a different propeller than the one listed above. Other propellers we tested gave generally lower thrust levels due to increased loading of the motor. Before using a different propeller test it to verify that its performance is acceptable to you.

Note the test results show just how important the selection of Propeller, Motor and Solar Panel configuration is.
Thrust can be halved by changing even one of these parameters.

ADDITIONAL DATA:
After examining the data here it seemed that some additional data on high performance motors would possibly be of use to students who wished to participate in the higher level competition.
Consequently tests were conducted on both a Faulhaber 2232 6 Volt Motor and a Faulhaber 2224 6 Volt Motor, using the Solar Panels and propellers listed here .
Additionally the Scorpio 2 Blade white plastic propeller and some 2 Blade high pitch unit from Radioactive were tested as well.
Additionally tests were carried out with a 2224 6 Volt motor using a 4:1 gear reduction. These results are included and are VERY interesting.
This additional data is given in the table following the photographs.

RESULTS:

TEST 1 SCORPIO MOTOR (30 mm Dia. Prop MA 3045/A)

% SUN	SOLAR PANEL				
	DS ALL IN SER	DS 3 IN SER//	DS 2 IN SER//	SCORPIO SER	SCORPIO//
100	35	78	64	85 (65)	55 (60)
80	27	61	56	70 (58)	55 (60)
60	19	45	51	55 (36)	55 (52)
40	10	29	42	32 (18)	45 (50)
20	0	11	20	14 (6)	31 (19)

The above table shows the results obtained from testing the Scorpio motor. The figures in the table are thrust values in gm. The best figures are highlighted to indicate which set up you would choose for your boat
The red figures in brackets were obtained by fitting a 40 mm diameter. Propeller (again from Radio Active England Cat. RAD-MA3045M2) they show how thrust is reduced due to overloading the motor.

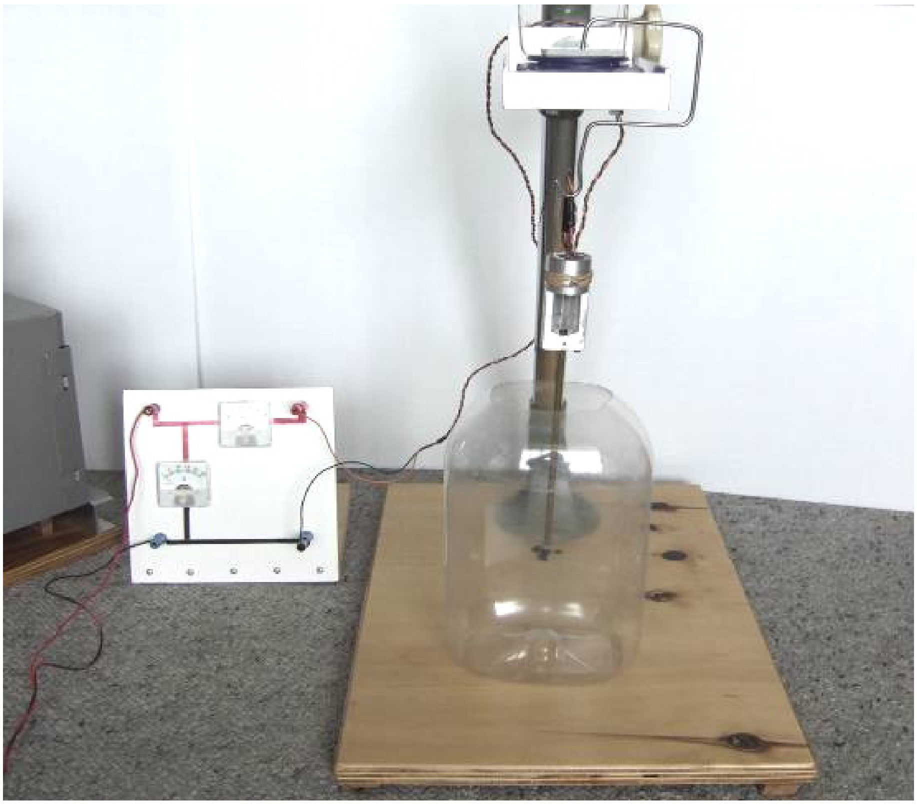
TEST 2 DICK SMITH P8980 MOTOR (30 mm Dia. Prop MA 3045/A)

% SUN	SOLAR PANEL			
	DS SER	DS 3 IN SER//	SCORPIO SER	SCORPIO//
100	70	34	43	15
80	55	33	43	15
60	41	33	42	15
40	23	31	41	15
20	9	23	28	15

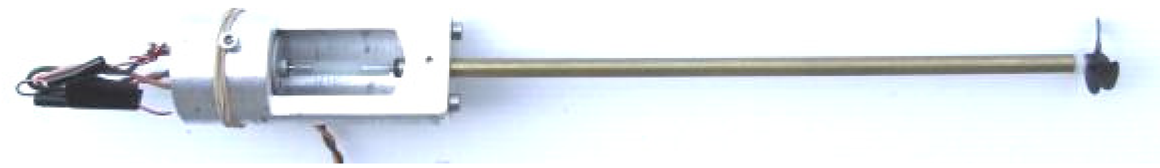
The above table shows the results obtained from testing the Dick Smith motor. The figures in the table are thrust values in gm. The best figures are highlighted to indicate which set up you would choose for your boat
Note the thrust figures for Scorpio// are low and all the same this is because this solar panel configuration had insufficient voltage available to drive any more current into the motor no matter what the light level was. The same thing can be seen in the thrust results above 49% sun for the **DS 3 IN SER//** test.

NOTE: Static thrust was measured in all these tests. The thrust delivered by the propeller when your boat is moving through the water will differ from the static thrust due to the effect of the boats forward speed.
Free running tests on your boat to determine the best change point from series to series and parallel is required.
FOR SIMPLICITY OF SET UP YOU MAY DECIDE NOT TO CHANGE THE SOLAR PANEL CONFIGURATION FROM SERIES TO SERIES PARALLEL AND ACCEPT THE SLIGHT DROP OFF IN PERFORMANCE.

Photographs of test set up and equipment tested.



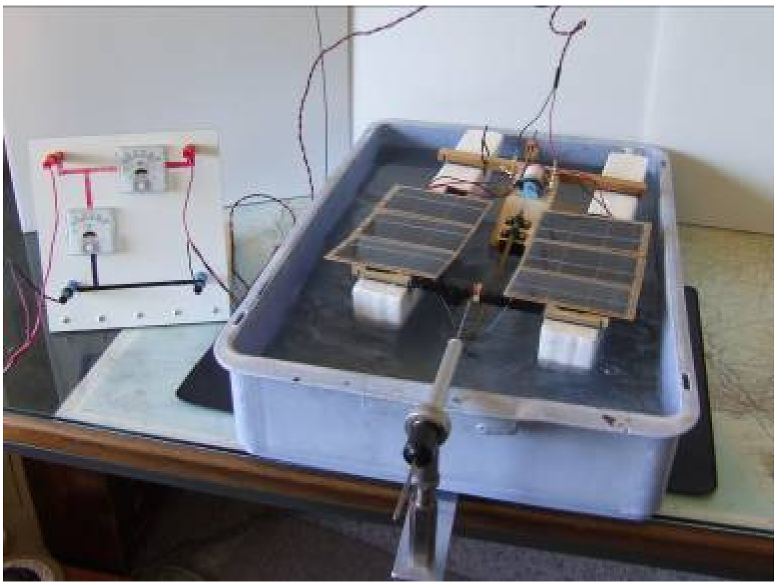
Overall view of motor and propeller hanging in water jar.



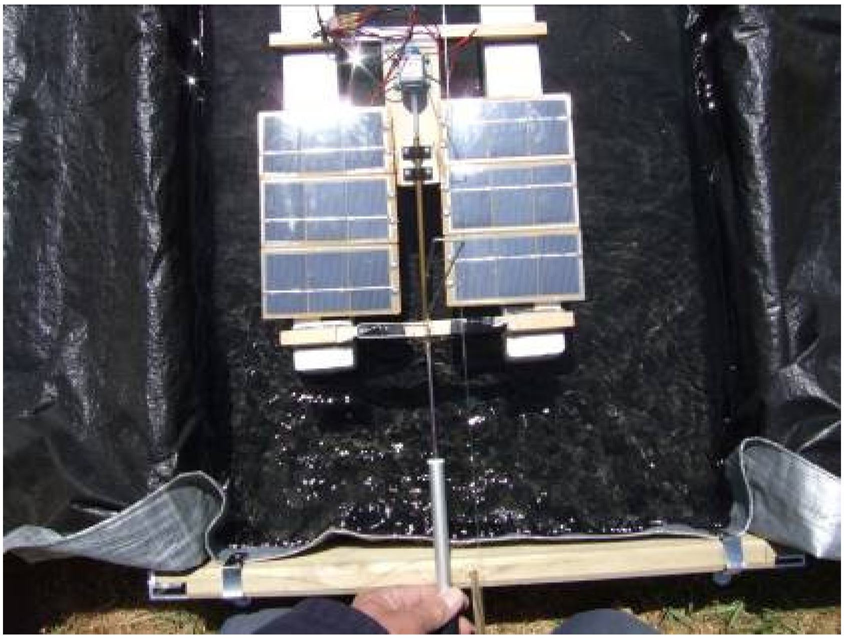
Motor and propeller mounted in holder.

Detail view of motor and propeller holder supported on scale.

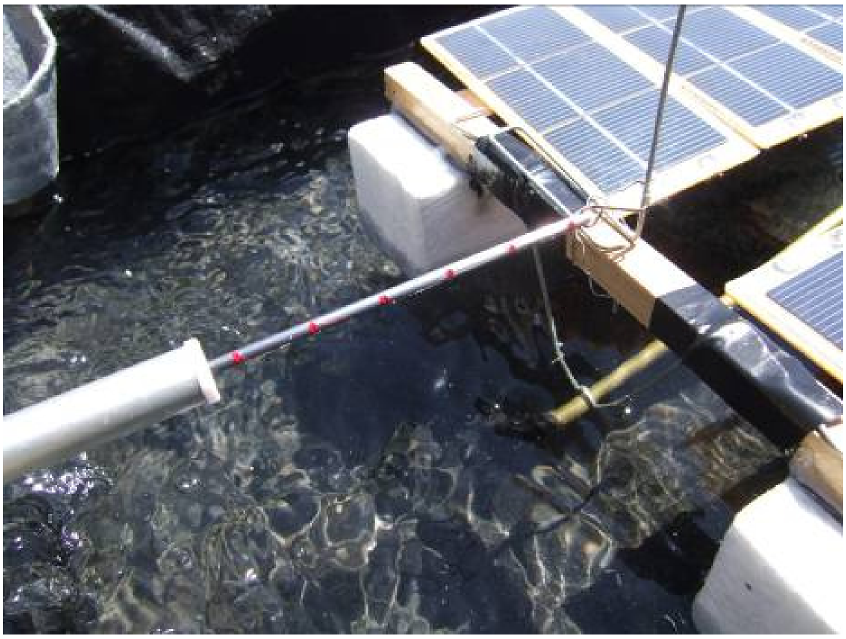
ALTERNATE TEST METHOD:
Shown below are photographs of an alternate test using the actual boat in either a pool or a test dish. The boat pulls against a spring balance which measures thrust (caution make sure your spring balance is accurate when placed in the horizontal position.) This still however has the problem of measuring static thrust.



Boat in test dish



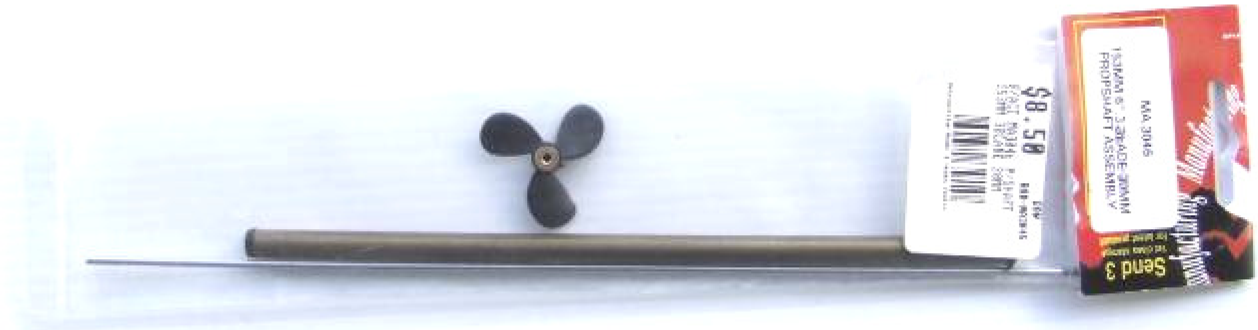
Boat in test pool



Thrust measuring with spring balance

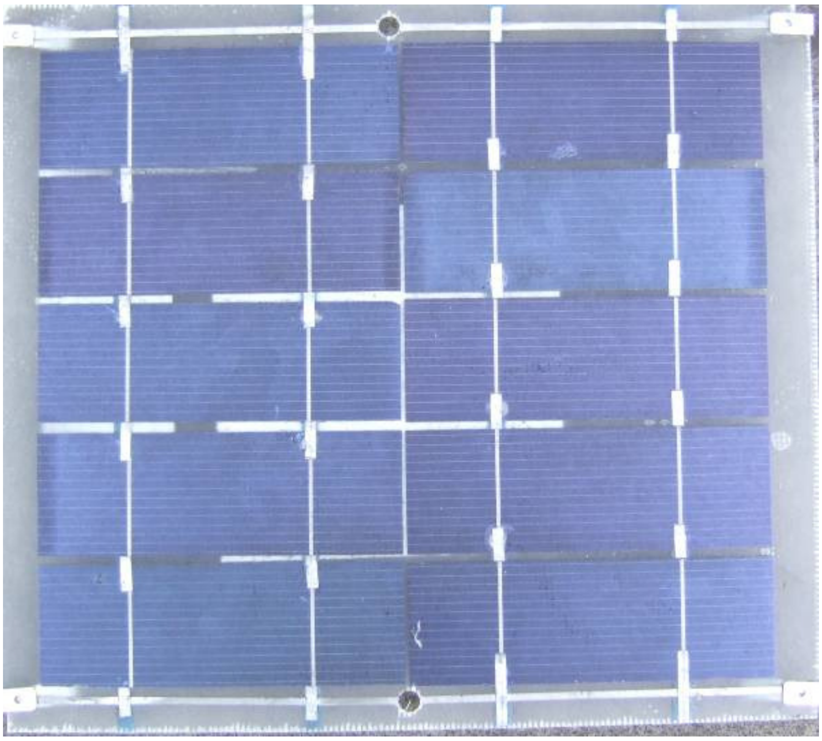
PHOTOGRAPHS OF COMPONENTS:

SCORPIO Motor on left and DICK SMITH Motor on right.

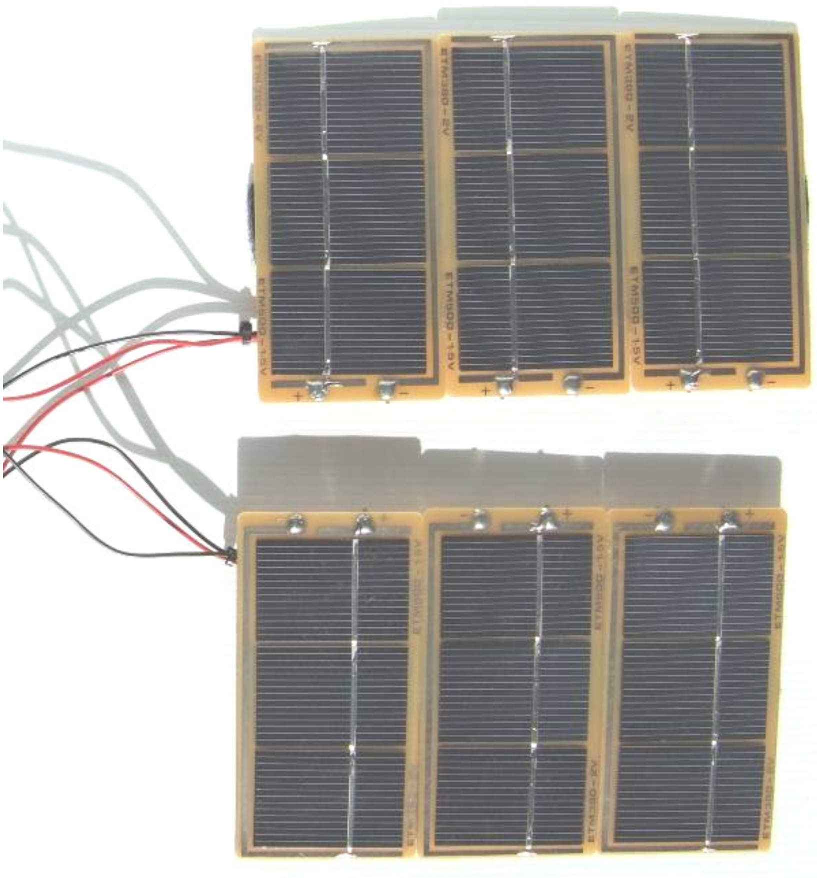


Propeller and tube assembly as supplied by radio Active England.
(MA 3046)

Propeller top and bottom view. (MA 3045A)



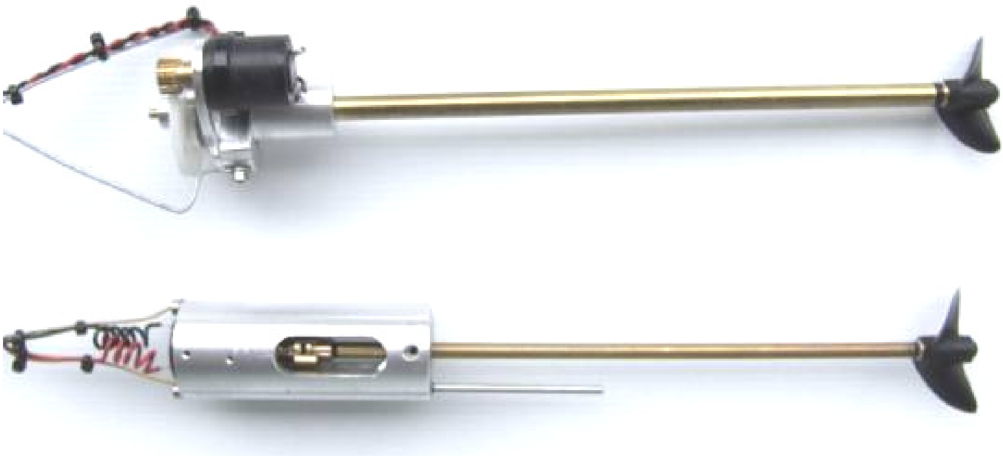
SCORPIO SOLAR PANEL



DICK SMITH SOLAR PANEL 6 SEGMENTS (Cat. No. O 2015)
1.5 Volt 500 mA

Below are photographs of the propellers used in the initial tests, the Radioactive propellers are shown previously but the Scorpio propeller was not. The 2 bladed high pitch propellers used in tests on Faulhaber motors are shown later.
Following the photographs is a table of results from many tests. The table shows thrust in grams produced by the motor propeller combination at the specified sun level.
The yellow highlight on the table shows the probable settings to give best thrust.

PROPELLERS LEFT TO RIGHT 30mm RADIO ACTIVE (MA 3045A) 40 mm RADIO ACTIVE (MA 3045/M2) SCORPIO.



FAULHABER MOTOR TEST RIGS, GEAR REDUCTION UNIT ABOVE

DETAIL OF GEAR REDUCTION TEST SET UP 4:1 RATIO

Propeller comparisons from Left to Right,
TOP ROW: Scorpio , Radioactive 40mm Dia. MA 3045/M2 , Radioactive 30mm Dia. MA 3045A
BOTTOM ROW: Radioactive 50mm Dia. MA ???? , 45mm Dia. MA 3003 , 40mm Dia. MA ????

Model Solar Boat MOTOR & PANEL Tests Jan 2006

Faulhaber 2232 — **Dick Smith Panel**

Sun %	Prop R/A 30 mm 3B Series	Prop R/A 30 mm 3B Series //	Prop R/A 40mm 3B Series	Prop R/A 40mm 3B Series //	Scorpio 2B White Series	Scorpio 2B White Series //
100	76	72	58	103	59	101
80	61	65	47	88	44	90
60	46	66	32	71	31	66
40	30	52	20	42	20	43
20	13	29	9	20	8	18

Faulhaber 2232 — Scorpio Boat Panel

Prop R/A 30mm 3B Series	Prop R/A 30mm 3B Series //	Prop R/A 40mm 3B Series	Prop R/A 40mm 3B Series //	Scorpio 2B White Series	Scorpio 2B White Series //	Prop R/A 40mm 2B Series	Prop R/A 40mm 2B Series //
90	30	125	62	114	63	83	80
88	30	100	58	92	64	60	73
78	29	71	51	73	63	47	70
60	27	51	52	53	59	31	53
30	25	22	25	29	38	16	30

Faulhaber 2232 — **Dick Smith Panel & Scorpio Electronics**

Sun %	Prop R/A 30 mm 3B Series //	Prop R/A 40mm 3B Series //	Scorpio 2B White Series //
100	84	80	88
80	72	70	72
60	57	54	58
40	40	35	37
20	13	12	11

Faulhaber 2232 — **Scorpio Boat Panel**

Not tested as the Scorpio Electronics will not function on this Panels low voltage.

Faulhaber 2224 — **Dick Smith Panel**

Sun %	Prop R/A 30 mm 3B Series	Prop R/A 30 mm 3B Series //	Prop R/A 40mm 3B Series	Prop R/A 40mm 3B Series //
100	74	66	56	87
80	57	65	45	82
60	44	63	35	70
40	28	51	21	43
20	13	26	8	20

Faulhaber 2224 — **Scorpio Boat Panel**

Prop R/A 30mm 3B Series	Prop R/A 30mm 3B Series //	Prop R/A 40mm 3B Series	Prop R/A 40mm 3B Series //	Scorpio 2B White Series	Scorpio 2B White Series //	Prop R/A 40mm 2B Series	Prop R/A 40mm 2B Series //
78	25	113	49	90	42	72	52
		90	48	77	42	60	52
		72	49	56	37	45	49
		46	49	35	33	30	45
		25	36	17	26	16	30

Faulhaber 2224 6 Volt 4:1 Gear Reduction — **Dick Smith Panel**

Sun %	Prop R/A 40mm 2B		Prop R/A 45mm 2 B		Prop 50mm R/A 2 B	
100	140	61	125	89	116	95
80	104	62	95	84	98	90
60	74	56	72	78	75	88
40	47	47	48	75	54	76
20	40	21	23	45	28	52

Faulhaber 2224 6 Volt 4:1 Gear Reduction — **Scorpio Boat Panel**

Prop R/A 40mm 2 B		Prop 45mm R/A 2 B		Prop 50mm R/A 2 B	
90	31	104	31	120	27
90	31	100	32	105	27
80	27	100	31	95	27
72	26	82	29	72	25
52	23	48	25	34	18

Scorpio Solar Motor — **Dick Smith Panel**

Sun %	Prop R/A all series	30mm 3 Blade 3 in s //	2 in s //
100	35	78	64
80	27	61	56
60	19	45	51
40	10	29	42
20	0	11	20

Scorpio Solar Motor — **Scorpio Boat Panel**

Prop RA 30mm		Prop RA 40mm		Scorpio 2B White	
85	55	65	60	68	68
70	55	58	60	51	65
55	55	36	52	38	60
32	45	18	50	23	43
14	31	6	19	10	21

Dick Smith P8980 — **Dick Smith Panel**

Sun %		
100	70	34
80	55	33
60	41	33
40	23	31
20	9	23

Dick Smith P8980 — **Scorpio Boat Panel**

43	15
43	15
42	15
41	15
28	15

Both Faulhaber Motors were 6 Volt Versions. Thrust figures in the body of the table are in gm. Note they are static thrust.

APPENDIX 3:

DEMONSTRATION BOAT
(Built specifically for demonstration at Workshops)

The selection of components was based on choosing components that when correctly assembled would yield a boat that would run under most conditions. (See table 1 for static thrust measurements taken when testing a drive unit constructed from these components.)
This is critical particularly for first time builders where a boat that does not run has an extremely negative effect.
NOTE: Performance data given here should be used as a guide only. Actual performance will vary due to build standard and characteristics of individual components. **ALWAYS** test your boat to determine the optimal settings for it.

TEST RESULTS - STATIC THRUST AT VARIOUS SUN LEVELS

% SUN	PANEL IN PARALLEL	PANEL IN SERIES
20	23 gm	8 gm
40	31 gm	22 gm
60	33 gm	41 gm
80	33 gm	55 gm
100	34 gm	70 gm

TABLE 1

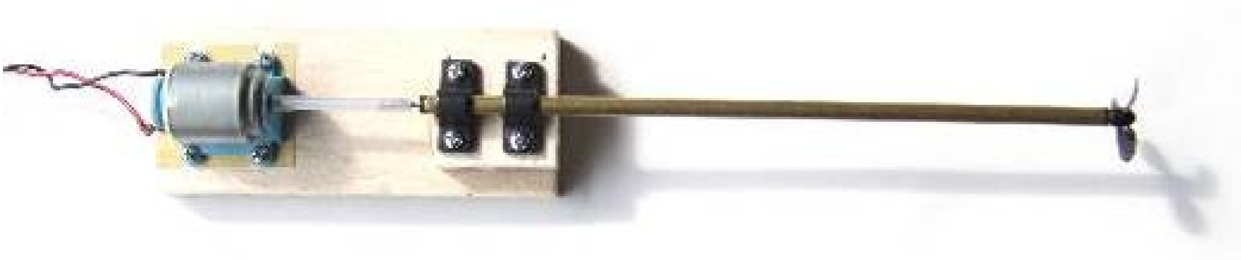
NOTE: Static thrust was measured in these tests. The thrust delivered by the propeller when your boat is moving through the water will be less than the static thrust due to the effect of the boats forward speed.
Because of this effect it is quite possible that the use of a larger propeller will give better performance on a boat moving through the water than the smaller propeller used in the above tests.
Test your boat when running free to determine the exact best Sun level to change the panel configuration from series to series and parallel and which propeller is the best at the different sun levels and panel configurations.

SOLAR PANEL:
From table 1 it can be seen that in order to obtain the highest thrust possible the solar panel must be configured to suit the Sun level.

For maximum static thrust the Solar Panel is configured:
For Sun levels above 40% all cells in series which gives a nominal Short Circuit Current of 500ma with Open Circuit Volts of about 10.5 Volts in full Sun.
For Sun levels below 40% , 2 groups of 3 cells in series, these are then parallelled which gives a nominal Short Circuit Current of 1000ma with an Open Circuit Voltage of about 5.75 Volts in full Sun.

DRIVE COMPONENTS:

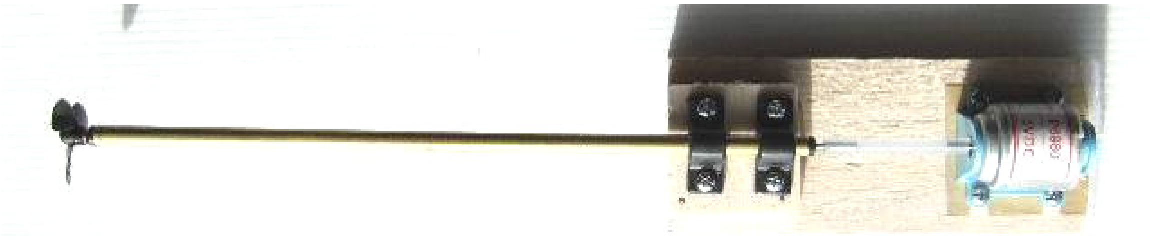
Photographs of the drive components assembled together are shown below.
You may wish to use this method of mounting motor and propeller shaft assembly. The balsa wood block holding the motor and shaft in alignment can then be secured to the boat. This technique makes it easy to align motor and shaft and maintain this alignment. Poor alignment will reduce the power transferred to the propeller and slow the boat down.
HINT: Lubricate the propeller shaft where it rotates in the plastic bearings at each end of the brass tube with a small quantity of light oil. (Sewing machine oil or similar is satisfactory) This will reduce friction and increase the power available to drive your boat. BE CAUTIOUS too much oil on the shaft under the coupling may cause slipping between the coupling and propeller shaft.

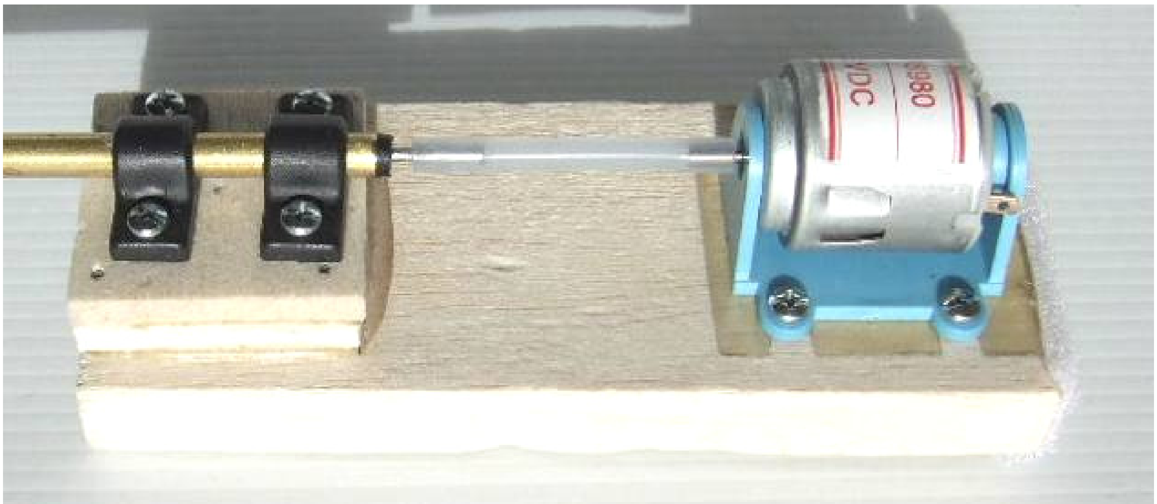


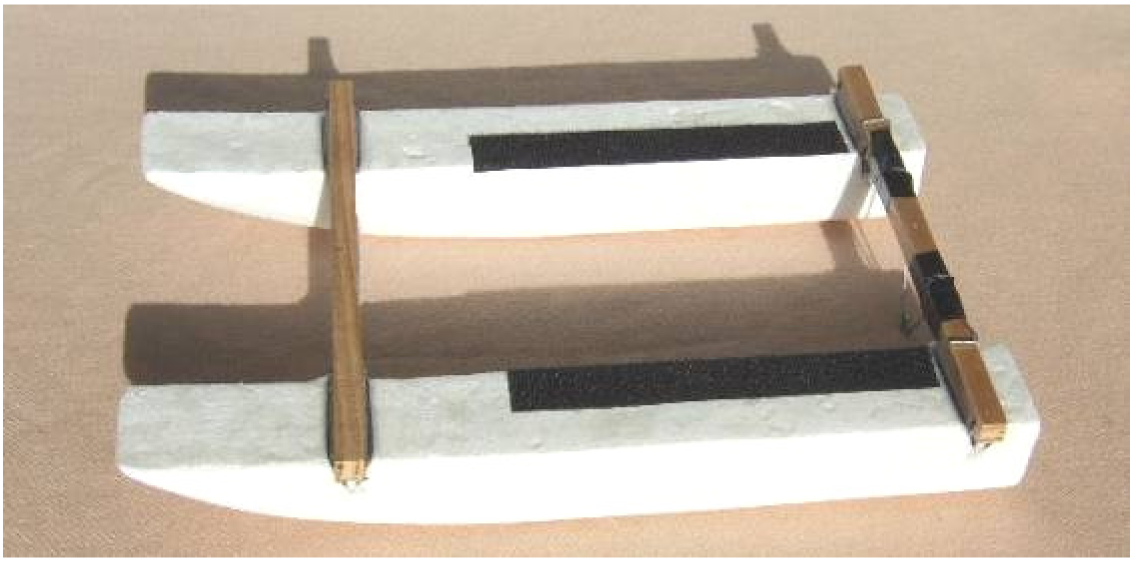
ELECTRICAL WIRING:

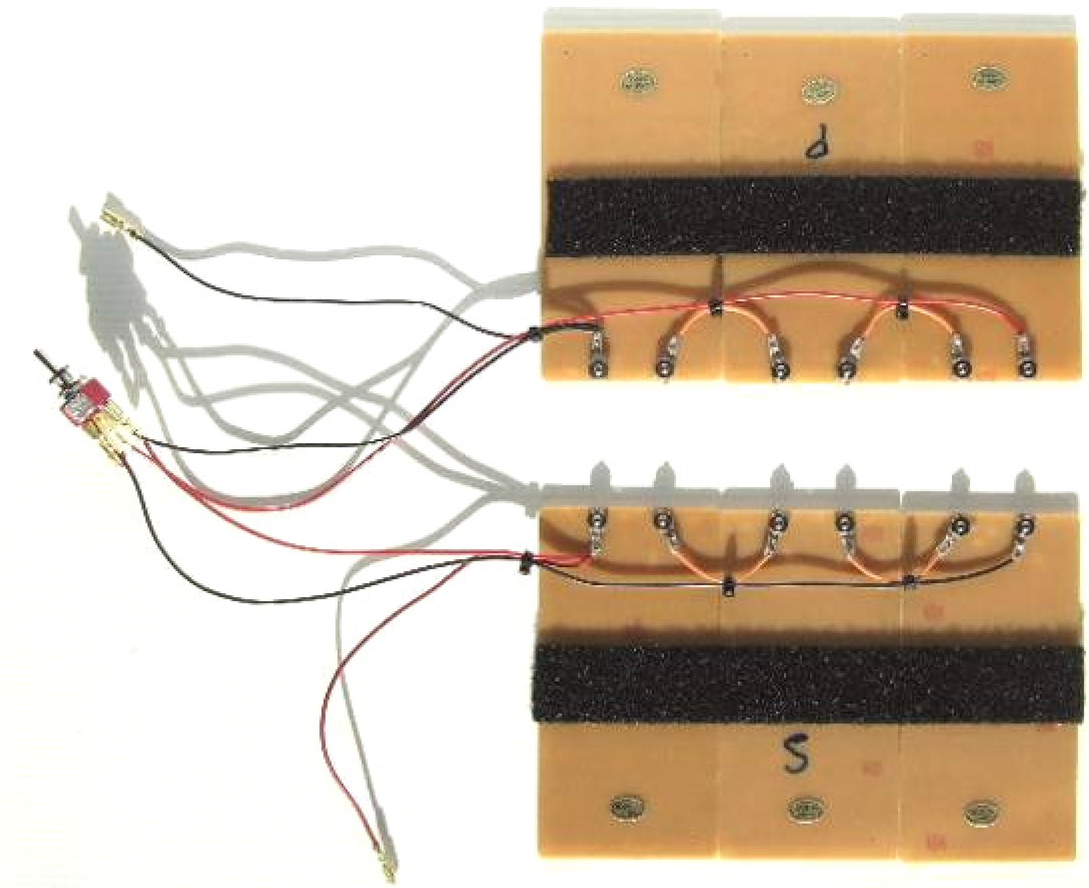
Colour codes your wires Red for Positive and Black for Negative is the convention. By doing this you make it easier to follow the circuit diagram and very much easier for trouble shooting. Trying to find and fix a problem when confronted by a birds nest of identical wires is frustrating and wastes a lot of time.
Connections can be made by soldering.
Take care to secure all wires so they will not wobble around and break the terminals off, a particular problem with the very thin motor terminals. If there is any chance of bare wires or terminals touching each other insulate them with tape.

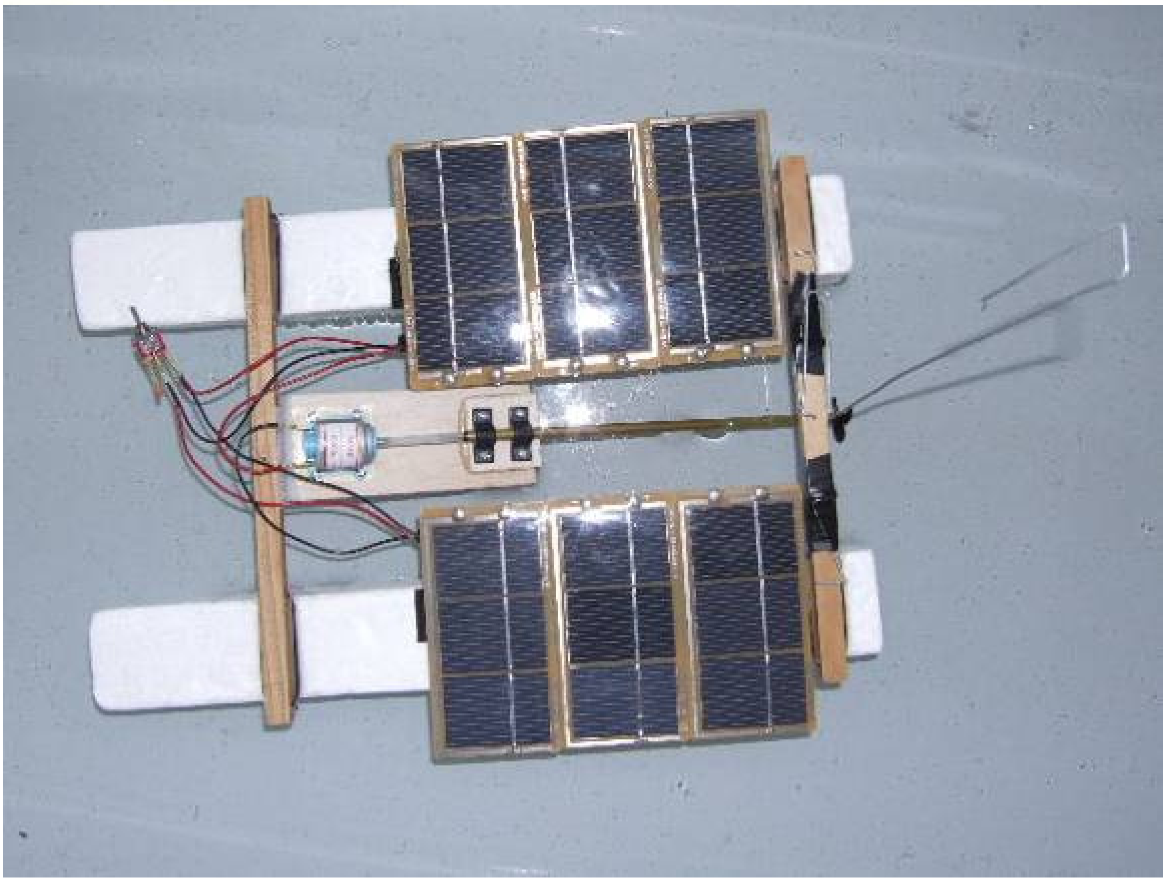
FOLLOWING ARE PHOTOGRAPHS OF THE SAMPLE BOAT CONSTRUCTED USING THESE COMPONENTS





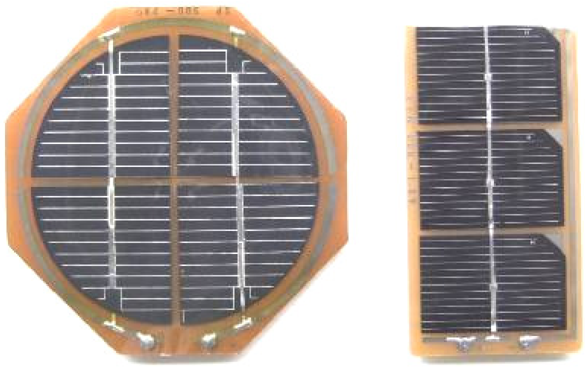






APPENDIX 4: SOLAR CELLS AND SEGMENTS DATA

DICK SMITH

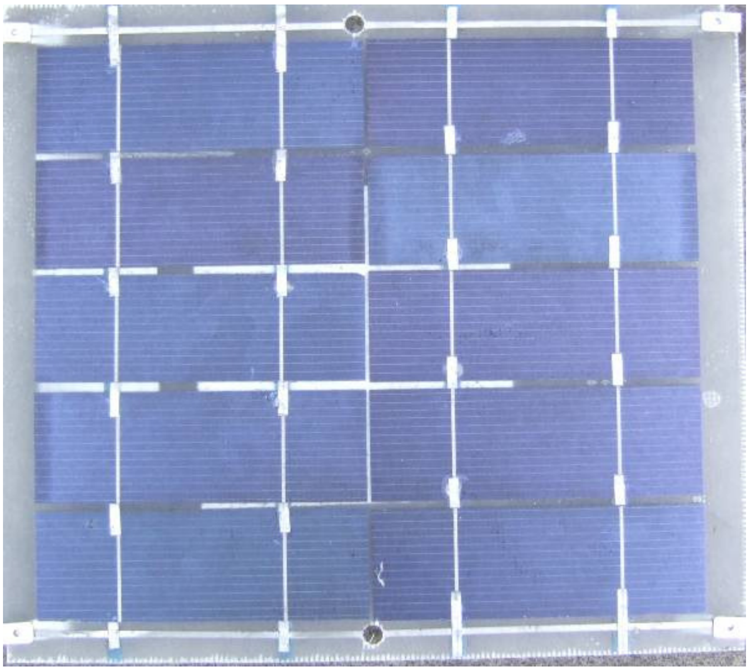


Dick Smith segments used for cars boats and kit cars.

OCV 2.0 V ISC 500 ma.
Power typical: 0.76 W
Area active 78 cm sq.
For 350 cm sq. 4.48 segments

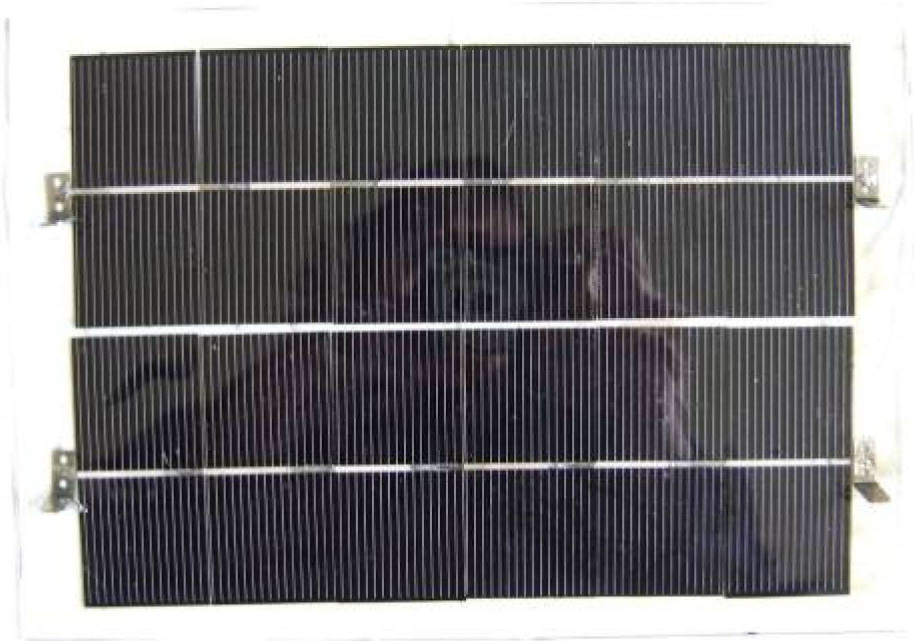
OCV 1.5 V ISC 500 ma.
Power typical: 0.57 W
Area active 54 cm sq.
For 350 cm sq. 6.48 segments

SCORPIO TECHNOLOGY



Scorpio Technology Boat Panel also suitable for cars (use 2) or kit cars.
OCV approx 6.2 V ISC 1100 ma.
Power: Approx 5 Watts
Area just less than the 350 sq. cm. maximum required for boats.

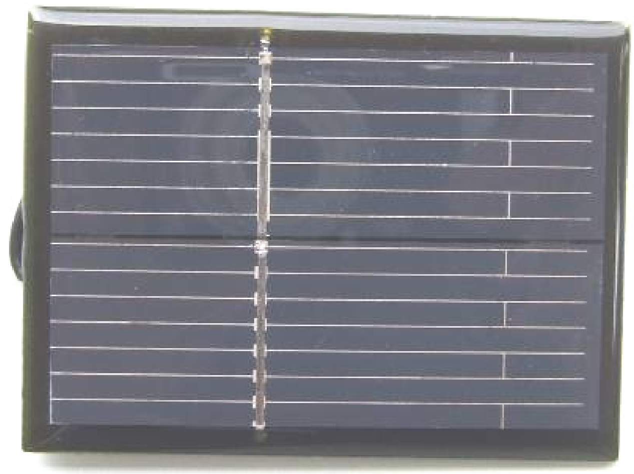
(Discontinued early 2007)



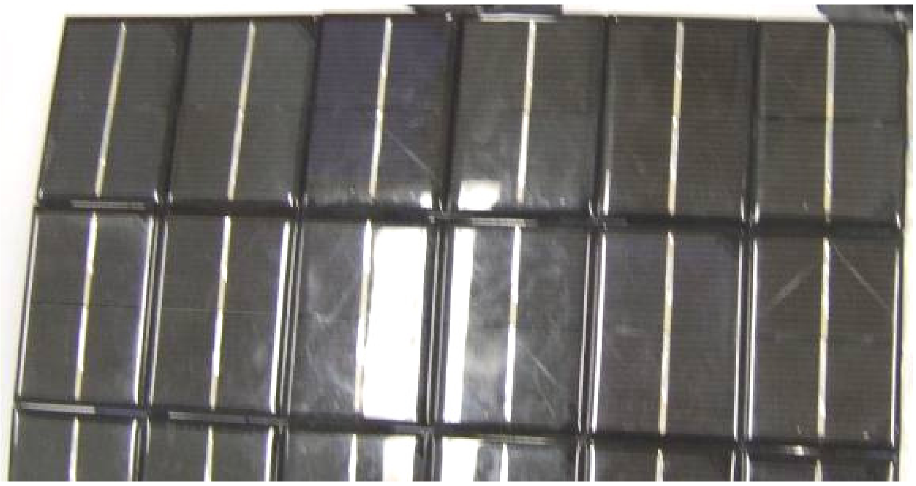
New Scorpio Panel commenced production in June 2007

Scorpio Technology Boat Panel also suitable for cars (use 2) or kit cars.
OCV approx 7.5 V   ISC 1130 ma.
Power: Approx 5.6 Watts
Area just less than the 350 sq. cm. maximum required for boats.

TECHNICAL EDUCATION CENTRE



Tech Ed Adelaide
OCV 1.0 V   ISC   450 ma.
Power typical: 0.35 W
Area active   31 cm sq.
For 350 sq cm. 11.3 segments



New Tech Ed Adelaide (2006)
OCV 1.0 V   ISC   500 ma.
Power typical: 0.48 W

APPENDIX 5:

REPORT ON NEW SCORPIO BOAT PANEL 5/07

Two sample panels of the proposed new design were tested on the light box 5/5/07 the results obtained are listed below.

Light box set 100% Sun

	Panel 1	Panel 2
Open circuit volts	7.4	7.34
Short circuit current ma.	1127	1152
Power watts	5.52 (1001 ma at 5.52V)	5.6 (1002 ma at 5.6V)

Both panels were weighed and recorded a weight of 51 gm.

(Compare this power output to the power output from 6 Dick Smith segments which also meet the panel area requirement of the regulations. Those tested produced 4.9 watts at 100% Sun setting on the light box, while weighing in at 210 gm.)

To better compare the performance of this new boat panel to that of the previous Scorpio boat panels, static thrusts produced by a Scorpio motor and propeller when powered by the different panels showed:

At 100% Sun 36% more thrust was produced when the new panel was used.
At 10% Sun the new panel produced the same thrust as was produced by the old panel at 20% sun.

A significant improvement.

CAUTION: The new panels are very thin and very easily damaged by rough handling. Make certain that this is well known to the users of any similar panels.

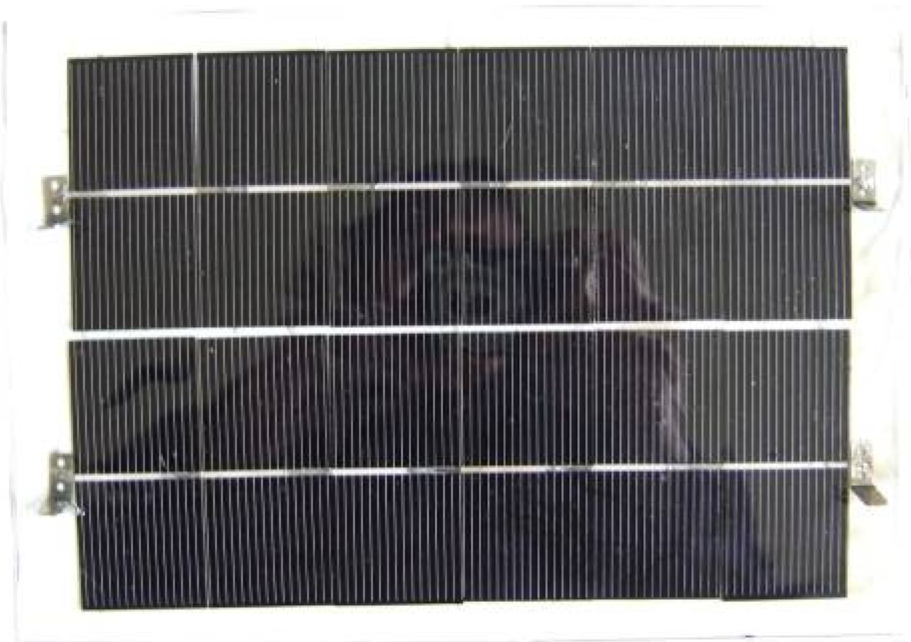
FEATURES OF THE NEW PANEL:

- Designed to have maximum allowed panel area for boats in the AIMSC competition. (350 cm sq.)
- High power output > 5 Watts. From the mono crystalline silicon cells.
- Cells sized to give voltage and current output characteristics to suit Scorpio Motor. (This maximises performance)
- Panel configuration of 2 strings of cells with connectors at each end of the strings allows series and parallel connection of the 2 strings of cells to better match the panel output to the motor as sun level varies.
- Very light weight construction, improves boat power to weight ratio and hence performance. (CAUTION: Handle carefully to avoid damage.)
- Panel can easily be stiffened and strengthened if desired at the expense of some weight increase. (From 98 gm. approx. to 198 gm. approx.) When strengthened it will still give a well built boat excellent performance.

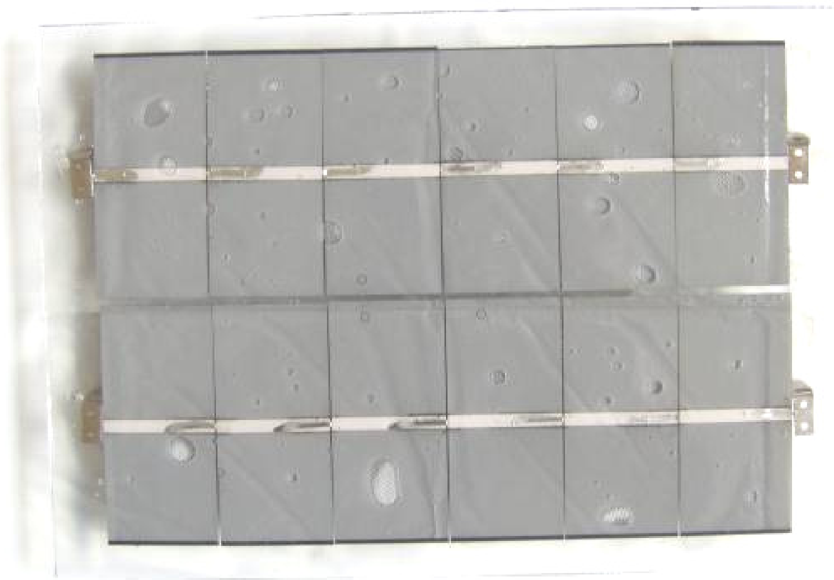
POWER OUTPUT:

Testing of the power output of this panel on a light box set at 100% Sun and obtained the following results.

Open circuit Volts	**7.52 Volts**	
Short circuit current	**1.132 Amps**	
Power (maximum)	**5.6 Watts**	**(@ 5.56 Volts and 1.020 Amps)**



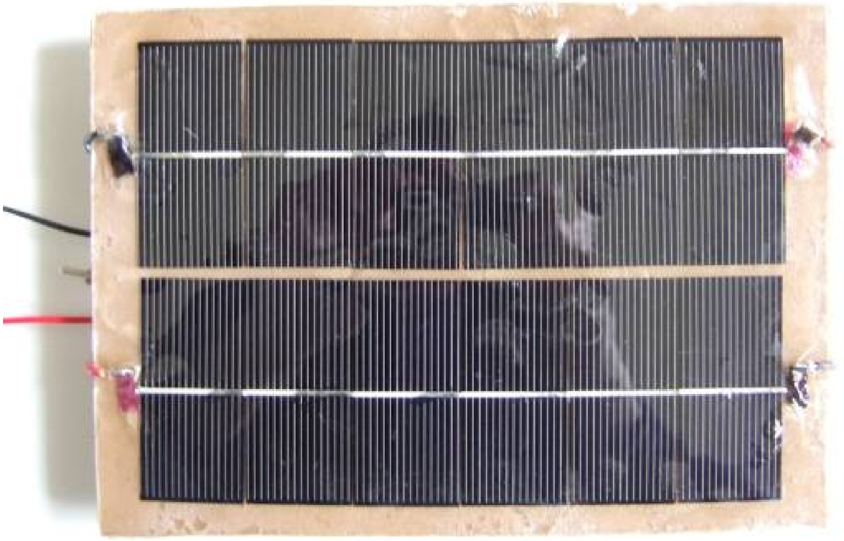
TOP VIEW OF NEW PANEL



UNDERSIDE VIEW OF NEW PANEL

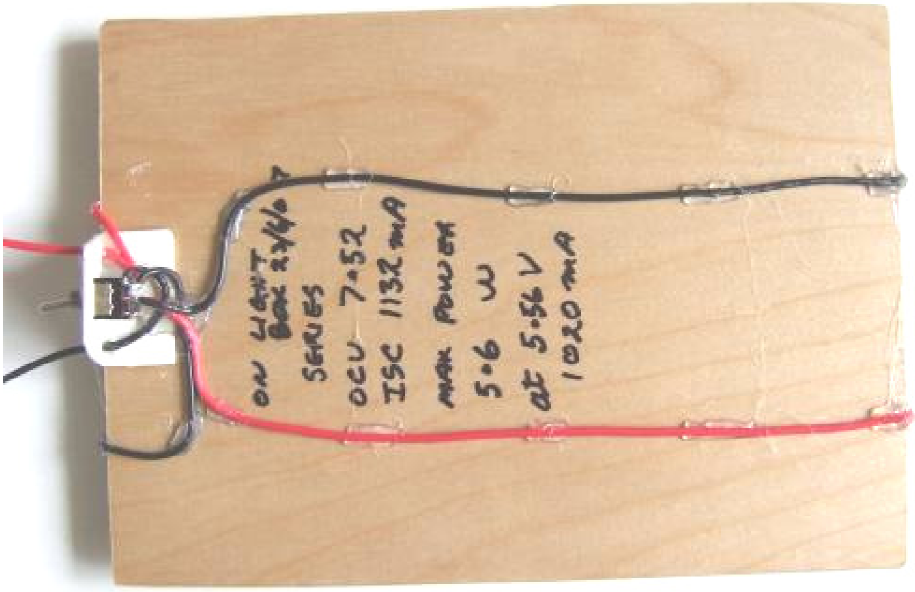
PANEL STRENGTHENING:

These panels give very good test results. Their lightweight construction makes them less suitable for use by inexperienced students. To address this problem and make these new solar panels more suitable for the less experienced students the new panel must be modified to increase its strength.
The following example modifications use sandwich construction techniques.
Using a piece of 6 mm thick Clegecell glued to the underside of the solar panel with silicon gutter sealer and then glued a 0.4 mm thick piece of ply wood to the bottom of the Clegecell with wood working glue, panel strength can be significantly increased.
The result is a reinforced panel weighing slightly less than 200 gm. but with an incredible increase in panel stiffness and strength. This strengthened panel will withstand any normal handling by students.



TOP VIEW OF NEW STRENGTHENED PANEL

Note: the Panel has had wires and a switch attached so it can be easily switched from all cells in series to two strings of cells parallelled for testing undertaken with the Scorpio Solar Motor. This configuration with 2 wires coming away from the panel removes the requirement to constantly connect and disconnect wires to the panel lugs and consequently removes the possibility of breaking the lugs from the panel.



UNDER SIDE VIEW OF NEW STRENGTHENED PANEL

CROSS SECTION OF STRENGTHENED SOLAR PANEL ON TOP CLEGECELL IN MIDDLE AND PLY ON BOTTOM

CLEGECELL (Clegecell is the trade name for expanded PVC foam used as a core material in fibreglass construction.)

MOTOR AND PROPELLER TESTING:

In order to better evaluate the new panel, a test was performed using the panel on a light box at various Sun levels powering a Scorpio Solar Motor driving various propellers. The static thrust obtained is recorded in the table below.

% SUN	R/A 3/30		R/A 3/40		S 2/30		R/A 2/35X		R/A 2/35 Std	
	S	//	S	//	S	//	S	//	S	//
100	76	100	60	101	52	86	54	75	76	112
80	68	93	50	9	48	83	32	61	55	94
60	52	84	35	73	36	72	25	50	38	79
40	35	69	20	48	21	49	16	33	26	55
20	12	34	7	21	9	21	6	16	7	23
10	0	11	0	6	0	8	0	6	0	9

Thrust obtained in gm. is shown in the table. The panel was configured with all cells in series denoted as Series in the table or 2 strings of cells parallelled denoted as // in the table.

Propeller details:

R/A 3/30 is Radio Active 3 Blade 30 mm Diameter propeller
R/A 3/40 is Radio Active 3 Blade 40 mm Diameter propeller
S 2/30 is Scorpio 2 Blade 30 mm Diameter propeller
R/A 2/35X is Radio Active 2 Blade 35 mm Diameter X Series propeller
R/A 2/35 is Radio Active 2 Blade 35 mm Diameter Std. Series propeller

ADDITIONAL TESTING WITH FAULHABER MOTOR:

Additional testing was then performed in the same manner as above but using a Faulhaber 2232 6 Volt motor instead of the Scorpio motor.
This type of motor is suitable for use in the Advanced and Senior divisions and has been used by many competitors at the national event.

Propeller details:

R/A 3/30 is Radio Active 3 Blade 30 mm Diameter propeller
R/A 3/40 is Radio Active 3 Blade 30 mm Diameter propeller
S 2/30 is Scorpio 2 Blade 30 mm Diameter propeller
R/A 2/35X is Radio Active 2 Blade 35 mm Diameter X Series propeller
R/A 2/35 is Radio Active 2 Blade 35 mm Diameter Std. Series propeller

% SUN	R/A 3/30		R/A 3/40		S 2/30		R/A 2/35		R/A 2/35X	
	S	//	S	//	S	//	S	//	S	//
100	135	40	140**	60	136	78	140	106	NOT TESTED	
80	120	40	130 **	63	108	75	131	88		
60	100	40	74	58	81	74	100	88		
40	65	34	48	52	54	65	68	80		
20	34	28	17	39	24	49	30	60		
10	15	25	7	26	9	24	12	33		

**** For these tests the torque reaction was so severe that an accurate reading was not possible due to the twisting of the balance.**
Thrust obtained in gm. is shown in the table. The panel was configured with all cells in series denoted as Series in the table or 2 strings of cells parallelled denoted as // in the table.

The testing was conducted by hanging the motor and propeller assembly vertically on a Digital balance with the propeller in the water. The reduction in weight recorded by the balance when the motor is running is the static thrust produced by the propeller. Photographs of the test set up follow.

MOTOR AND PROPELLER HANGING FROM BALANCE IN WATER

PROPELLERS TESTED

FROM LEFT TO RIGHT:

3 Blade 40 mm Dia. Radio Active Propeller Cat. No. MA 3045/M2
3 Blade 30 mm Dia. Radio Active Propeller Cat. No. MA 3045A
(Radio Active 81 Font Lane Cranham Essex IXL. England)
2 Blade 30 mm Dia. Scorpio Propeller