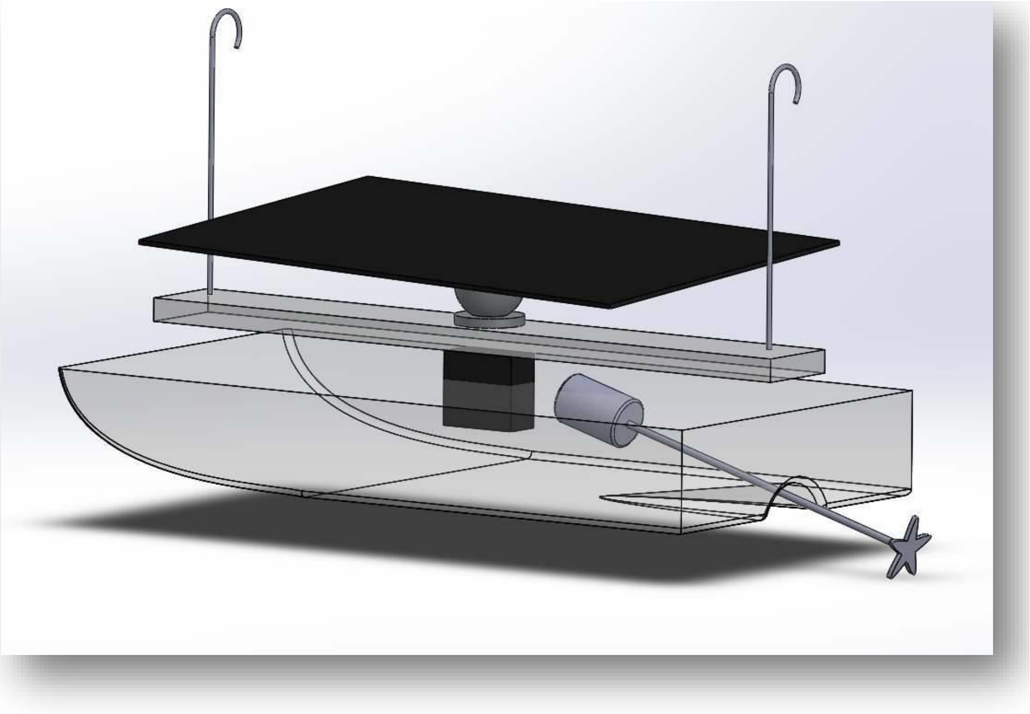
SOLAR BOAT DESIGN CHALLENGE



10/6/2017

Mechanical System Design

Authors:

Daniel Zanati, Matt Corneliusen, Alexandra Orton, Syed Hassan Ali

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AUTHORS AND SIGNATURES

As a group we have acknowledge that the level of input is shared equally among members.

DANIEL ZANATI 7662637

ALEXANDRA ORTON 4966023

MATT CORNELIUSEN 100378451

SYED HASSAN ALI 2098571

hassan Ali

INTRODUCTION

This report will follow the development and production of the Boat for The Victorian Solar Vehicle Challange2017, applying our engineering knowledge in a systematic way. In this project we have felt the exhilaration of the creative process and slipped the bonds of the known to venture far into unexplored territory.

The invention of boats has played a significant role in the development of human history from trade to travelling and transportation to exploration; boats have become an indispensable expression of human development.

The team is required to design a boat with a mechanism which can direct the boat from one end of a pool to the other and return, using solar power as the energy form.

The constraints given to our team were as follows: first, the boat is to be solar powered, secondly, it isn't allowed to employ any energy storage device and thirdly, the boat must return to its starting point without manual or remote controls.

This project also gives our team members a good insight into solar energy from an engineering perspective and how to exploit sunlight and build a mechanism which can even operate efficiently in the respect of any forecast weather or in an atmosphere of inadequate supply of solar energy.

In this report we will look at how to optimise the performance of our boat using factors from material selection to thrust and the methods and calculations that resulted in our team coming to its conclusions.

What follows is a document compiling the information received, discovered and the process taken by our team for the creation of the boat. Included in this summary is an in-depth literature review, design process, research of similar designs, in-depth force analysis, Failure Mode Effect Analysis and a review done by each group member.

After reading this report we believe the reader will have a good understanding of the Boat and the knowledge incorporated in its design and manufacture.

LITERATURE REVIEW

Propeller Design

Marine transport is undoubtedly one of the most varying forms of vehicle design. From large cargo ships that allows the world economy to trade, to sail ships that harnesses the power of the wind for leisure, there are several technologies that an engineer can deploy to drive a boat forward. Propeller design is complex and several design features that ensure high efficiency propulsion discussed in this literature review. The means by which these features aided our design of an efficient propeller will be explained thoroughly.

Background:

The overall premise of the propeller is based on the Archimedes screw, a water pump designed by the Greek mathematician and engineer to transfer water from a low-lying water source to a higher one. The basis of the screw is to transfer rotational movement to a displacement of water, with the shear force acting on the fluid that forces it forward. Most screw propeller designs today are based on the Archimedes screw.

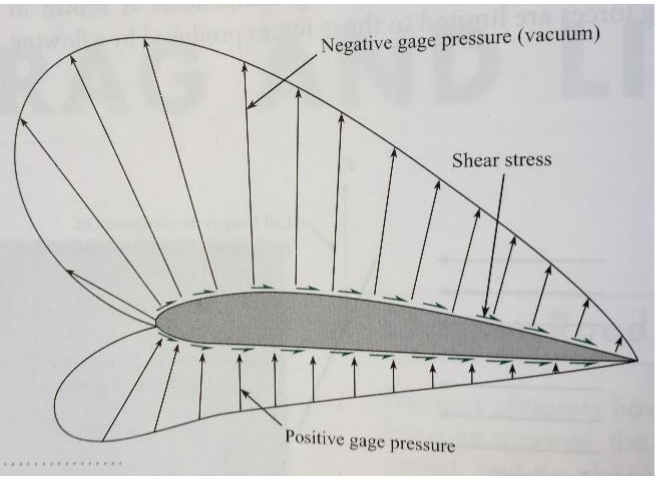

FIGURE 1 PRESSURE DISTRIBUTION ON AN AEROFOIL

Aerofoils

An aerofoil (air foil) moving through a fluid creates a negative pressure on top of the wing, and a positive pressure below. The foil is shaped in a way that fluid moving over the foil moves faster than it does below the foil. This difference in fluid velocity creates a pressure difference that produces a lifting force.

Water can be considered an incompressible fluid. The aerofoil moving through water allows us to use Bernoulli's principle to relate fluid velocity to pressure. This is because his principle does not account for the transfer of kinetic and potential energy from the compression or expansion of fluid. As outlined in his publication Hydrodyamica[1]:

$$\frac{v^2}{z} + gz + \frac{P}{\rho} = H$$

Where:

V = Velocity (m/s)
P = Pressure (Pa)
ρ = Density (kg/m^3)
H = Constant
g = Gravity's acceleration (m/s^2)

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[1] Bernoulii, D. (1738). *Hydrodynamica.* 1st ed.

z = Elevation (m)

If H is a constant, decreasing the velocity would increase the pressure acting on the aerofoil. The bottom of the aerofoil does exactly this, lowering the velocity that creates a high pressure, and the top increasing the velocity which creates a low pressure. This positive and negative pressure difference creates lift. This effect is visually represented by Figure 1[2]

The coefficient of lift is calculated by:

$$Cl = \frac{2Fl}{S\rho V^2}$$

Where:

FL = Lift Force (N)
S = Area on foil (m^2)
V= Velocity (m/s)
ρ = Density (kg/m^3)

The coefficient of lift calculates how efficiently an aerofoil provides lift in terms of the velocity of fluid it moves through and the area of which the force acts on. It is also affected by the angle of attack.

Angle of Attack

The angle of attack refers to the blades angle to the relative velocity of the moving fluid it is passing through. The coefficient of lift peaks at between 11to15 degrees due to the occurrence of the stagnation point of the fluid flow moving up the chord of the aerofoil[3], and drag induced forces subtracting from the lift forces created by the aerofoil. It is common for propellers to have a variable pitch, this allows the optimum angle of attack to remain constant as the radius of the propeller increases from the hub. As distance x increases from hub x=0, linear velocity is a function of radius x angular velocity. As

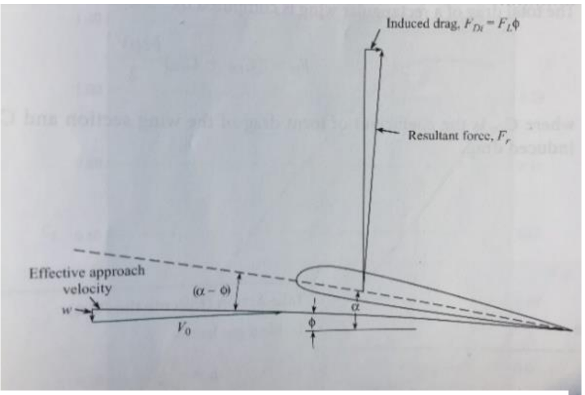
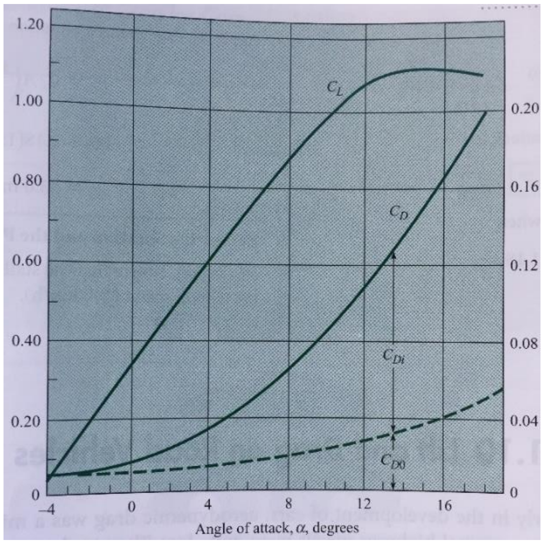


FIGURE 2 RELATIVE ANGLE OF ATTACK



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[2] Elger, D., LeBret, B., Crowe, C. and Roberson, J. (2016). Engineering fluid mechanics. 10th ed. Singapore: Wiley, pp.400-437.

[3] Prandtl, L. "Applications of Modern Hydrodynamics to Aeronautics." NACA Rept., 116, (1921)

the velocity of the aerofoil increases, the fluid velocity angle increases so a smaller pitch angle is needed to obtain optimum attack angles. This phenomenon is noticeable in aeronautical propellers as they have long fin blades that are optimum in working with the density of air. It does occur in marine propeller, but as the propeller works in a heavy density medium the blades are a lot shorter so it does not appear to have as great a variable pitch.

As shown in the graph[4], the coefficient of lift is maximum when the angle of attack is around the 12 to16 degrees. Past this point the coefficient of lift drops dramatically due to Stall, which is the phenomenon where the coefficient of lift drops as angle of attack increases. Stall occurs due to the stagnation point of the fluid flow moving up the aerofoil away from the tailing edge. Known as the Kuta Condition[5], where fluid flow separates at the leading edge of the aerofoil and meets again at the very end of the tail smoothly, creating minimal drag. Drag is induced when the stagnation point starts rising from the tailing edge, this creates an area where negative pressure acts on the foil. This is stall and lift is reduced and drag is increased.

General Propeller Features

There is numerous theory and design principles when it comes to designing and building a propeller. However, it will ultimately come down to experimentation and trials to determine the best fit propeller for our boat. We know for instance pitch is measured in the distance the propeller would theoretically move in a full rotation of the hub. But there is slippage that is determined by the speed of the boat, materials of the propeller itself and the torque that the motor supplies which is a result of how much sun there is available to us for the solar panel to convert. Number of blades is something that is also heavily determined by the vehicle speed and torque available from the electric motor as more blades do not necessarily produce more thrust, as the wake of each blade can interfere with trailing blades. Factors such as these will be determined from experimentation when we manufacture the vehicle, and testing optimum propeller design when different sun conditions arise.

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[4] Elger, D., LeBret, B., Crowe, C. and Roberson, J. (2016). Engineering fluid mechanics. 10th ed. Singapore: Wiley, pp.400-437.

[5] Crighton, D. (1985). The Kuta Condition in unsteady flow. Department of applied mathematical studies, (1), pp.1-4.

Solar Power

How is the sun's light transmitted into usable electricity? Light and IR radiation from the sun's rays are directed onto a solar panel which essentially knock the outer orbiting electrons off of the silicon atoms in the solar cell, therefore allowing them to do some sort of usable work. (PV lighthouse, 2017) [6]. Great, why don't we just directly hook up a DC motor to a solar cell then? Because unfortunately, powering a motor directly with a solar cell can be problematic and very inefficient. The problem being that when a motor is overloaded or completely stalled the voltage reduces, the motor then acts as a low resistance resistor and the current increases to the panel's maximum. When it does this the total power available to the motor decreases. The maximum power point (MPP) of any solar panel can be observed to be the point at which the voltage and current are at their maximum for a particular solarity.

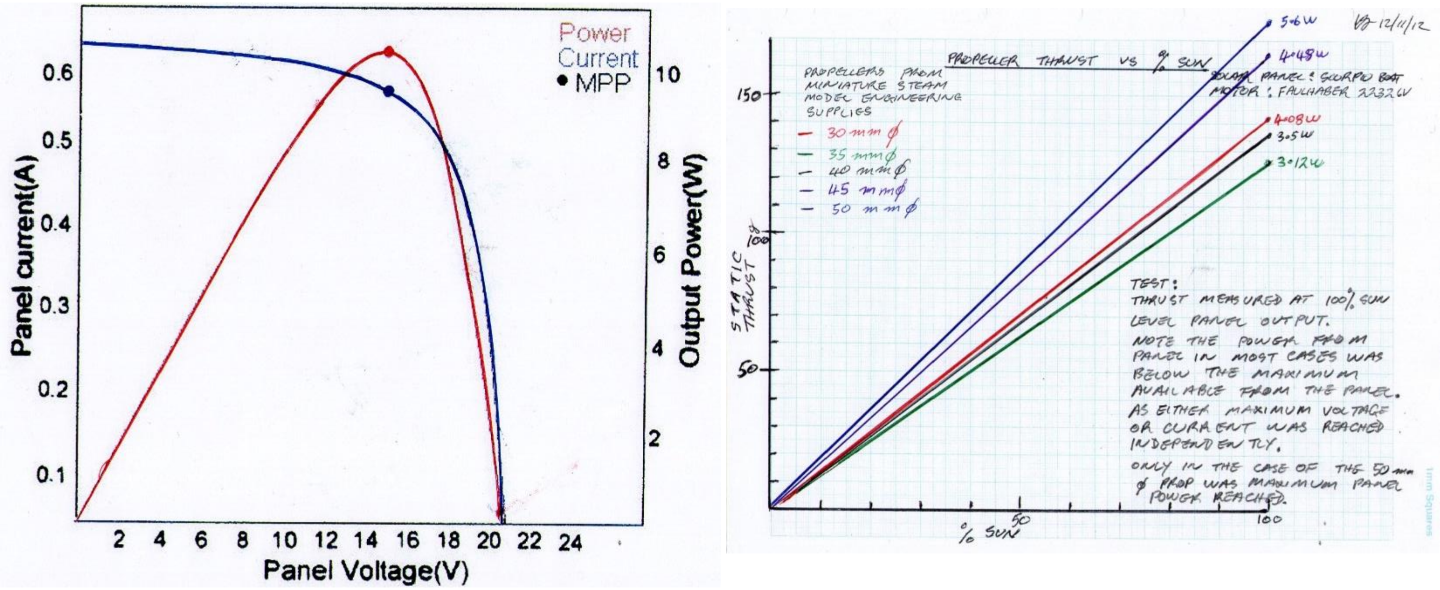

Figure (p. 25 Master boat shop doc)

Resistive loads on a solar cell that are very low or very high cause the solar panel to output low power from the solar cells. This can be observed from the above figure on the left, low resistance causes high current flow, therefore drastically reducing power output. This is the same for the case of high resistance. For example, at maximum and minimum currents on the graph to the left, the solar cells output nearly 0 W, whereas operating at approximately 0.6 A the panel can output its maximum power. Solar panel, motor and propeller characteristics all interact in a complex way. For maximum energy transfer it is critical that the correct combination is selected. (Master boat workshop doc 2014,

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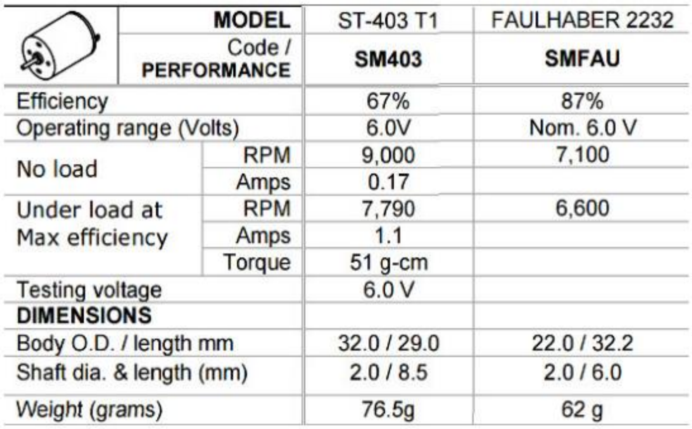
[6] PV Lighthouse 2017, *Absorption of Light*, PV Lighthouse, viewed 25 September 2017, <https://www2.pvlighthouse.com.au/resources/courses/altermatt/The%20PV%20Principle/Absorption%20of%20light.aspx>.

p. 23)[7] Load matching can be split into two major categories; Mechanical or Electronic adjustments. Electrical is often the simple and straight forward way to load match, however it can be very costly and considering this is for a solar boat race, water and electronics don't mix well. Mechanical load matching on the other hand requires a little more knowledge of the physics behind solar power and DC motors. Because of I^2R losses it is the more logical choice to wire the panel in series rather than parallel, a series configured panel will double the output voltage of the two panels with the current remaining the same, whereas in a parallel configuration the current is doubled with the voltage remaining constant. (Refer to calculations section to see this theory.)

Mechanical load matching.

This can be achieved through making modifications to the propeller, the speed at which the propeller operates at or even changing the entire motor itself. Because motor speed in a DC motor is directly proportional to the voltage supplied, it is critical that the voltage at which the motor operates is as close to the voltage at the maximum power point of the solar panel. Reducing the pitch of a propeller can help reduce the load on the motor whilst operating and subsequently increase the speed and voltage supplied to the motor. Similar results could be easily obtained by reducing the diameter of the prop so that it pushed a smaller column of water. The two most commonly available motors from Scorpio Technology are the Standard ST-403T1 or the high efficiency Faulhaber 2232. (Scorpiotech solar catalogue 2017 p. 2)[8] If found that at top speed, the motor was spinning at approximately 8,000 rpm the standard ST-403 T1 would be the ideal choice because at that rpm the motor will be drawing a voltage close to that of the maximum power point voltage of the solar cells. Sometimes this method of load matching turns into trial and error as there are a lot of variables that are either assumed or are just totally uncontrollable, for example, propeller slip and drag on the boat.



		MODEL	ST-403 T1	FAULHABER 2232
		Code / PERFORMANCE	**SM403**	**SMFAU**
Efficiency			67%	87%
Operating range (Volts)			6.0V	Nom. 6.0 V
No load	RPM		9,000	7,100
	Amps		0.17	
Under load at Max efficiency	RPM		7,790	6,600
	Amps		1.1	
	Torque		51 g-cm	
Testing voltage			6.0 V	
DIMENSIONS				
Body O.D. / length mm			32.0 / 29.0	22.0 / 32.2
Shaft dia. & length (mm)			2.0 / 8.5	2.0 / 6.0
Weight (grams)			76.5g	62 g

Figure (Scorpiotech solar catalogue p. 2)

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[7] Garner, I 2014, 'Model Solar Boat Master Workshop Document', MSV committee, viewed 25 September 2017, issue 1, p. 23

[8] ScorpioTech Mt Waverly 2017, Model Solar catalogue, Scorpiotech Mt Waverly, Victoria, catalogue.

Electronic load matching

This method of load matching seems to be much simpler than mechanical load matching as there are multiple manufacturers of electronics kits and systems that are just plug and play with instant results. The easiest modification that can be done electrically is to wire the solar panels into a different configuration (series or parallel). At high sun levels the panel will output more current and therefore would be better to choose a series configuration to reduce the I^2R losses. Conversely with low prevailing sun levels the output current will be significantly lower therefor it may be necessary to wire the cells into a parallel configuration to make use of the current increase to provide more torque to the propeller. Another way to drastically improve the solar cells performance it to make use of an electronics kit like the Automax solar MPPT, it essentially tracks the output from a solar panel and holds it at the MPP voltage regardless of the loading conditions. However, this unit is quite expensive and removes a lot of the ability to engineer anything. However, the solar power panel controller (SPPC) is much more cost effective and does a very similar thing. The SPPC rapidly switches the motor on and off using a transistor/mosfet (MTP3055) (SPPC low V instructions 2017)[9] which is very similar to how a handheld drill motor operates. This rapid switching causes the inductor situated at the output of the SPPC circuit to modify the current and voltage supplied by the solar cell that exactly matches the motor requirements.

Figure

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[9] Scorpiotech Mt Waverly 2017, SPPC Low voltage instructions, Scorpiotech Mt Waverly, Victoria, Instructions.

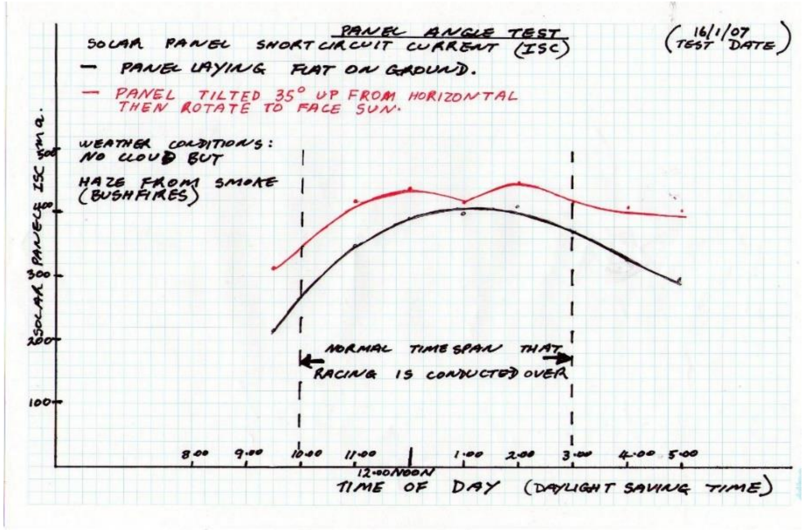

Figure (p. 5 Master boat shop doc)

Solar power and angle of tilt

Depending on the time of day, one might wish to tilt the solar panel towards the sunlight to increase the surface area that is pointing normal to the sun. What sort of increase in power should be expected and would it be valuable to ensure this is a feature on the team's boat? The device required to tilt the panel may add significant weight percentage to a lightweight boat. Testing of this theory was performed using the scorpiotech solar cells on the date (16/01/07). (Master boat workshop doc 2014, p. 17)[10]

As you can see from the graph above, there is some power to be gained by facing the solar panel at the sun during the very middle of the day. Whereas, at approximately 10:00am and 3:00pm (Start and Finish) there is a considerable increase in power to be had. At the time of 9:30am, laying the panel flat on the ground; the short circuit current (ISC) read 225mA. After tilting the panel towards the sun the ISC was recorded at 320mA. This is a power increase of 42%! - a compelling reason for allowing the solar panel to tilt towards the sun. Garner 2014, 'Model Solar Boat Master Workshop Document', MSV committee, viewed 25 September 2017, a **very** important factor when tilting the panel towards the sun is that you ensure the panel isn't acting like a sail on a ship and causing large wind drag. The drag due to the solar panel acting like a sail could be great enough to cancel out the benefit of tilting the panel. (Master boat workshop doc 2014, p. 5)[11]

Couple calculations

$$Equations: V = IR, P_{loss} = I^2R, P = VI$$

$Knowns: Solarpanel \in series. ie(Voltagedoubles)Powerloss \in aresistorofR = 1ohmV = 7V@MaximumpowerpointP = 6W$

$$I = \frac{P}{V} = \frac{6W}{7V} = .85A$$

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[10] Garner, I 2014, 'Model Solar Boat Master Workshop Document', MSV committee, viewed 25 September 2017, issue 1, p. 17

[11] Garner, I 2014, 'Model Solar Boat Master Workshop Document', MSV committee, viewed 25 September 2017, issue 1, p. 5

$$\therefore P_{loss} = 0.85A^2 * 1\Omega = 0.73 Wofpowerisdissapated \in theresistor$$

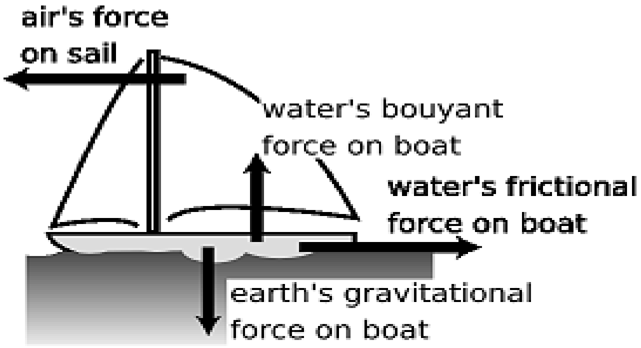
$$Solarpanel \in . ie(Currentdoubles)$$

$$V = 3.5V$$

$$I = \frac{P}{V} = \frac{6}{3.5} = 1.71A$$

$$\therefore P_{loss} = 1.71A^2 * 1\Omega = 2.94 Wofpowerisdissapated \in theresistor$$

It can be clearly seen above that wiring the panel in a series configuration keeps the current at a relatively low level but drastically reduces the amount of power loss in a 1Ω resistor. This shows that it would be advantageous for the boat to be wired in series given that the internal resistance of a Faulhaber 2232 DC motor is approximately 0.8ohms. If wired in parallel almost 50% of the available power from the solar cell will be lost to heat in the environment.



The Scientific view

An object floats when the weight force on the object is balanced by the upward push of the water on the object. If the weight force down is larger than the upward push of the water on the object then the object will sink. Objects float at different levels in the water because as most regular objects are lowered into the surface of water, the upward push of the water steadily increases until it is in balance with the weight force of the object, and the object then continues floating at this level with the two forces in balance.

No object can float without some part of it being below the surface of the water

Buoyancy[12]

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[12] John Parson. (2013). *Buoyancy*. Available: http://study.com/academy/lesson/center-of-buoyancy-definition-formula.html. Last accessed 03/09/2017.

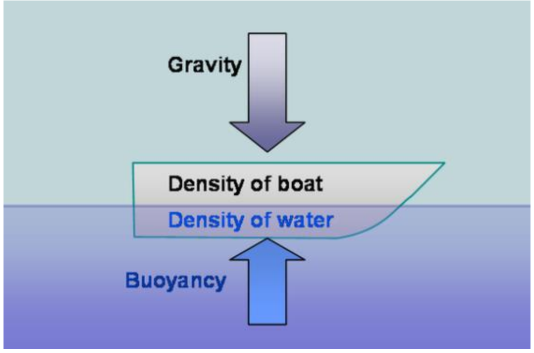
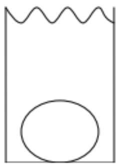


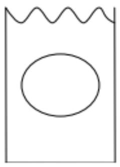
FIGURE : BUOYANT FORCE, GRAVITY AND DENSITY

[13]Fluid pressure acts all over the wetted surface of a body floating in a fluid, and the resultant pressure acts in a vertical upward direction. This force is called buoyancy. The buoyancy of air is small compared with the gravitational force of the immersed body, so it is normally ignored.

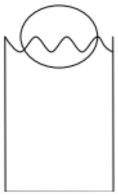
Buoyancy is the upward force that an object feels from the water and when compared to the weight of the object, it is what makes an object float, sink, or remain neutrally buoyant in the water. When an object floats, the upward buoyant force exerted by the water is greater than the downward force of the weight of the object. You can also understand this concept with numbers. If an object's density is less than water's density (1 g/cm^3), it will float. When an object sinks, the weight of the object is greater than the upward buoyant force exerted by the water and its density is greater than 1 g/cm^3. When an object is neutrally buoyant, meaning it neither sinks nor floats, then the weight of the object is equal to the upward buoyant force exerted by the water. When neutrally buoyant in water, the object also has the same density as water.



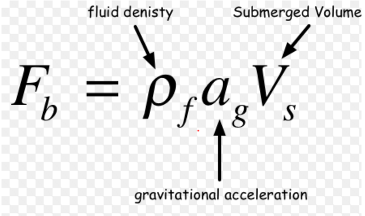
Density of Object>1 g/cm³



Density of Object = 1 g/cm³



0 g/cm³ <Density of Object<1 g/cm³



$$F_b = \rho_f a_g V_s$$

Centre of Buoyancy[14]

The centre of buoyancy of an object is located at the point that would be the centre of mass of the displaced fluid that would occupy the volume that is actually occupied by the buoyed object.

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[13] John Parson. (2013). *Buoyancy.* Available: http://study.com/academy/lesson/center-of-buoyancy-definition-formula.html. Last accessed 03/09/2017.

[14] Michael Smith. (2010). *Centre Of Buoyancy.* Available: https://www.pdhpe.net/the-body-in-motion/how-do-biomechanical-principles-influence-movement/fluid-mechanics/flotation-centre-of-buoyancy/. Last accessed 5/09/2017.

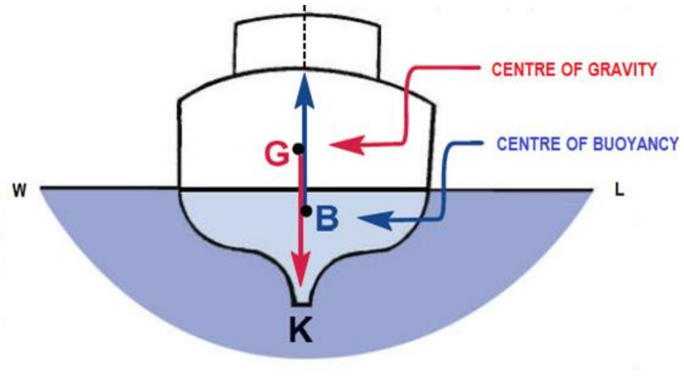

FIGURE CENTRE OF GRAVITY AND CENTRE OF BUOYANCY[15]

In the same way that gravity can be thought of as pulling on a compact object by acting on its centre of mass, the buoyant force can be thought of as acting on a compact object (a particle) at that particle's centre of buoyancy.

An object whose centre of mass is lower than its centre of buoyancy will float stably, while an object whose centre of mass is higher than its centre of buoyancy will tend to be unstable and have a tendency to flip over in the fluid that is buoying it up.

The centre of buoyancy is the centre of gravity of the displaced fluid.

Friction/Tribology[16]

Tribology is the study of what happens when things 'rub'. This involves friction and wear when solids rub against other solids (such as in mechanical bearings) and the effect of liquids (such as 'lubricants') and other fluids.

Friction at a solid-liquid interface is still called friction. It is a 'damping' or 'dissipative' force, in part due to the viscosity of the liquid (internal friction), but also subject to other (external) factors such as the 'roughness' of the solid surface.

Whereas the friction between two solids is typically described as 'static' and 'kinetic' friction with the 'roughness' of each surface being proportional to the co-efficient of friction (both static and kinetic), the presence of a liquid on the surface changes the friction by introducing fluid dynamics. Static friction is no longer present and the kinetic friction is now affected not only by the surface roughness but also by the properties of the liquid, including viscosity.

A liquid flowing along the surface of a solid will experience a shear stress at the surface due to its roughness. As the solution of the governing fluid mechanics equations involves knowing the boundary conditions, in most cases, the velocity of the liquid at the solid surface is given as zero, known as the 'no-slip' condition.

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[15] Trent Millard. (2013). *Ship Hydrodynamics.* Available: http://www.mecaflux.com/en/ship%20Hydrodynamics.htm. Last accessed 11/09/2017.

[16] Theo. (2014). *Friction between Solid and Liquid Surface.* Available: https://physics.stackexchange.com/questions/147248/friction-between-liquid-and-solid-surface. Last accessed 05/09/2017

In some cases, a liquids may exhibit very low viscosity near the solid surface, such that, it may have some (non-zero) velocity relative to surface of the solid, which is known as 'slip'.

Cavitation[17]

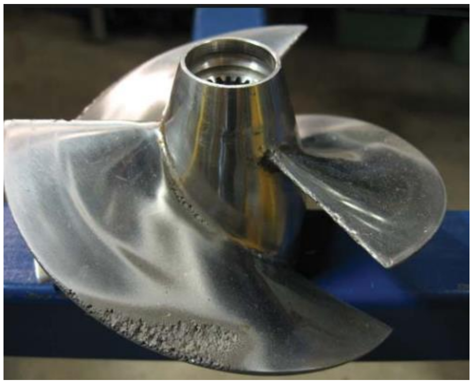

FIGURE CAVITATION ON THE BLADES

Cavitation occurs when vapour pockets form in a liquid flow because of local reductions in pressure (for example at the tip of a boat's propeller blades). Depending on the number and distribution of particles in the liquid to which very small pockets of undissolved gas or air may attach, the local pressure at the onset of cavitation may be at or below the vapour pressure of the liquid. These particles act as nucleation sites to initiate vapourisation. Vapour pressure of a liquid is the partial pressure of the vapour in contact with the saturated liquid at a given temperature. When pressure in a liquid is reduced to less than the vapour pressure, the liquid may change phase suddenly and "flash" to vapour. The vapour pockets in a liquid flow may alter the geometry of the flow field substantially. When adjacent to a surface, the growth and collapse of vapour [18]bubbles can cause serious damage by eroding the surface material. Very pure liquids can sustain large negative pressures—as much as —60 atmospheres for distilled water—before the liquid "ruptures" and vapourisation occurs. Undissolved air is invariably present near the free surface of water or seawater, so cavitation occurs where the local total pressure is quite close to the vapour pressure.

Cavitation can be split into two categories based on the cavity behaviour; inertial and non-inertial cavitation. Inertial cavitation occurs when a bubble in a liquid collapse rapidly and produces a shock wave. It is observed in control valves, pumps, propellers and impellers. Non-inertial cavitation occurs when a bubble is forced to change size or shape due to an energy input, and it can also be observed in pumps and propellers.

Cavitation is usually an undesirable occurrence, as it can cause major damage to moving parts in a machine or system. Eliminating cavitation is usually an area of focus in the design of parts such as a propeller. In the context of our boat design, cavitation on the propeller will have to be considered.

The rotation and movement of a propeller’s blades in a fluid causes area of low pressure to be formed. This occurs as the fluid accelerates around and travels past the blades. The pressure can become very low as the blades increase in speed, and as it reaches vapour pressure, the fluid vaporises and small gas bubbles and made. When these bubbles later implode they can damage the propeller blades.

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[17] Justin Chen (1999). *Fundamentals Of Fluid Mechanics*. 5th ed. Berlin: Thomas Press. 765.

[18] Justin Chen (1999). *Fundamentals Of Fluid Mechanics*. 5th ed. Berlin: Thomas Press. 765

Cavitation causes the flow around a propeller to be uneven, and the formation of cavities effectively alters the shape of the blade sections. This results in a reduced thrust and to a lesser degree, a reduced torque, as well as reduced propeller efficiency.

Preventing Cavitation[19]

Propellers are usually designed so that cavitation does not occur in their operating conditions, or its effects are kept to a minimum to the point where they can be considered negligible.

Sometimes though, the propeller operating conditions are such that it is basically impossible to avoid cavitation. This can be the case for small high-speed boats that operate propellers at high powers, high rpm and have a restricted diameter. For these the propellers are designed to operate in the fully caveating regime.

Propeller cavitation can be eliminated or reduced by:

1. Increasing the cavitation number

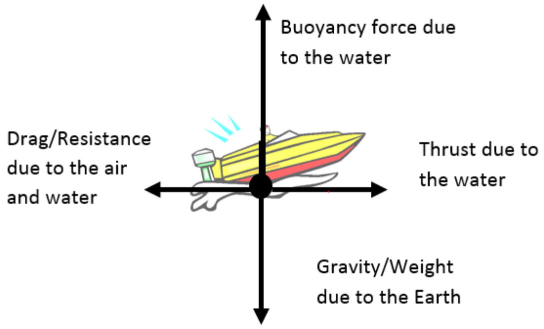
2. Decreasing the load on the propeller

3. Designing the propeller for uniform loading.

In our case Cavitation is not of importance at all because we are going to run the boat just few times and takes a huge amount of time for cavitation.

However, this concept is really important while building a boat or aircraft propellers.

Drag[20]



FIGURE, FORCES ACTING ON THE BOAT AND DRAG CAUSED BY WATER AND AIR

[21]Drag is a mechanical force. It is generated by the interaction and contact of a solid body with a fluid (liquid or gas). It is not generated by a force field, in the sense of a gravitational field or an electromagnetic field, where one object can affect another object without being in physical contact. For drag to be generated, the solid body must be in contact with the fluid. If there is no fluid, there is no drag. Drag is generated by the difference in velocity between the solid object and the fluid. There must be motion between the object and the fluid. If there

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[19] J.M. Michel. (2011). *Introduction to Cavitation and Supercavitation*. Available: http://www.dtic.mil/dtic/tr/fulltext/u2/p012072.pdf. Last accessed 03/09/2017.

[20] Trent Millard. (2013). *Ship Hydrodynamics*. Available: http://www.mecaflux.com/en/ship%20Hydrodynamics.htm. Last accessed 11/09/2017.

[21] Jake Owen. (2014). *Friction between Solid and Liquid Surface*. Available: https://physics.stackexchange.com/questions/147248/friction-between-liquid-and-solid-surface. Last accessed 05/09/2017

is no motion, there is no drag. It makes no difference whether the object moves through a static fluid or whether the fluid moves past a static solid object.

Drag is a force and is therefore a vector quantity having both a magnitude and a direction. Drag acts in a direction that is opposite to the motion of the aircraft. Lift acts perpendicular to the motion. There are many factors that affect the magnitude of the drag

The definition of drag tell us that there are several parameters to solving for the drag force which will be resisting the boat. These parameters are the speed of the object in relation of the fluid (v), the density of the fluid (ro), the cross sectional area of the boat which is in contact with the fluid and the drag coefficient which depends on the shape of the objects and the Reynolds

Number. The Reynolds number can be found on a graph or by using the formula where v is the kinematic viscosity of the fluid.

$$\mathrm{Re} = \frac{\rho v l}{\mu} = \frac{v l}{\nu}$$

Where:

v = Velocity of the fluid
l = The characteritics length, the chord width of an airfoil
ρ = The density of the fluid
μ = The dynamic viscosity of the fluid
ν = The kinematic viscosity of the fluid

Solving for the drag force then gives the equation:

$$F_D = \frac{1}{2}\rho v^2 C_D A$$

Ventilation

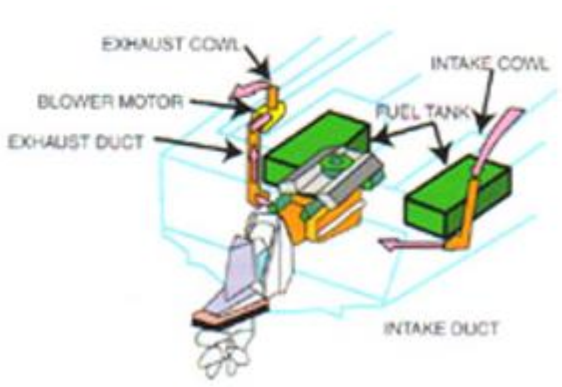

FIGURE VENTILATION ON A MOTOR

[22][23]Ventilation is an uncontrollable phenomenon. There are two instances where ventilation may occur.

1. If the motor is set too, high air can get sucked from the surface and introduced around the propeller blades.

2. Exhaust gases get drawn into the propeller head.

In both cases, the loads from the water around the propeller blades get replaced by air or exhaust gases. This causes the propeller to slip more than it usually does, and results in a sudden increase in the motor response and the RPM and a reduction of speed. Ventilation in some cases may then lead to cavitation as well.

Ventilation is also introduced by manufacturers in some cases to controlled situations. Small holes are usually introduced on the side of the propeller barrel. This lets small amounts of exhaust to be drawn in around the blade making the engine generate a high RPM for a burst of acceleration from standstill.

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[22] John Winters. (2009). *Ventilation and Resistance*. Available: http://www.greenval.com/shape_part1.html. Last accessed 15/09/2017

Hull Design[24]

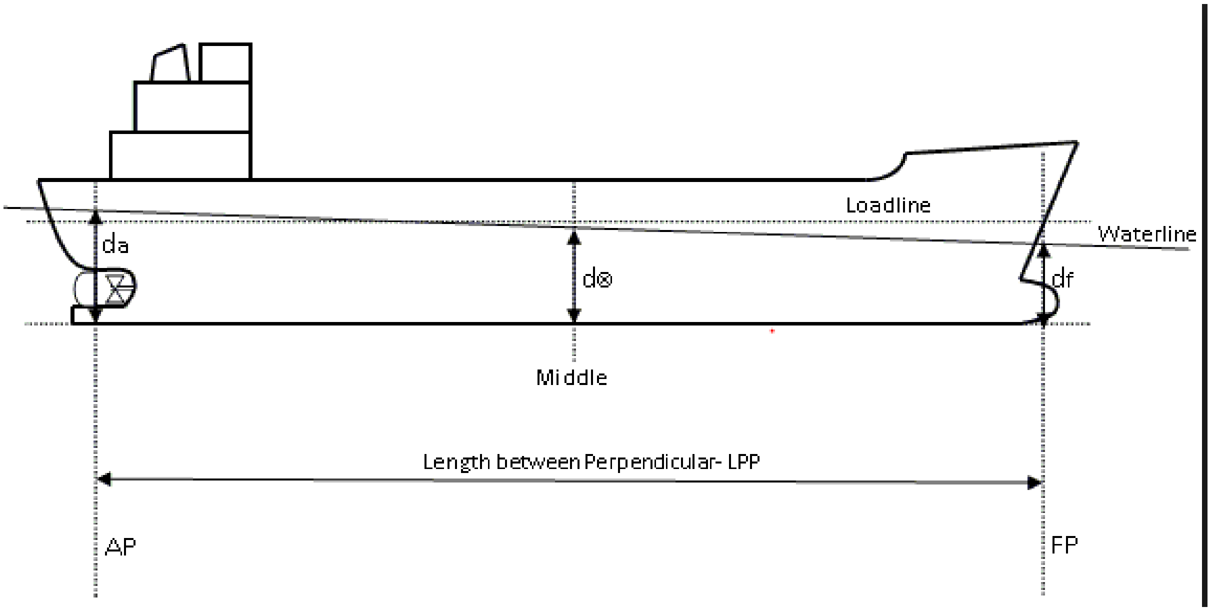

FIGURE BOAT LENGTH

2526

Length Overall

Length overall, or more commonly known as LOA, is defined as if the boat is viewed from top, the length from the tip of the bow to the stern of the boat in a straight line, is defined as the length overall. Alternatively, it can simply be stated as the maximum length of a vessel’s hull when measured parallel to the waterline. Note that components such as outward motors, rudders and other extensions are not included in the measurement.

Loaded waterline length Also known as LWL, the loaded waterline length is known as the length of the boat where it sits in the water, or in other words, the length of the hull at water level. This excludes the features of the boat which are out of the water. The LOA in most cases is longer than LWL since

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[24] Soumya Chakraborty. (2016). *Hull of a Ship – Understanding Design and Characteristics*. Available: https://www.marineinsight.com/naval-architecture/hull-ship-understanding-design-characteristics/. Last accessed 05/09/2017.

[25] J.M. Michel. (2006). *Terminology and Definition*. Available: http://www.splashmaritime.com.au/Marops/data/less/Shipk/Design/definitions%20ship%20k.htm. Last accessed 23/09/2017

features such as the bow rise outwards. This length is used to calculate many properties such as how much water the hull displaces, hull speed, area etc.

Width

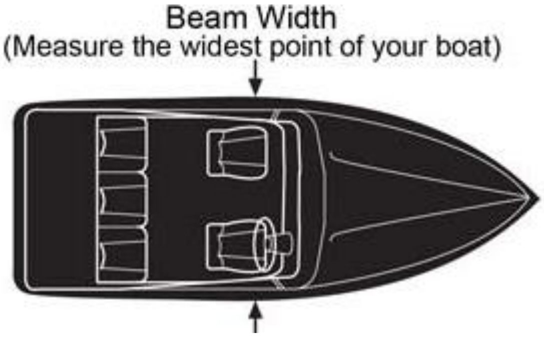

FIGURE BEAM WIDTH OF BOAT

The width of a boat is measured at its widest point of the hull and is called the beam width. The reason its measured at its widest point is to determine if the boat can make passage when near an obstacle. The beam width of a boat determines its handling capability; a narrow beam width will be able to move faster but will not tolerate heavy waves because of the small area. Whereas a wider beam, while more stable, will be able to cut through waves more efficiently.

The typical length-to-beam values for most sailboats range from 2:1 to 5:1 (racing sailboats) while large ships have ratios as large as 20:1

Monohull designs use the following equation to calculate the beam size.

Beam = (LOA)^(2⁄3) + 1

Multi-hull vessels, such as the Catamaran, have more than one hull. The beam lengths for these vessels are measured from the centreline of one hull to the centreline of the other. The following equation relates the Catamaran beam size to its length.

Beam = (LOA / LBRC)

LBRC is defined as the length beam ratio of the Catamaran and is typically between values of 812 for cruisers and 12 onwards for racers.

Other measurements for the beam include the beam at waterline (BWL) which is the same as the loaded waterline length but for the width of the beam.

Draft[27]

The draft of a boat (D) is equal to the vertical distance measured form the waterline to the bottom of the hull, also known as the keel. Calculating draft is important as it indicates the minimum level of water required for the vessel to safely navigate. It can also calculate the weight carried by the vessel by calculating the total water displaced and then using Archimedes principle.

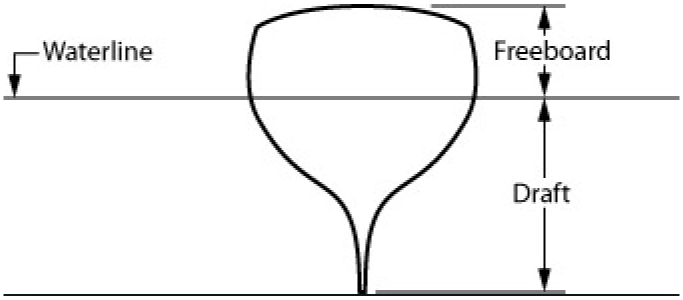

FIGURE DRAFT LENGTH OF BOAT AND FREE BOARD

Boats have different values for the draft at the stern and the bow therefore the mean draft is calculated by averaging the drafts at the stern and bow.

Beam - draft ratio[28]

The beam draft ratio or BDR can affect the resistance of a boat and in fact can have the greatest impact, and the waterline should be made as narrow as possible in the confines of maintaining stability. A beam-draft ratio near 2 minimises frictional resistance and values lower than that decreases wave making. On the other hand, higher values may increase load carrying capacity.

The optimum beam draft range is from 1.5 – 2.8.

The beam and draft are related by the following equation.

BDR = BWL / D

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[28] John Winters. (2009). *Frictional Resistance.* Available: http://www.greenval.com/shape_part1.html. Last accessed 15/09/2017.

Hull Speed[29]

In a general sense, the larger the boat, the faster it will go, and the maximum speed of any given hull is largely dependent on its waterline length. The simple idea behind this is that the boat cannot travel faster than the wave it creates. The length of the wave created is also proportional to the height of that wave. So higher the wave, the length between the crests of the waves created increases and therefore the faster it travels.

The theoretical value for hull speed can be calculated by the following,

Hull Speed (V) = $1.34 \sqrt{LWL}$

Coefficients

For hull design, there are a few coefficients which must be considered.

· Mid-ship Coefficient

The mid-ship coefficient is defined as

Mid-ship Coefficient (Cm) =AmD/BWL

Where Am is the maximum section area of the hull.

Cm depends on mid-ship shape of the vessel (which is discussed later). Standard values for some designs include: a value of 0.5 for a deep section and a value of 0.785 for an ellipse section.

· Froude Number

A low Froude number is desired for a single hull boat to travel efficiently, as this reduces the drag on the hull.

Drag limits the hull speed according to the formula:

$V=(gL/(2pi))1⁄2$

Where L is the waterline length

g is the gravitational constant

V is the hull speed

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[29] Charles Doane. (2010). *Crunching Numbers: Hull Speed & Boat Length.* Available: http://www.boats.com/reviews/crunching-numbers-hull-speed-boat-length/#.Wdo5ZxCWbIU. Last accessed 17/09/2017.

J.M. Michel. (2006). *Terminology and Definition.* Available: http://www.splashmaritime.com.au/Marops/data/less/Shipk/Design/definitions%20ship%20k.htm. Last accessed 23/09/2017

This is the limit for a single hull vessel in theory, however it can be exceeded if a large amount of power is used.

A catamaran involves more complicated calculations, the appropriate formula being:

V=1.34*(wetted length)1⁄2

But this formula for drag is often not a true representation of the limiting factor for hull speed for a catamaran. This is due to the fact that 'boats with waterline length to beam ratios greater than 8:1are not limited by hydrodynamic drag factors.'

A more important factor to consider for catamaran hull design is the Prismatic Coefficient.

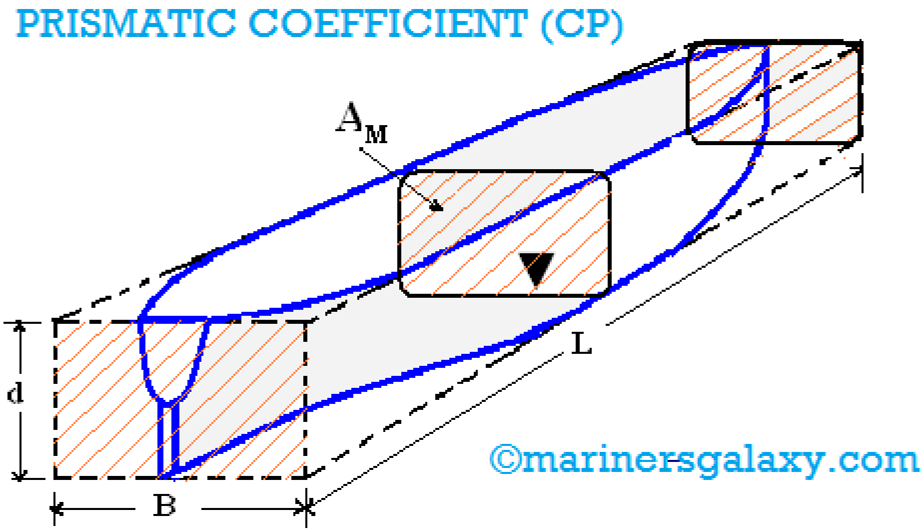
- Prismatic Coefficient

The prismatic coefficient (Cp) is defined as

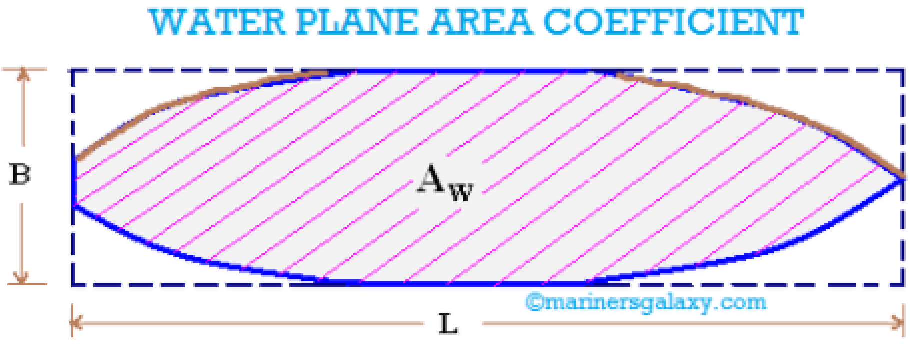
Cp = Δ/Am x LWL

Where ∆ is the displacement volume of the boat.

The prismatic coefficient provides a general idea about the distribution of displacement, or the fineness of the ends relative to the midsection of the hull. In other words, a low prismatic coefficient means a fine end and a large midsection, and a high prismatic coefficient there is more displacement distribution towards the end. Typical values range from 0.55 to 0.64.

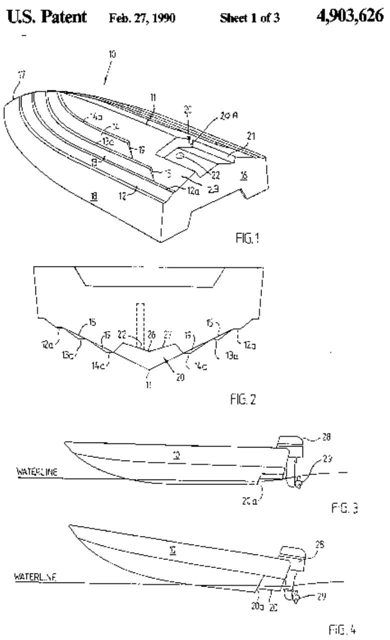


- Water Plane Coefficient



The water plane coefficient (Cw) is defined as
Cw = Aw/BWL x LWL
Typical values for water plane coefficient range from 0.69 to 0.72.
Fully Loaded Displacement
The equation for fully loaded displacement, in kg is
LDC = BWL x LWL x D x Cp x Cm x 1025 (For Catamaran hulls, multiply the equation by 2)
This value could to refer to how much water is displaced by the hull when you put it in the water or the weight of the hull.
There are many factors to consider when deciding on hull design such as material, weight, shape and size. The shape of the hull also determines how the boat travels, and one method of travel to look in to planing. As part of the brief is for the boat to go to the end of the pool and back, a symmetrical hull or a turning mechanism in the boat is to be considered.

Planing Hull



A planing hull describes a hull with a V shaped bottom section which extends from the bow to a shoulder. The design of the planing or hydroplaning hull has been developing for decades with the forming of vents to allow air to form under the boat. The corrugations or chines redirect the flow of the water, thus creating lift. It is also important to monitor the lift through longitudinal length as well as positioning load in a correct planing altitude. The desired angle is between zero and eight degrees angle of attack (Haines, J 1990) and this can be altered through these two means. Another factor is the outboard motor which can be raised or lowered to reduce drag in the water. It has three modes at three different speeds; displacement mode, plowing mode and planing mode. These happen at low, medium and fast speeds respectively, the planing happening as the boat lifts its body out of the water and skims across the top, making it laterally unstable and allowing it to turn rapidly.

Flat bottom boat

The flat bottom means less water displacement for less drag and is very stable in calm waters[30]. It travels on top of the water. It is common in hunting vessels, and sometimes referred to as a jon boat[31].

Deep v hull

The deep v hull has a large amount of the hull displaced in the water, which provides a way to tackle rough water. This also means that it consumes a lot of energy as it drags through the water. This is altered through the chines which are a little recess in the hull that creates a lift in the hull.

Displacement Hulls

By their very name, displacement hulls travel through the water rather than on top and displace water they sit in in order to move. This increases drag however they can move effectively with little propulsion, it also means they travel a lot slower through the water. They are used on large vessels such as barges and container ships.

Round Hull

This hull moves through the water effectively at low speeds and turns well, however can be unstable without the addition of a keel or some sort of stabiliser. Examples of this type of hull are sailboats, canoe or kayak. The hull shape allows the boat to roll with the waves, they are designed to travel at slow speeds[32].

Catamaran Hull

The Catamaran hull is traditionally a very stable design with a wide stance and the ability to break through waves due to its design. It is made up of two isolated demi hulls; the wide size will allow the carrying of the solar cell so the potential for the style is evident. Some considerations to be made are the length and the width of the boat so as to bear the cell on top; this is down to the separation length ratio (S/L) (Utama, I 2013). This formula will be investigated if the catamaran design is selected, along with resistance calculations for the power required. Because of its design, a catamaran may need a large area to turn around.

Chines

Chines are a way of describing the way the hull angles up on its way to the top side of the hull. Most of the different hulls described can be categorised by the number of chines. For a v shaped hull this is considered a single chine, with a flat bottom boat being a 2-chine hull and the common planing fishing boat being a 3-chine hull where the v bottom bends on both sides before reaching the topside[33].

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[30] BOATsmart. 2017. *Boating Knowledge Base*. [ONLINE] Available at: https://www.boatsmartexam.com/knowledge-base/article/boat-hull-types/. [Accessed 2 October 2017].

[31] Nautic Expo. 2017. *Jon Boats*. [ONLINE] Available at: http://www.nauticexpo.com/boat-manufacturer/jon-boat-16862.html. [Accessed 6 October 2017].

[32] Manitou Pontoon Boats. 2013. *Types of Boat Hulls*. [ONLINE] Available at: https://www.manitoupontoonboats.com/types-of-boat-hulls/. [Accessed 7 October 2017].

[33] ThoughtCo.. 2017. *What is a Vessel's Chine?*. [ONLINE] Available at: https://www.thoughtco.com/what-is-a-vessels-chine-2292984. [Accessed 3 October 2017].

DESIGN STRATEGY

Design strategies are there to help either yourself or your team form a general or very specific plan of action that aims at solving the problem at hand. Given that every problem is different, there a many different design strategy that will suit the problem perfectly. For example, in designing a ship that can take humans to the Andromeda galaxy, a relatively divergent or lateral thinking style would benefit this problem as it is not as straight forward. Choosing a design strategy may not be straightforward therefore adopting a broad strategy that really allows you to search for possible solutions would be ideal. Whereas, designing a more comfortable wheelchair for the elderly would utilise a more Convergent or linear thinking style as these styles benefit from choosing a fairly explicit design strategy that can assess clear objectives and alternatives. “The purpose of having a strategy is to ensure that activities remain realistic with respect to the constraints of time, resources etc. within which the design team has to work.” [34]

Problem exploration

“Mind mapping is a proven method that helps people surpass the initial chaos that occurs in the mind when the problem arises.” [35] It visually displays aspects of a problem in groups to understand what parts of the problem are interrelated. Our team decided to group this problem into 5 main categories. Floating, moving, solar power, turning around and assembly/production. These were the largest problems that we would have to overcome as a team. Similarly, to framing, common themes re-occur within the problem map. For example, all parts during production will require some form of fastening, cutting or gluing. Or, turning the boat around with a servo motor requires some form of solar power etc. Being a team of predominately mechanical engineers, we wanted to challenge ourselves by utilising electronics for such things as turning the boat around. Therefor soldering appears a few times as a common theme amongst the different problems.

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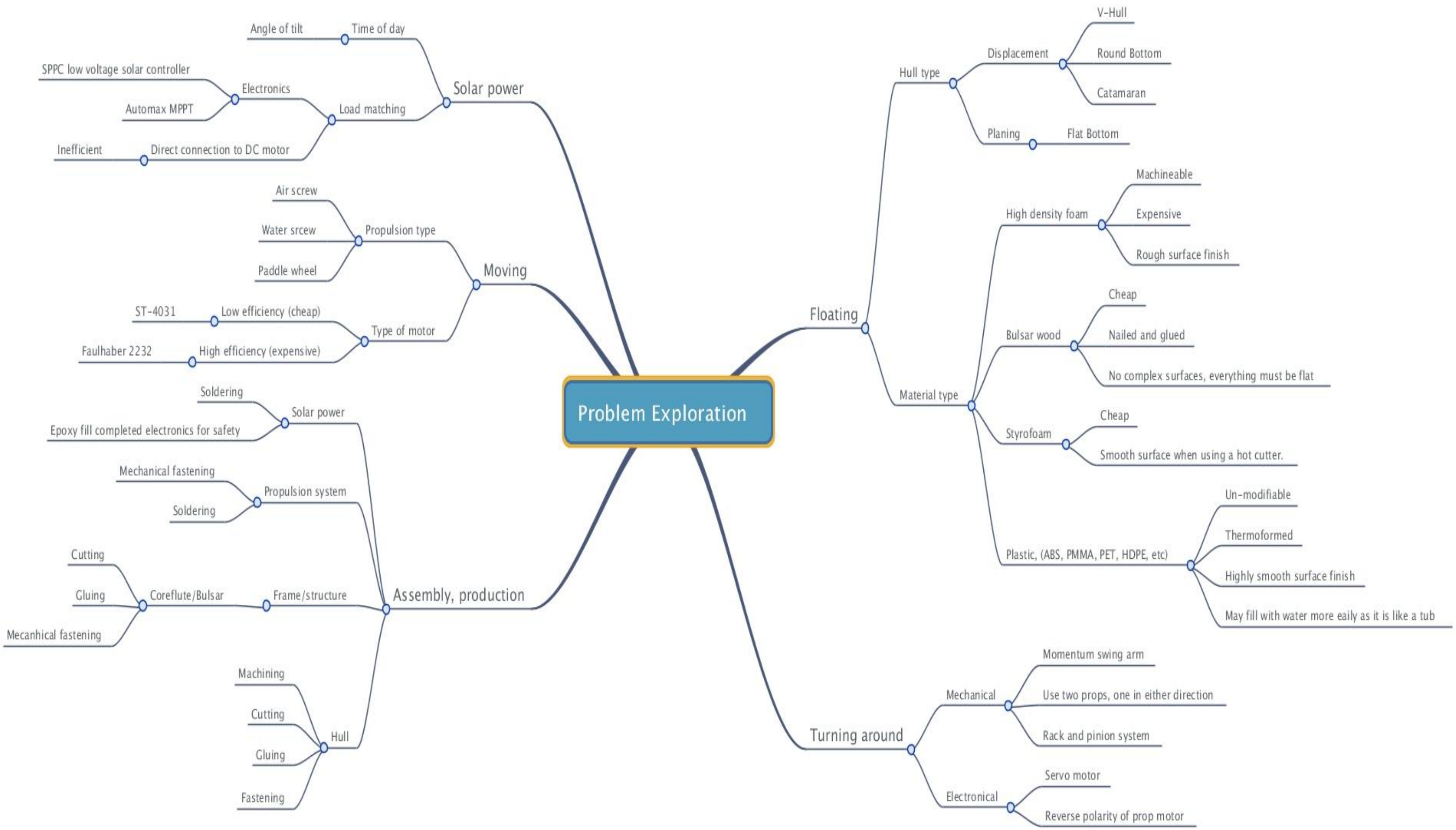
[34] Cross, N., 2008. Engineering Design Methods. Wiley.

[35] https://www.mindmeister.com/blog/problem-solving-with-mind-maps/


Problem Exploration
Solar power
Time of day
Angle of tilt
Load matching
Electronics
SPPC low voltage solar controller
Automax MPPT
Direct connection to DC motor
Inefficient
Moving
Propulsion type
Air screw
Water srcew
Paddle wheel
Type of motor
Low efficiency (cheap)
ST-4031
High efficiency (expensive)
Faulhaber 2232
Assembly, production
Solar power
Soldering
Epoxy fill completed electronics for safety
Propulsion system
Mechanical fastening
Soldering
Frame/structure
Coreflute/Bulsar
Cutting
Gluing
Mecanhical fastening
Hull
Machining
Cutting
Gluing
Fastening
Floating
Hull type
Displacement
V-Hull
Round Bottom
Catamaran
Planing
Flat Bottom
Material type
High density foam
Machineable
Expensive
Rough surface finish
Bulsar wood
Cheap
Nailed and glued
No complex surfaces, everything must be flat
Styrofoam
Cheap
Smooth surface when using a hot cutter.
Plastic, (ABS, PMMA, PET, HDPE, etc)
Un-modifiable
Thermoformed
Highly smooth surface finish
May fill with water more eaily as it is like a tub
Turning around
Mechanical
Momentum swing arm
Use two props, one in either direction
Rack and pinion system
Electronical
Servo motor
Reverse polarity of prop motor

Problem specification

Objectives tree

- Boat must turn around
- Boat must move along the water at decent pace
- Efficient
- Ensure that the boat floats
- Use as much of the solar power that is available
- Must move in a straight line
- Ensure that the boat is inherently stable in the water ie Centre of mass lower than centre of buoyancy (and vertically in line)
- Hold all electronics safely and keep them free from water.
- Win the boat race
- Plane along the water surface

Things to do:

Frame the problem

The design constraints are as follows: the boat must be solar powered and not use any energy storage devices, it must float effectively and be able to travel up and back the 10m length of the pool.

It is important to note that these aren't the only requirements of the boat, our team set a few design constraints. We wanted the boat to rotate around and always keep the bow of the boat moving in the forward direction. Given that the propellers work more efficiently moving in the forward direction, (Tests Scorpio Panel & Motor, 2017)[36] as well as the hull being uni-directional, this will also reduce drag. We also wanted to keep the design as simple as possible in order to reduce the necessity for troubleshooting that could have been avoided. Lastly, we wanted to be competitive and potentially manufacture the fastest boat.

Therefore, given these design/team constraints, the best way to frame the problem is:

"Design and build a comprehensive but simple solar-powered boat that can move a total of 20m in two directions."

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[36] Garner, I 2014, 'Tests Scorpio Panel & Motor – Miniature Steam Propellors', MSV committee, viewed 25 September 2017, issue 1, p. 17

Systemic thinking

The problem exploration mind map above, highlights the key problems that will be addressed in this report. The map indicates that some problems have re-occurring themes. One of these problems is electronics. This problem arises in propulsion, solar power and turning around. The team needed a way to better visualise this problem and understand how common themes inter-relate between different problems. "Systemic Thinking enables people to deliberately and systematically gain significantly deeper insights into challenging situations and complex domains by surfacing the interaction-patterns that underlie, drive and govern them." (Systemic Thinking 2017)[37] Therefore, systemic thinking was employed to analyse the above mind map. To begin, three major themes were established within the problems; electronic, mechanical and engineering. Some problems, goals and solutions that were not included in the original mind map will be included here. The full list of solutions for each goal/problem has not been be fully tried and tested by the team, therefore the solutions listed are 'possible solutions' and have not been proved right or wrong.

ELECTRONIC

Goals	Problems	Solutions
• **Use solar power** • **Travel a total distance of 20metres**	• Load matching • Turning the boat around • Converting solar power into mechanical energy • Keeping electronics dry • Assembly	• SPPC solar controller • MPPT controller • Use a servo motor • Electronic DC motor • Reverse polarity of motor • Wire solar panel in series or parallel. • Solar panel • Potting electronics with epoxy • Watertight container • Waterproof spray • Soldering iron

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[37] Systemic Thinking. 2017. *Systemic Thinking*. [ONLINE] Available at: http://www.systemicthinking.com/. [Accessed 05 October 2017].

MECHANICAL

Goals	Problems	Solutions
Travel a total distance of 20 metres **Use every available resource to construct a boat**	Load matching Turning the boat around Assembly	Change propeller size/type Add gearbox Reduce pitch of motor Fasteners/screws Cutting/gluing etc Machining

Given that the main goal of the project is to design a solar boat, far fewer foreseeable problems occur here in the mechanical theme. A vast majority of these problems and solutions first anticipated relate to either the electronic or engineering theme.

ENGINEERING

Goals	Problems	Solutions
Design a boat that is hydrodynamic **Create a rigid and strong boat**	Creating a hydrodynamic hull Moving Assembly Turning around Selecting type of propulsion Selection of materials Assembly Converting solar power into mechanical energy	Use strong lightweight materials Use water screw type propulsion Fasteners/screws Cutting/gluing Machining Change Propeller size and pitch Gearbox SPPC solar controller MPPT controller Use servo motor Wire solar panel in series or parallel.

As shown in the table above, the engineering theme encompasses almost every problem that we encounter in both the electronic and mechanical themes. This makes sense, given that all of the problems the team has encountered with the boat project have attempted to be solved with an engineering approach.

CONCEPT GENERATION

Concepts were generated by giving each member a week to come up with individual ideas considering any aspect of the boat design. Given the literature review was split among members, it is common that each member's ideas followed the theme of their literature review. In addition, as each member did not know what each other's generated ideas were, there are some overlapping ideas. Because each member created several ideas there is still a diversity of concepts.

Daniel Zanati

Idea #1 Mechanical Motor Flip

This involves having the boat impact the end of the pool and using the boats momentum to flip the motor, shaft and turbine 180 degrees to allow it to return to the starting line. This allows the turbine to be always rotating in its efficient direction vs reversing the rotation of the turbine and 'reversing' the boat, which as described in the literature review to be inefficient.

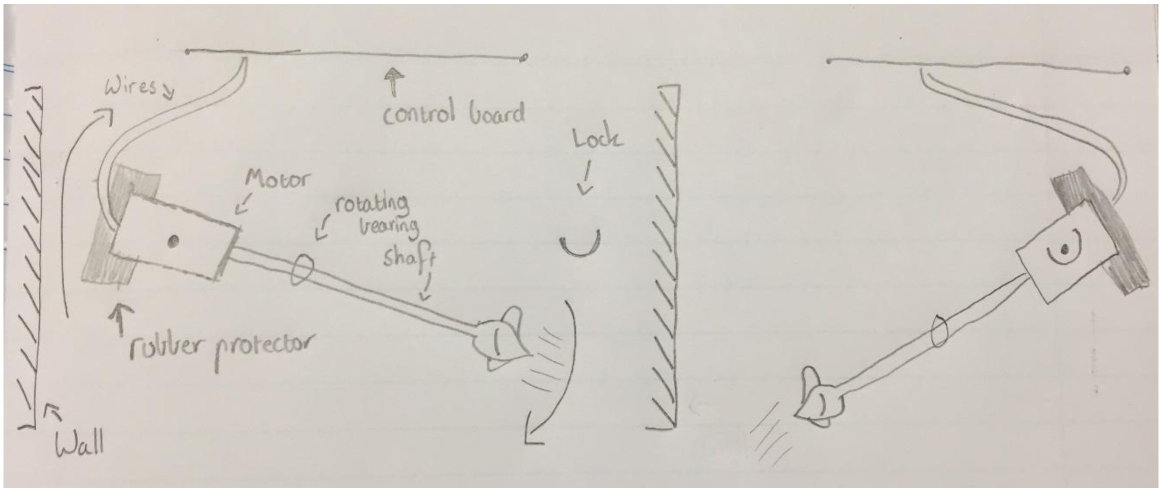


FIGURE 3 ***MECHANICAL DRIVE SYSTEM FLIP***

As the diagram shows, as the boat pushes against the end of the pool, the motor is forced to rotate and lock into the opposite direction. The design can be further improved by making the system loaded with potential energy in the form of rubber bands or springs. As the momentum of the boat can vary considerably due to the sun conditions and overall boat design, it may not have enough momentum to flip the drive system, allowing the loaded energy to overcome this difference.

Possible Implications:

- As there needs to be room for the drive system to rotate, the solar panel will need to be raised which also raises the centre of gravity of the boat, which can make it unstable.
- If it is a cloudy day, the boat may not travel fast enough to rotate the drive system. Implementing a loaded energy such as a spring would solve this issue.
- With a fast moving boat, impacting the motor may damage it
- A specific hull design will need to be used to allow room for the drive system to rotate

Idea #2 Symmetrical Double Motors

This idea again stems from the fact that we want to make use of the efficiency of the boats propeller, as directional turbines produce more thrust when used in the right rotation. Simply we would have two drive systems in the form of a motor, shaft and propeller, symmetrical in design but facing opposite directions. Moving the boat either direction can be controlled by directing the current to one or the other motor. Directing the current can be achieved by a light or pressure sensor, so that when to boat reaches the end of the pool, it knows when to switch the power to the other motor to drive it in the opposite direction. A possible advantage would be to activate both motors at the same time, with one motor rotating in the same direction as the thrust motor. But this may pull too much current from the solar panels, testing would need to be done to find the most efficient set up.

Possible Implications:

- The sensor will need to be able to detect the end of the pool before the propeller hits the wall to prevent damage
- Having an idle propeller 'pushed' against the fluid flow increases drag, and as this drag will be opposite to the thrust of the active propeller, the boat may want to travel in an unstable, unpredicted way
- High cost, will need to purchase double the components

Idea #3 Adjustable Solar Panel

A solar panels effectiveness in producing electricity is dependent on how much sun there actually is, and we can maximise its exposure by positioning the solar panel so it is facing perpendicular to the sun. We know the final performance test of the boat will be done in the afternoon, and not knowing which direction the pool will be facing, the four corners of the panel need to move in the axis perpendicular to the water.

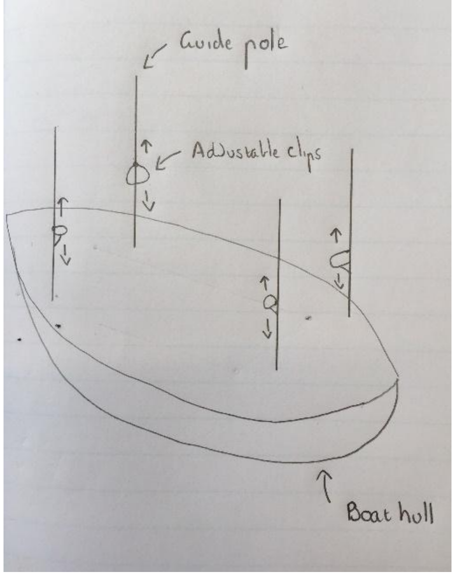


FIGURE 4 ***ADJUSTABLE SOLAR PANEL***

Each corner of the panel is able to move up and down, allowing infinite possible facing angles of the panel in respect to the boat. Each pole will be need to be securely positioned on the boat, and the clips holding the panel itself could be easily 3D Printed or improvised.

Possible Implications:

- Raising the solar panel would raise the centre of gravity of the boat, possibly making it unstable. This can be combated with the addition of small weights, offsetting the small changes to the weight distribution of the vehicle adjustable
- Clips need to be designed to grip the panel firmly so that it won't slip and fall into the water causing potential damage.

Matt Corneliusen

Idea #4 Flat Bottom Hull

The first design will utilise a flat bottom hull. As these hulls are a planning type hull they require less power than a displacement hull travelling at the same speed. To address the issue of turning the boat around and travelling back down the 10m length of pool, the boat will rotate underneath the solar panel through the use of a servo. Rather than using an electronics kit to control the servo, a servo trigger can be used. Once the bump sensor at the front of the boat is depressed the servo trigger will activate and rotate the servo around to an angle specified by the trim pots on the trigger

Possible Implications:

- Difficulty in controlling a servo via analogue
- Need to ensure that the centre of gravity is right underneath the servo to ensure boat doesn't tip in anyway.
- Slightly slower top speed due to a large wetted surface.

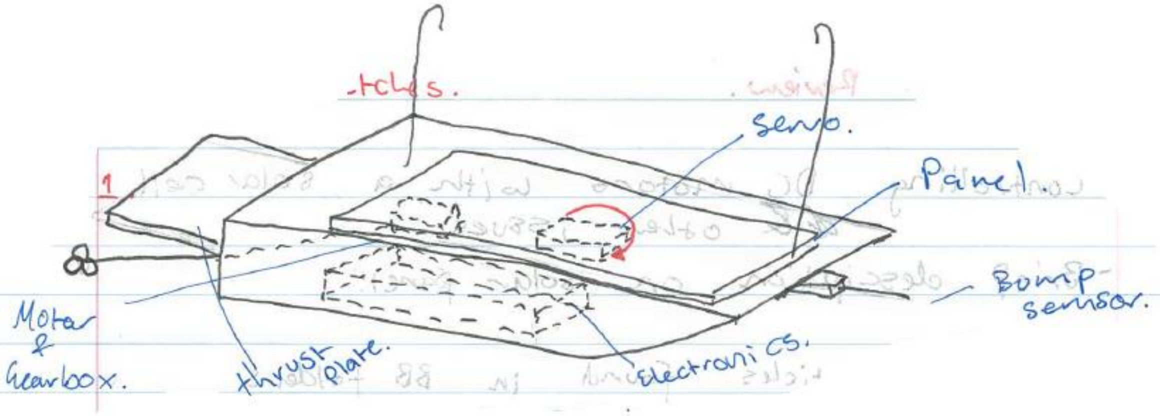


FIGURE 5 FLAT BOTTOM HULL

Idea #5 Catamaran Hull

This second design employs a catamaran style hull. These hulls have proven to be more stable than other hull designs. Given that we will be housing quite a few electronics it is important that the boat doesn't tip over into the water. To go back up the pool, the motor will be attached to a servo that allows the prop shaft and motor to rotate to face the opposite direction. To ensure that the boat travels the same in both directions the hull will be made symmetrical at either end of the boat.

Possible implications:

- Much more stable on the water
- May move slightly more slowly through the water given that there is 2 displacing style hulls.
- May have difficulty centring the centre of mass because electronics and other component will most likely be placed into one of either of the hulls.

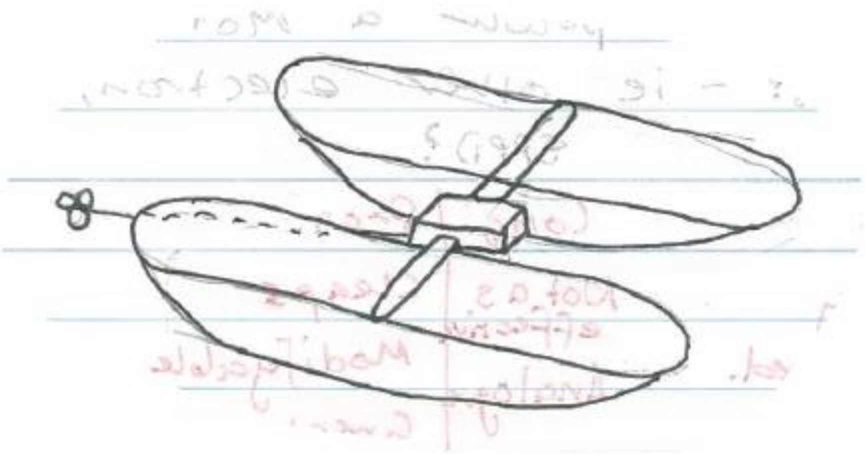


FIGURE 6 CATAMARAN HULL

Idea #6 V hull Design

The last design incorporates a v-hull style design and a similar turning mechanism to the first boat. If we had high sun intensity on the day of the testing this style of hull may be ideal. This hull requires a larger amount of energy to move into planning unlike a flat bottom. However once it is in the mode the wetted surface under the boat is greatly reduced and a higher top seed can be achieved.

Possible implications

- Higher top speed if the boat can successfully move into planning mode.
- Need more power/speed to put the boat into planning mode?
- Will be very unstable on the water unless ridges are put into the hull.

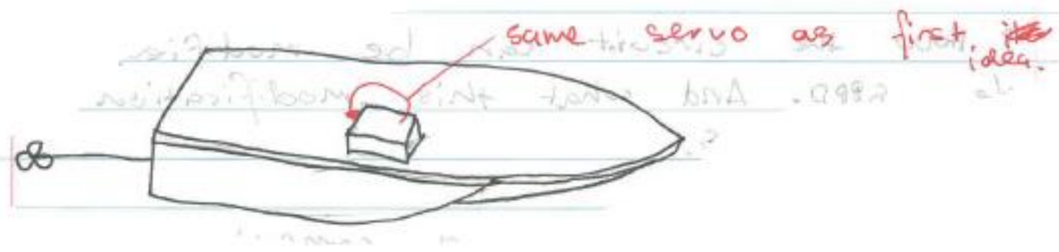


FIGURE 7 V HULL DESIGN

Alex Orton

Idea #7 Sliding Catamaran

This idea involves a catamaran hull which supports the solar panel, with a separate body in between. This body is on a slider which drags the catamaran and when it hits the wall, it switches and heads back the other way. This means that the solar panel can remain centred and in line.

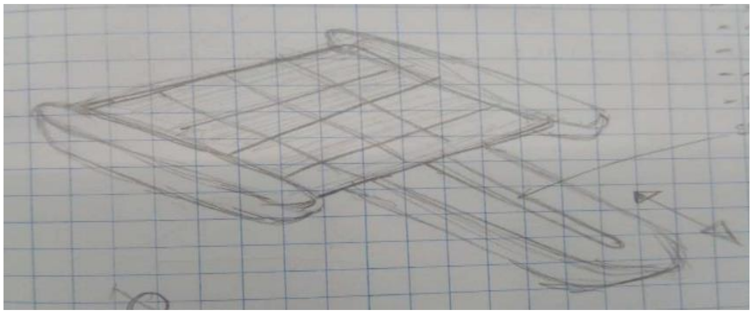


FIGURE 8 SLIDING CATAMARAN

Possible Implications

- The motors need to be considered, whether there are two motors of opposing directions or some sort of turning motor
- The solar panel remains in the same position so there is no accounting for where the sun sits in the sky.

Idea #8 Flat Bottom Boat

The idea is a stable boat that can travel at slow speeds effectively and with the most stability. The solar panel is simply supported and the hull would be able to be hollowed out.

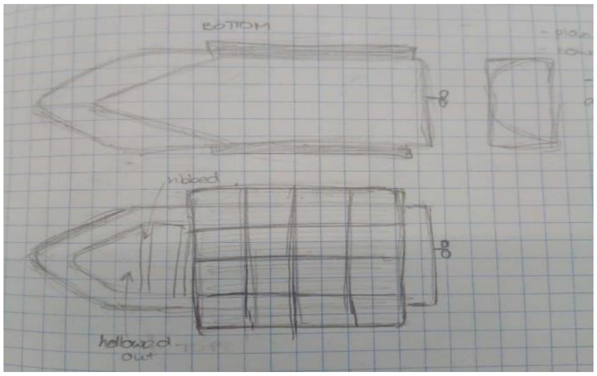


FIGURE 9 FLAT BOTTOM HULL

Idea #9 Paddle Boat

This idea is simple and stable, it came through the thought process of thinking about how to make the boat go back the way it came. The paddle boat is an old style of boat propulsion and I thought it would be simplistic and reliable. The hull was to be flat bottomed, so at the solar panel had a wide bed to sit on, potentially with the panel on some sort of way to orientate the panel

Possible implications

- Size of paddles
- Propulsion of paddles
- Sourcing paddles or manufacturing them

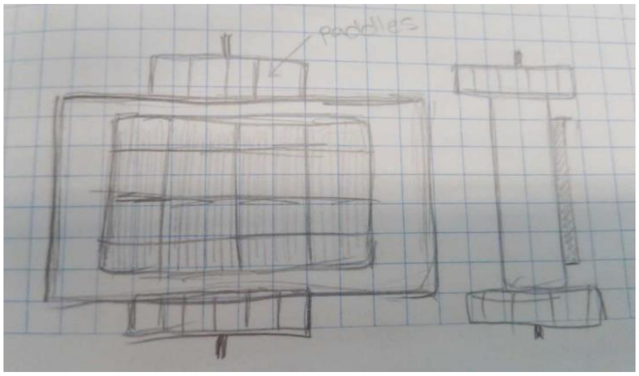


FIGURE 10 PADDLE BOAT

Syed Hassan Ali

Idea #10 Trimaran Boat

A trimaran is a multihull boat that comprises a main hull and two smaller outrigger hulls which are attached to the main hull with lateral beams. Most trimarans are sailing yachts designed for recreation or racing; others are ferries or warships.

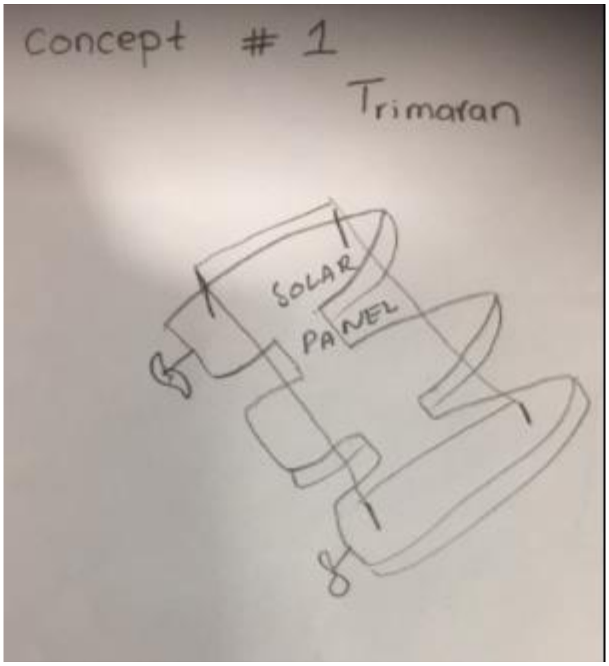


FIGURE 11 TRIMARAN

It would be very easy to reach end of the pool. They are very easy to design and manufacture.

Flat bottom hulls are best suited to shallow water and good Stability with three connected hulls and Solar panels would be well supported across the three hulls.

However,

Boat would have to turn around completely which is a complex mechanism loosing time and speed.

Hulls would increase the drag and Solar panel sitting wouldn't be optimal for full sun

Flat bottom hulls travel on the water instead of through the water, so it wouldn't move as quickly as a V-hull boat.

Idea #11 Catamaran Boat

A catamaran is a multi-hulled watercraft featuring two parallel hulls of equal size. The two hulls combined also often have a smaller hydrodynamic resistance than comparable mono-hulls, requiring less propulsive power from either sails or motors.

However,

Solar panel sitting flat might not receive the max sunlight. The hull will sit lower in the water than a flat or round bottom hull.

There is a possibility that solar panel might get wet, as a result it will lower the efficiency

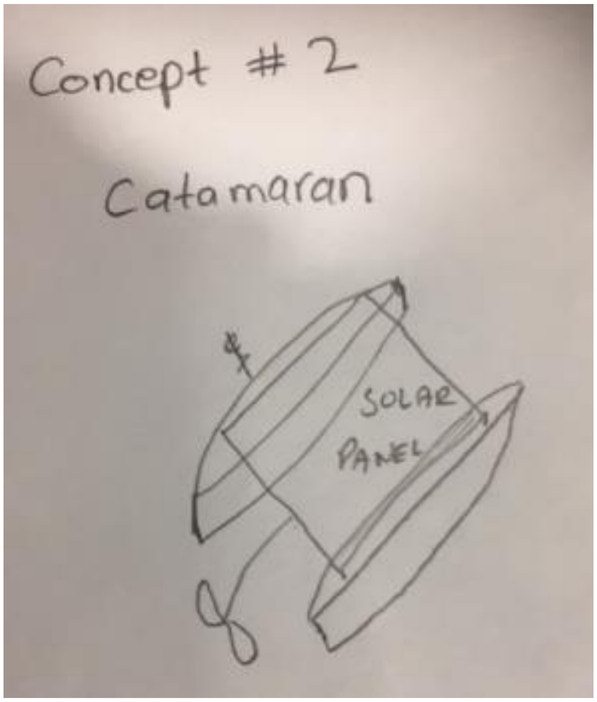


FIGURE 12 CATAMARAN BOAT

Idea #12 V-Hull Boat

A V-hull, is the shape of a boat or ship in which the contours of the hull come in a straight line to the keel V-hull designs are usually used in smaller boats and decreases the drag

Solar panel can be set to an angle to receive maximum sunlight and the boat hull is stable in calm weather.

But, It requires more power to run compared to other hulls such as flat and angled solar panel can result in unstability of the boat.

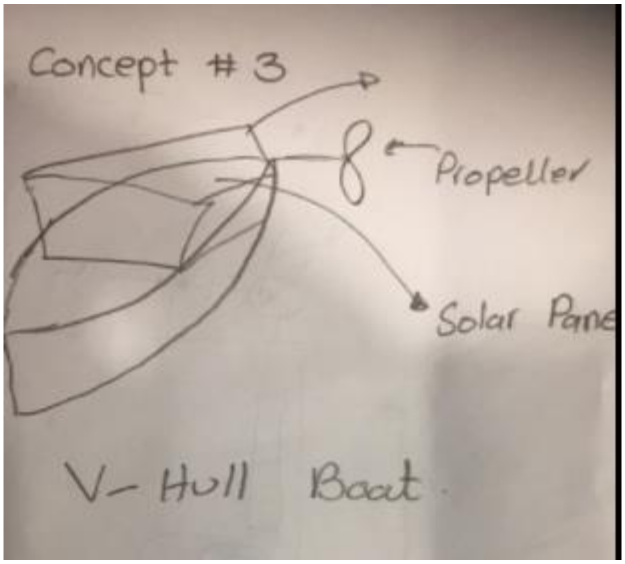


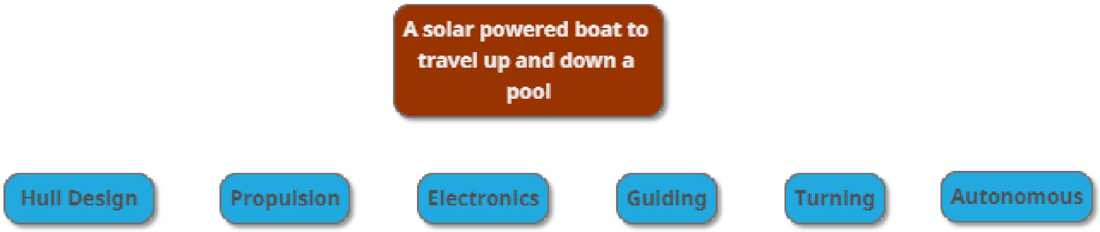
FIGURE 13 V-HULL BOAT

The Design Space

Overall, it can be seen above that the key features of a boat design has been addressed. The first being the hull design. As a group we all went off and came up with 3 different design ideas for the boat. When we met up again it was evident that the hull design seemed most important feature of the boat. The second two most observed features were the method of propulsion (Paddle wheel, single prop or double prop) and a way to address the problem of turning around. This method of concept generation proved to be successful as it managed to encompass a large amount of the design criteria and present it in a visual way.

SYSTEM EVALUATION CRITERA

Marine vehicle design can vary substantially to its intended purpose. But there are some basic underlying design characteristics that all boats employee that we will evaluate in its purpose to completing the task at hand. First, let's look at the objective of this project using an objective tree. This method allows us to create a clear and complete statement of design objectives that we wish to reach as a group, and builds the foundation to help make decisions to any design features we will deploy on our solar boat.



We are now starting to get an idea on how we are going to reach our main objective. All 6 objectives must be met for us to successfully complete this project. However, there will be an extra emphasis on some objectives due to the variety of ways they can be achieved and that's why it is important to create a weighting system so that ideas can be accurately assessed in their effectiveness in completing the sub objectives.

Though, there are some underlying ideas that we as a group believe will make a successful solar boat. Simplicity is always the golden rule, as complexity can lead to a higher chance of malfunction. Adding complexity to components should only be considered when a significant effectiveness/efficient gain will come out of it. It's also important to note, that we are designing and building this boat to be operated only a handful of times, to experiment with and to find the gaps in the literature review/results in testing and discovering the optimum characteristics for our boat to complete this objective effectively. If this boat was built to last multiple competitions and runs, better usability, materials and design would be weighted more heavily to improve the overall design for the boat.

On the following page we have created a list of importance categorising the relevant aspects of our boat that will allow us to complete the task set out. Propulsion is going to be the heaviest category considered at 30%. As a group we feel like we can make significant gains in the time it takes for the boat to reach one end of the pool by considering the efficiency of the motor used and the overall propeller design. However, as we have dived heavily into the understandings of propeller design in our literature review, ultimately the best propeller design will be discovered under testing and experimentation with different light conditions and other variables that we have not considered yet. The way we turn the boat is allocated 16 % and simplicity of the turning method overrules any design criteria, as complexity can lead to it failing all together. Overall, this list of importance will aid us a group when we look at our list of alternatives and decided on various design features on our solar boat.

Hull Design 20

•Shape	8
•Material	4
•Manufacturability	3
•Size	5

Propulsion 30

•Propeller Material		2
•Motor		10
•Cost	1	
•Efficency	7	
•Propeller Design		6
•No.of Blades	3	
•Size	3	
•Simplicity		6
•Type of Propulsion		6

Electronics 18

•Solar Panel Orintation	5
•Simplicty	3
•Use of solar inverter	8
•Manufacturability	2

Guiding 2

•Simplicty	2

Turning 16

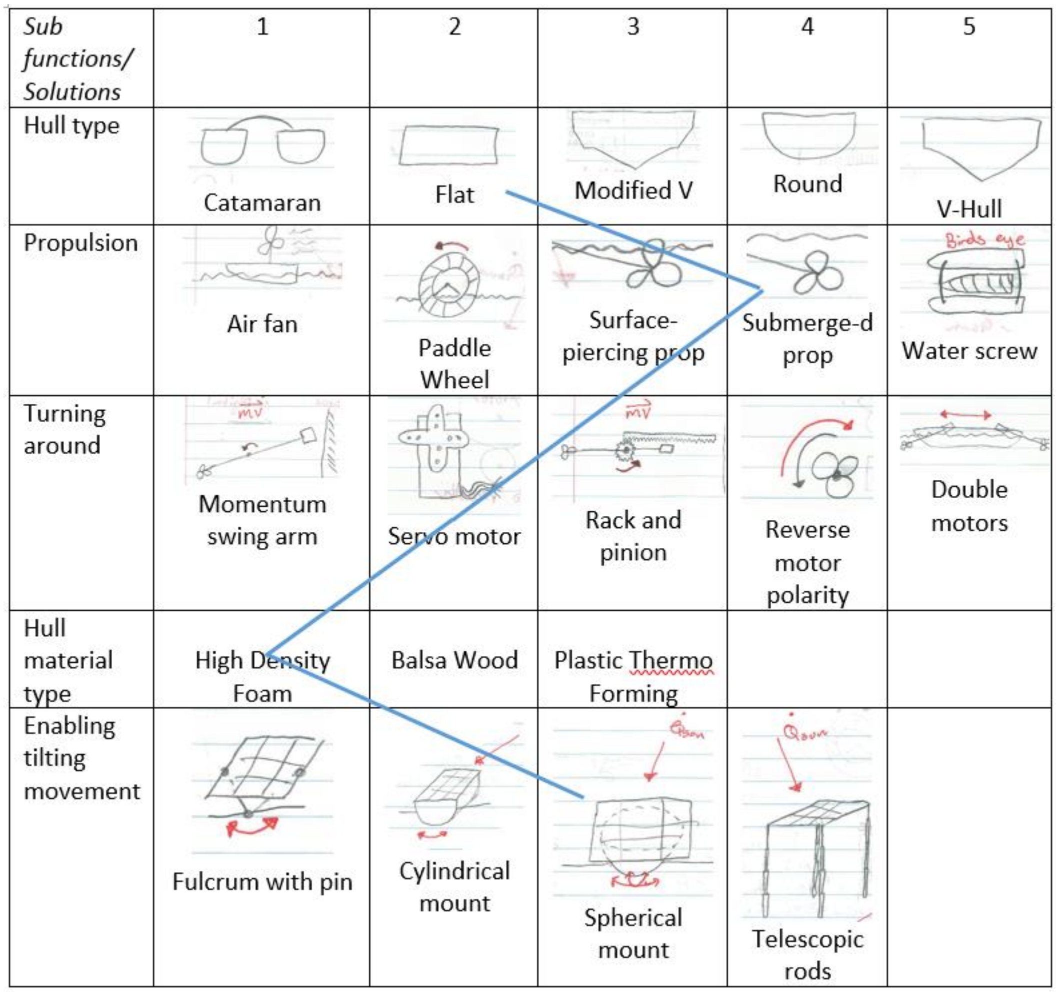
•Time to turn	6
•Simplicity	6
•Cost	2
•Power needed to turn	2

Overall build 14

•Water Proofing Electronics	4
•Appearence	4
•Build Quality	6

CONCEPT SELECTION

A formal group meeting was held where each concept generated was considered and weighted given the values set out in the system evaluation. A morphological chart was created to showcase a list of alternative solutions. The morphological chart lists the functions/features that are essential to the solar boat design and alternatives of each function so that we can see how each function relates to each other and how the system will work overall.



Sub functions/ Solutions	1	2	3	4	5
Hull type	Catamaran	Flat	Modified V	Round	V-Hull
Propulsion	Air fan	Paddle Wheel	Surface-piercing prop	Submerge-d prop	Water screw
Turning around	Momentum swing arm	Servo motor	Rack and pinion	Reverse motor polarity	Double motors
Hull material type	High Density Foam	Balsa Wood	Plastic Thermo Forming		
Enabling tilting movement	Fulcrum with pin	Cylindrical mount	Spherical mount	Telescopic rods	

This is the current design of the solar boat. Simplicity is the golden theme in the alternatives we choose from, however the given system criteria set before was considered as well. For the Hull we have chosen a flat bottom design, as in our literature review it is the most stable and it provides the lowest drag when at speed due to aquaplaning. The design will be further improved by cutting a water vane to improve fluid flow towards the propeller. The Hull would also be made out of High density foam, as it will be the best material to CNC machine to obtain the shape and provides the necessary properties for the hull to perform well hydro dynamically. Experimentation on a water proof coating will need to be determined.

We will have a submerged propeller as this will provide optimal thrust. And the way we will turn the boat is via a servo rotating the hull underneath. This allows the propeller to always operate in a forward moving path which is the most efficient method of thrust. The solar panel will be mounted via a car phone holder, which allows infinite movement around a small ball joint.

CONCEPT ANALYSIS

All the theory has been discussed in the above sections and in this section we have applied the mathematics and physics of those concepts on our design and we were able to attain meaningful results.

Buoyant Force

$F_B = \rho_f V_f g$

where F_B is the buoyant force,

ρ_f is the density of the displaced fluid,

V_f is the volume of the displaced fluid,

g is the acceleration due to gravity, 9.8 m/s^2

$F_B =$ N

W = mg

The Buoyant force is greater than the weight of the boat. Therefore, the boat will not sink but it will float as well.

The static thrust is given by the formula,

$T = C_T$ Density D^4n^2

And Power is given by formula,

$P = C_P$ Density D^5n^3

Where,

C_T = Coefficient of Thrust

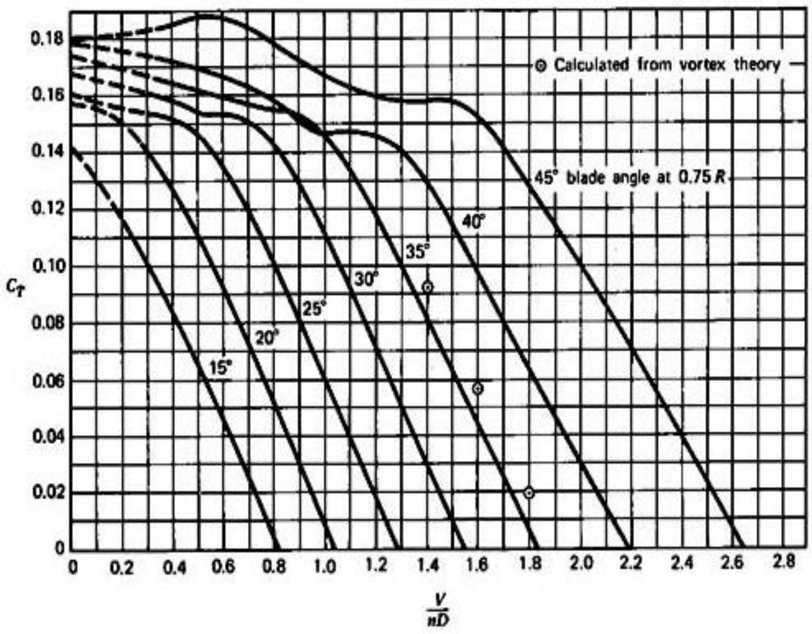
C_P = Coefficient of Power

Density = Density of the fluid (kg/m^3)

D = Diameter Of the Propeller (m)

N = Revolutions per Second (Rev/sec)

Graphs to Determine C_p and C_T



Calculating Power and Thrust on a two and three blades propeller,

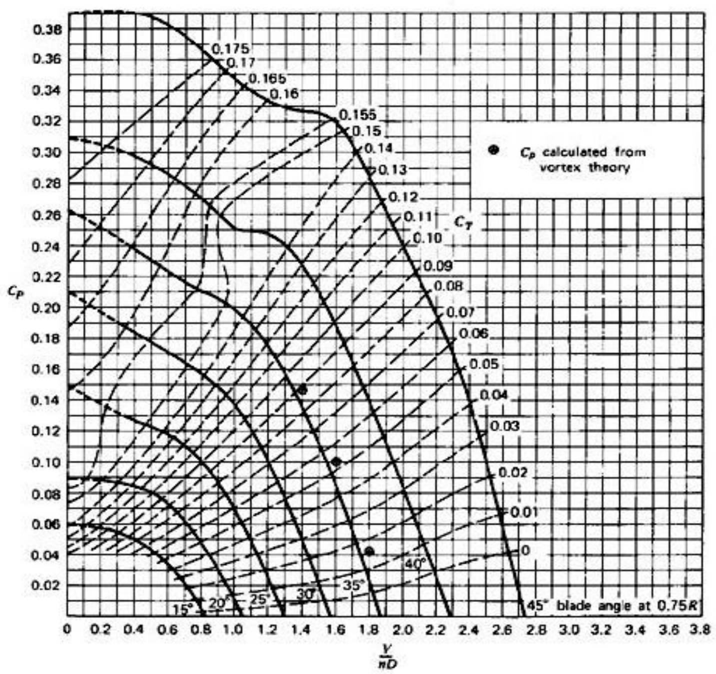
For two blade propeller **V/nD = 0.5 , C_T = 0.13**

For three blade propeller **V/nD = 0.4 , C_T = 0.08**

To calculate,

TWO BLADE PROPELLER (ANGLE 25 DEGREE)	**THREE BLADE PROPELLER (ANGLE 15 DEGREE)**
V/ND = V/(6,900/60)*D	**V/nD = V/(6,900/60)*D**
V= 0.5*(6,900/60)*28*10^-3	**V= 0.4*(6,900/60)*D**
V = 2.7 M/SEC	**V = 1.7 m/sec**

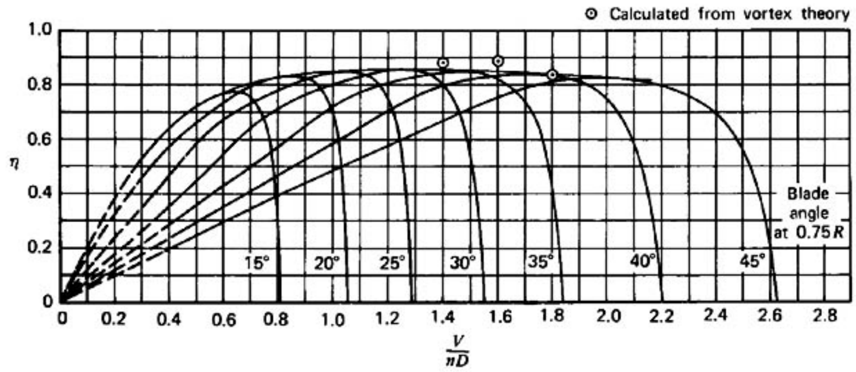
Calculating C_P For Two and Three Blade Propellers



C_P for two and three blades Propeller

Two Blades Propeller	**Three Blades Propeller**
C_P = 0.12	**C_P = 0.04**
P = C_P Density $D^5 n^3$	**P = C_P Density $D^5 n^3$**
P =0.12*1000*(28*10^-3)^5*(6900/60)^3	**P =0.04*1000*(25*10^-5)^5*(6900/60)^3**
P = 7.4 W	**P = 1.4 W**
Calculating Thrust	
C_T = 0.13	**C_T =0.08**
T = C_T Density $D^4 n^2$	**T = C_T Density $D^4 n^2$**
T = 1.9 N	**T = 0.48 N**

Efficiency Of Propellers



The efficiency for two- blades (15 degree propeller)

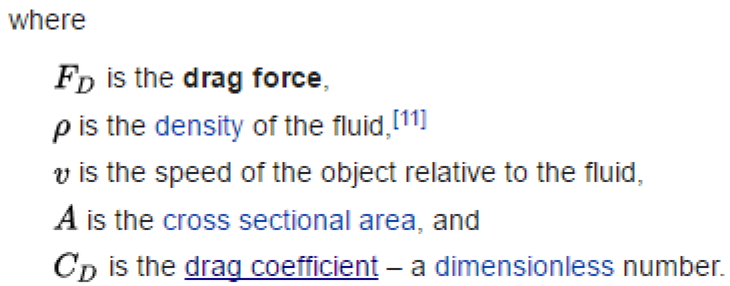
Efficiency = 67%

The efficiency for three blades (20 degree propeller)

Efficiency = 75%

Drag Force

$$F_D = \frac{1}{2}\rho A C_D v^2$$



where

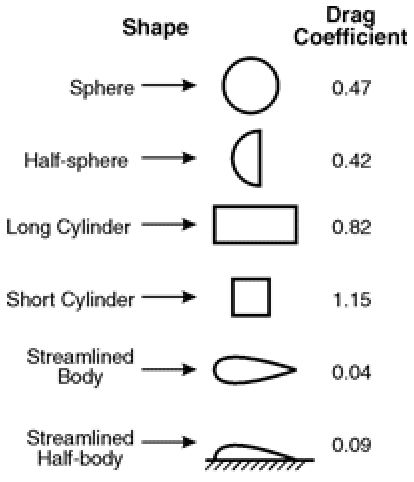
F_D is the **drag force**,

ρ is the density of the fluid,[11]

v is the speed of the object relative to the fluid,

A is the cross sectional area, and

C_D is the drag coefficient – a dimensionless number.



Measured Drag Coefficients

Calculating Drag Coefficient,

Calculating Drag Force on a three and two propeller boat,

Where,

Density = 1,000 kg/m^3

TWO PROPELLER	**THREE PROPELLER**
F_D	**F_D**
F_D = 0.3 N	**F_D = 0.3 N**

TOTAL THRUST- TWO PROPELLER	**TOTAL THRUST- THREE PROPELLER**
$T_{TOTAL\ THRUST}$ = THRUST – DRAG = 1.9 – 0.246	**$T_{Total\ Thrust}$ = Thrust – Drag = 0.488-0.3**
$T_{TOTAL\ THRUST}$ = 1.654 N	**$T_{Total\ Thrust}$ = 0 .188 N**

According to the calculations the propeller with blades more Total thrust, however there would be errors because it’s theoretical thrust.

The only way to confirm the velocity is by testing.

FAILURE MODE AND EVENT ANALYSIS

Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service.

Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual.

Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

MOTOR FAILURE	IF THE WATER ENTERS THE MOTOR IT COULD BLOW UP THE MOTOR	THE CONSEQUENCES WOULD BE THE BOAT WOULDN'T BE ABLE TO COMPLETE THE RACE
MECHANICAL FAILURE	MECHANICAL FAILURE COULD BE IF THE PROPELLER BREAKS	THE BOAT WILL NOT BE ABLE TO FINISH THE RACE
INSUFFICIENT POWER	IF THE SUNLIGHT IS NOT ADEQUATE, SOLAR PANEL WOULDN'T WORK	RESULTING THE BOAT WILL MOVE SLOW
SWITCH FAILURE	IF THE SWITCH JAMS THE BOAT WILL NOT BE ABLE TO ROATE	HENCE, THE BOAT WILL FAIL TO COMPLETE THE RACE
INJURY	IF THE BOAT SWITCH IS TRUNED ON BEFORE PUTTING IN WATER AND THE PROPELLER ROTATES	IT COULD LEAD TO SERIOUS INJURIES SUCH AS FINGER CUT ETC

The possible area of failure is analysed by doing FMEA and estimated the hazard of each situation. This provided a very good understanding of every component of the boat and from this we can reduce or eliminate those hazards before testing our design

CONCLUSION AND RECOMMENDATIONS

The conversion of the suns energy to drive a model boat can be quite a complex interaction. As a team, we diligently researched the correlation between a boat and the water it moves upon. However, it was found that a lot of the data and information obtained relative to watercraft related more heavily to commercial or personal type rather than models. Therefore, in this report we had to predict and assume scenarios/values to obtain reasonable and achievable goals for ourselves. Any foreseeable problem was analysed using FMEA, this helped reduce the likelihood of these problems occurring with our boat by engineering to prevent them.

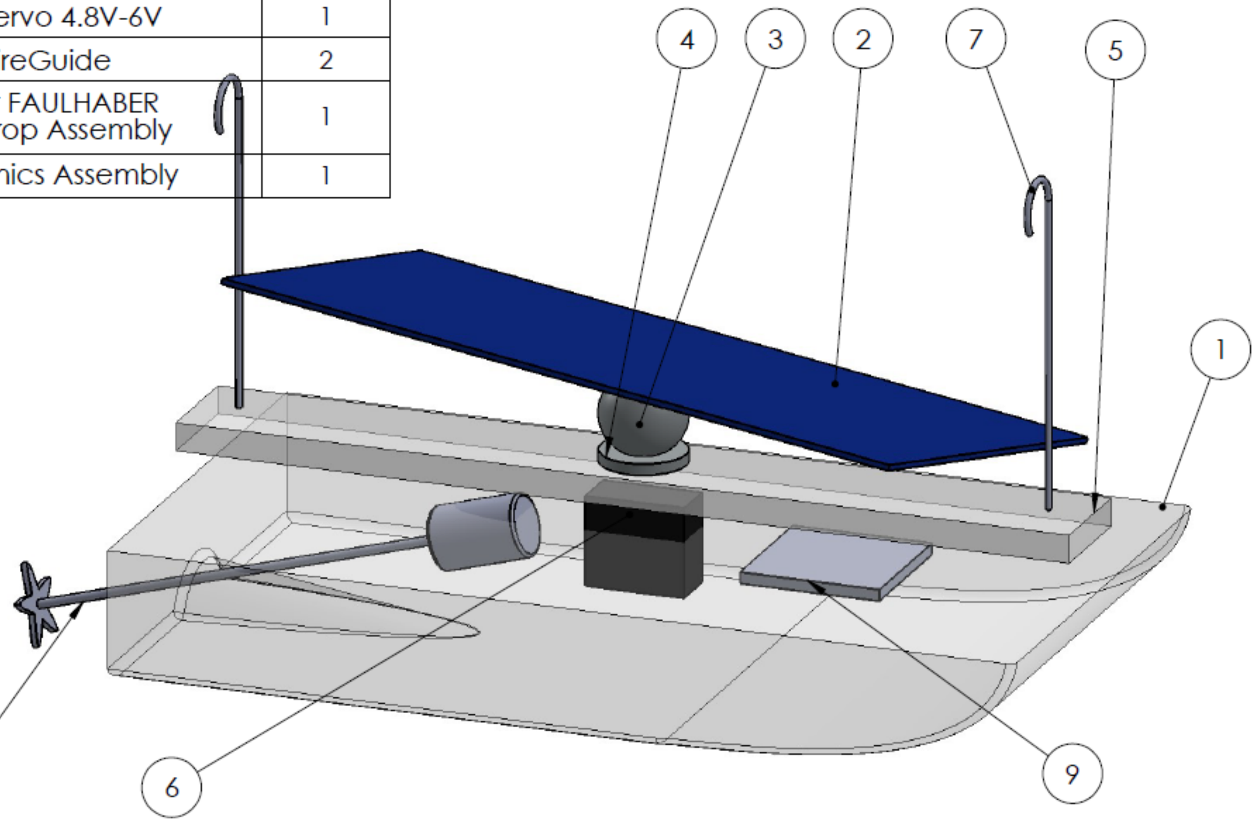
Various design strategies, have been adopted over the course of this project. From brainstorming to final concept selection, we as a team have shown various ways that a model solar boat can/will be built. There have been various hurdles that we as a group have encountered, some of these main hurdles being; understanding the interaction between the suns light and a solar panel, the physical interaction between a boat and water and sourcing and testing electronic and mechanical parts. This report carefully analysed the most effective and efficient boat design features suited to our problem. The morphological chart method used in the concept selection section allowed us to select the best alternatives from a visual list, thus building a well-designed, well thought out boat.

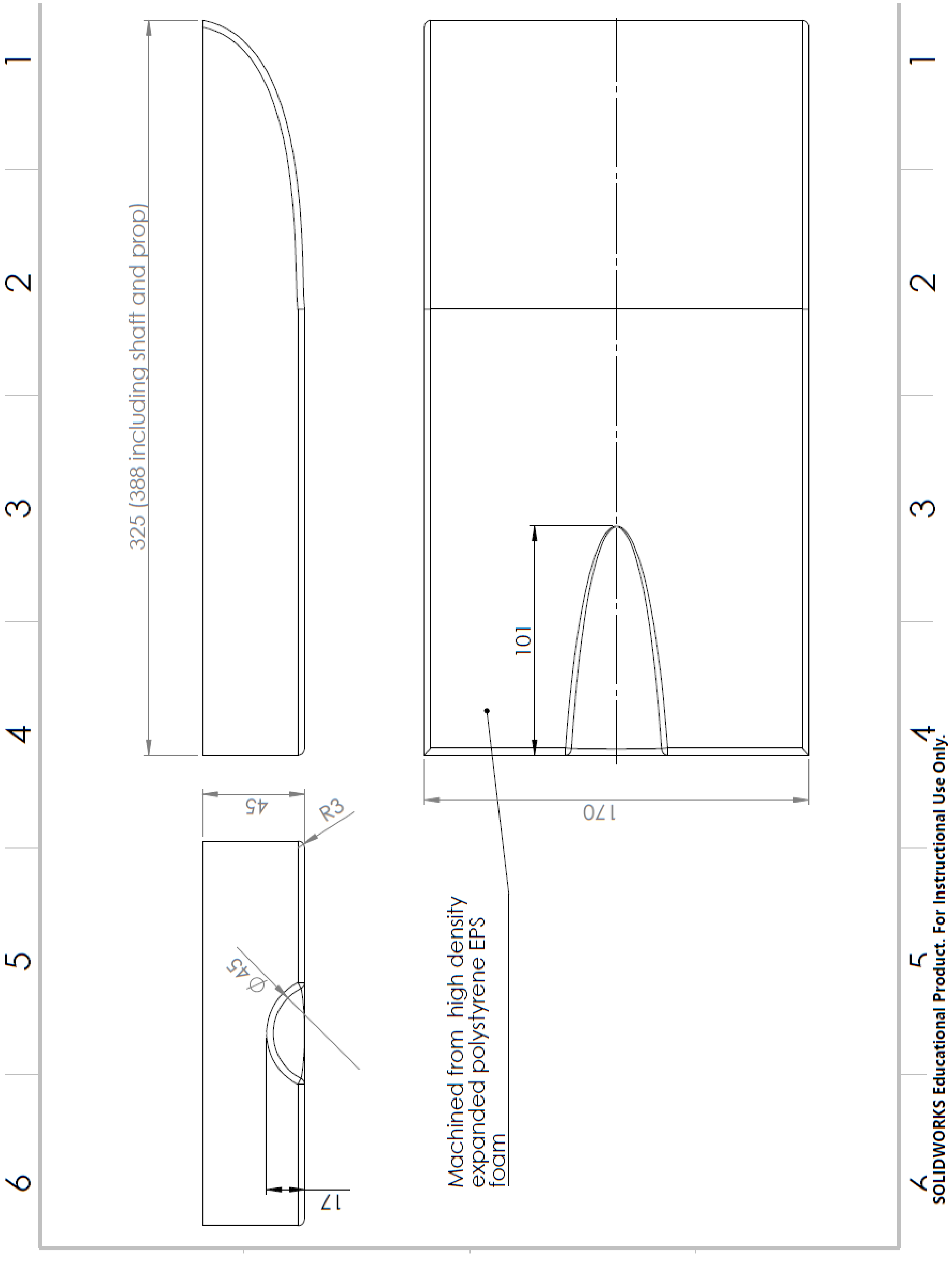
Due to time constraints and lack of funding, the testing of certain features was inadequate to understand their full potential and therefore some alternatives were selected on the basis of ease of installation/design. This coincides with our goal set in the system evaluations criteria section to keep the design relatively simple and avoid over complications. For example, proper testing could not be completed on different hull types therefore, a flat bottom hull may not have been the best choice of hull design for the application of low speed model boats.

Overall, this project was a great way to improve our skill set as engineers by meticulously working as a team to design and build a model solar boat. It tested our knowledge across many disciplines including but not limited to; mechanical and electronic engineering, mathematics and problems solving. It also greatly improved our time and group management skills and gave us a good understanding of how to successfully design and project manage. Given that we are all mechanical engineers this project really tested our knowledge and research capabilities.

APPENDIX

ITEM NO.	DESCRIPTION	QTY.
1	Foam Body	1
2	Solar Panel	1
3	Spherical Magnet	1
4	Metal Washer	2
5	Cross Bar	1
6	Mini Servo 4.8V-6V	1
7	WireGuide	2
8	Motor FAULHABER 2232 Prop Assembly	1
9	Electronics Assembly	1




1
2
3
4
5
6
325 (388 including shaft and prop)
101
170
45
R3
Ø45
17
Machined from high density expanded polystyrene EPS foam
SOLIDWORKS Educational Product. For Instructional Use Only.