The Design and Building of a Human Powered Submarine

Don Burton
Independent Entry
Frederick, Maryland 21703

Abstract: The human powered submarine race is a contest where ideas and education can be tested. This paper describes a submarine that will use a nine blade variable pitch propeller assembly to provide thrust for the submarine using human power. The design and fabrication ideas also look at the stream line of the ships hull, where the sides are concaved into the hull to see if the flow will guide the separated boundary layer will flow back into the propeller faster.

Introduction

The Human Powered Submarine Race (ISR)™ and the Foundation of Underwater Research and Education (FURE)™ have put together one of the more unusual races world wide. The contestant manual available at the race web site http://.www.isrsubrace.org is where to start your project.

All contestants are given a choice as to the design category they wish to enter. It can be a one or two person sub, propeller or non-propeller but all must be free flooding and with the diver or divers using scuba gear.

Safety has the highest priority of the race. No one is allowed to be in the water without a certification for scuba diving, also the craft must pass a land inspection and a water safety inspection for emergency egress and safety buoy.

Picture # 1: Rough form of the hull

Human Power Output

The data suggests that the horsepower that a human can produce be in the area of .33 hp.[1] for a male that is in very good shape, using a bicycle cadence of around 45-55 rpm. at the crank. Under water this amount could be reduced somewhat so the propullsor could have a horsepower of around .15 to about .25.

The amount of torque for this amount of hp. could be calculated using the formula:

$$T = 5252 \times h.p. / RPM \tag{1}$$

Therefore if the amount of horse power available is .25, times 5252 equals 1313, divided by 50 rpm, we have 26.26 foot pounds of torque available. This is the amount available at the propeller shaft. Compare this to your drag racing funny car, and say you have a 350 hp engine that red lines at 5000 rpm. You would have a torque amount of 367.64 foot pounds of torque. This is what pushes you back in the seat.
Knowing that the submarine will operate under water the force applied to the propeller has a certain amount of slippage when accelerating the water. Like drag racing the tires will spin at the instant start and depending on how efficiently the RPM's and gearing are used you can test for the right combination [3]. By looking at several methods of gearing I would like to achieve moving a large amount of water with a variable pitch propeller. There are two options you can use for using any propeller system; you can have a small diameter prop moving very fast or a large bladed prop moving slowly. As you look at the amount of water going by the propellers, they are the same amount, (conservation of mass) [2] the stream tube produced has an area that I wanted to look at; to see if there were any advantages as the stream effects on the hull. See Picture 1.

Hull Shape

The hull shape chosen was one that would place the flow stream along the sides of the hull to prevent boundary layer separation [6]. Most of the NACA airfoils show the side profiles, which provide the best form for lift. The profiles were used as a guide line for the placement of the concave sides, keeping in mind that the water would be spatial. The submarine would be moving through the water not so much as to generate lift, but to have a shape that is laminar and will channel the flow into the propeller blades for capturing the incoming water. See Figure1 and Picture 1

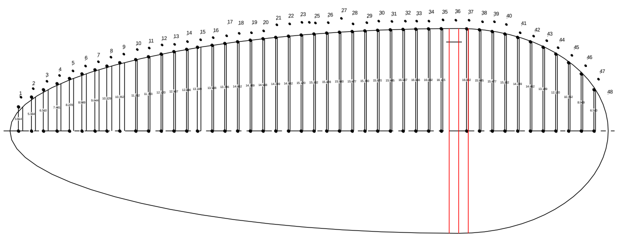


Figure 1 Hull shape

Picture # 2

By concaving the hull and the variable pitch propeller system in with the hull an advantage can be taken with the stream tube as it passes through the prop [4]. When the water is accelerated, it contracts on the out put end. This contraction would appear to squeeze the back end of the sub, forcing it forward.

The old Sintra form is used from the last ISR sub race was reconstructed to see if by concaving the sides inboard. This was done to aid the free stream flowing into the propeller disc area. Most of the port and starboard sides along the hull were brought in. The top and bottom rear area was the only area sunk in for gear placement purposes. The top rear concave section also is used as a hatch for drive assembly maintenance seen in Picture 4.

Picture # 3

Picture # 4

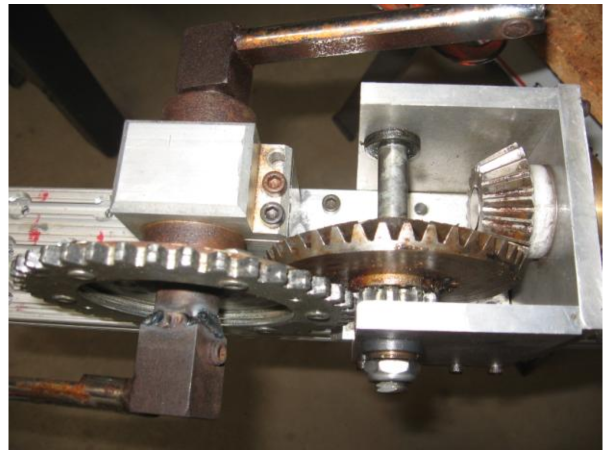
Picture # 5

Drive train

The drive train is made from a set of 4:1 ring and pinion gears and a set of 4:1 boat winch gears that have the bicycle pedals attached Pictures 6, 7, and 8. The unit was then mounted in to a home made aluminum shell and mounted to an aluminum extrusion. The aluminum extrusion helps to keep everything in alignment and then the assembly is mounted onto a wooden platform in the sub. A 36 inch stainless steel shaft runs from the small pinion gear to the propeller hub. There is a small mounting block at the end of the extrusion to hold the shaft as it exits the hull. Cooking grease is used to lubricate the gears and the bronze bushing so as to be environmentally cautious.

When the gears are running there is an eight to one ratio for the propeller. For every turn of the foot crank a blade will rotate eight times.

The length of the pedals were put as long as possible and yet fit into the interior of the sub and also to allow for foot rotation.



Picture # 6

Picture # 7

Picture # 8

Torque

The torque that can be generated is usually taken from the shaft. A Prawny brake (or a dynamometer) usually tests the amount of out put or torque on a shaft. By slowly applying a force to stop the shaft with a clamp, the clamp has an arm attached to it usually with one foot of distance from the center of the drive shaft. This distance represents the radius distance. So now the next formula is the one for torque (T). Where (F) is the force/weight applied, and (D) is the distance from center.

$$T=F*D \tag{2}$$

Using 10 lbs. of force: T=10 x 15”= 150lbs.of torque on the propeller shaft system. The force remains constant across a gear system.

$$(F=T/D) \tag{3}$$

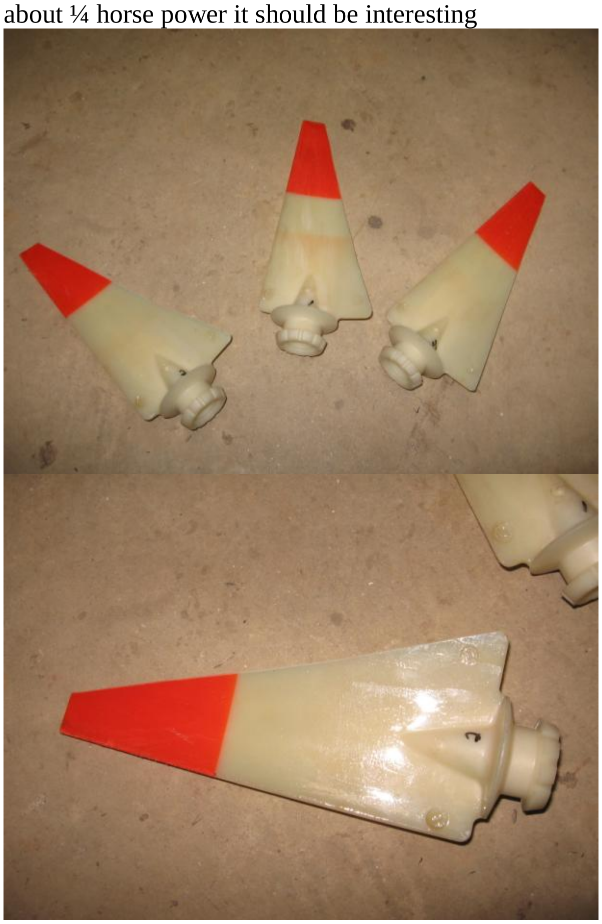
Propeller Assembly

The mounting of the blade fins has three selections for the Helix angle. A helix is a curve that is made by a point traveling around a cylinder at a constant rate with the same direction of the axis. [5] I will be able to place a combination of blades from two blades up to nine blades. I can also change the blade helix angle from 30 degrees to 45 and 60 degrees.

The whole assembly was purchased on line and I thought it would be a useful item to study.
The assembly comes with nine blades and has a tip diameter of 28 inches. The hub is split in half to allow for the blades to change pitch angle. The hub is made from an investment casting and is light weight.

The hub is cast so that there are notches for a small dowel to hold the stub portion of the blade at the pitch angle you want. The first notch I used had the pitch angle way to steep so I drilled and tapped for a set screw to adjust for smaller angles of attack.

This type of assembly should allow me to study if a person can really move 9 blades in the water. The amount of surface area to be cranked is a lot and with about ¼ horse power it should be interesting



Picture #'s 9a, 9b

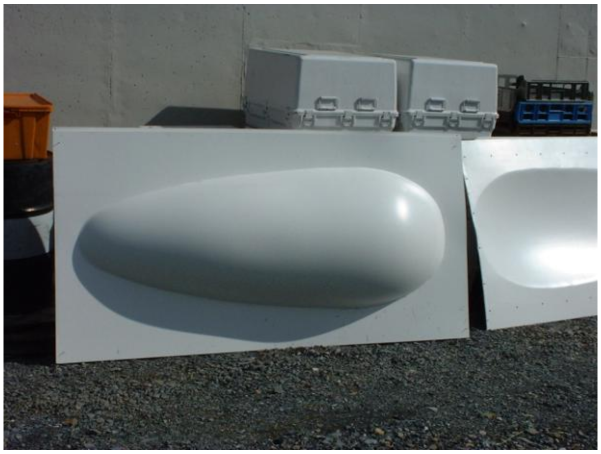
Picture #'s 10a, 10b, 10c

The Sintra® PVC Core Hull

I believe the newest material that will be introduced at this years sub race will be that of a material known as Sintra®. This is an expanded high density plastic PVC sheet with many properties, especially being water proof. I used two sheets one for the top one for the bottom. By using the 4’x8’x 6mm sheets I was able to incorporate a lot of the features that I needed for control surfaces seen in Picture #13.

Picture # 11

Sintra® is used in the sign making industry because it is easily formed and cut and can be shaped by blow molding which I used or vacuum forming and/or cutting and bonding using PVC adhesive such as that used in the plumbing industry. The material is very smooth, even when it is stretched out into the two hull forms that I wanted. As with any procedures, I try to use, it took me six attempts and six sheets before I achieved the proper shape. It seems the material has a memory to it and as soon as you take the heat off it wants to go back to a flat shape. The sheet also has some areas that are hot spots and I had to move the heater around and use baffles to find a sweet spot to get even heating. A Sintra® heat chart explains the various temperatures at which the material will start to deform /degrade. The material is very easy to work with and is lightweight even a 4 x 8 foot sheet. Once the material was at the proper shape little else had to be done to shape the hull. The material is not strong on the surface just like on a PVC pipe you have in a plumbing system. By roughing up the surface I added 5 layers of epoxy, sanding each layer for bonding .The Garrie Hill bike fairing was the source for this type of hull. [8].



Picture # 12

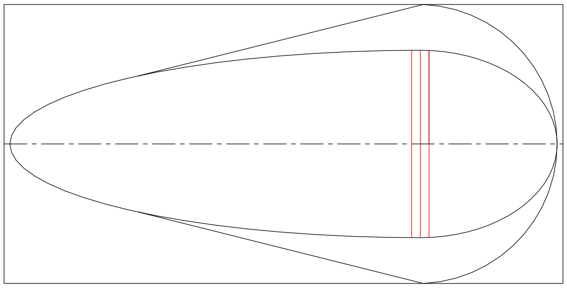


Figure 2

Picture # 13

The Hull Template

The hull template was cut from a 4’x8’ x3/4 inch piece of plywood. These pictures show the one that worked. Do not use particle chip board or the cheap piece of plywood. I found out that these types of boards tend to allow for small leaks through the layers and or the chips however small. THE SEAL IS VERY IMPORTANT!! Please make a note of this.

I projected the form from the center line every 2 inches to get one half of the shape seen in Figure 3. I made the first out line on a large piece of cardboard and to use as a template. This proved to be an advantage because of the two inferior wood products I used first. (a) Chip board and (b) the cheap plywood with the knot holes in it, both proved that the air would leak, even after I tried to seal the boards with paint.

Next a door gasket was used between the sandwiched plywood to create the barrier needed to form the hull. The top 4x8 plywood was then screwed around the perimeter to hold the seal and the two sheets together. The air line is shown going into the top of the oven.

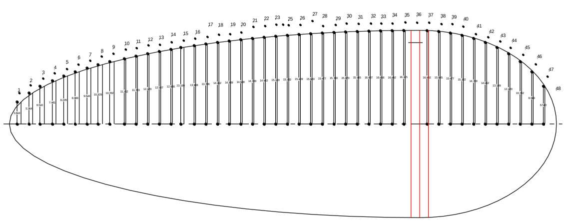
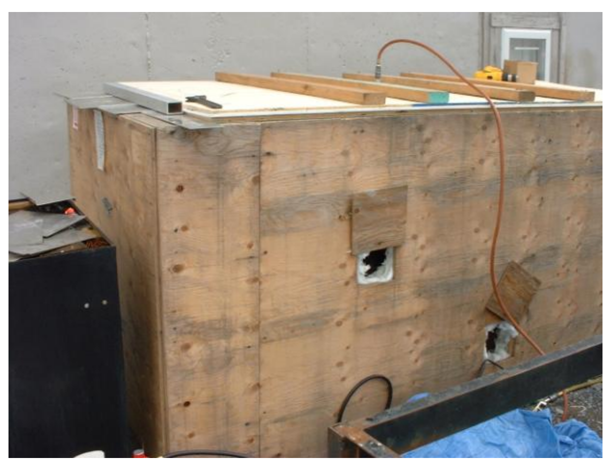


Figure 3

Picture #14

Picture # 15

Picture # 16



Picture # 17

The Oven

A large used packing crate was procured from the dumpster. It had the right dimensions for the hull project of the sub and was FREE. Shipping and handling not included. The original top was the cheap knotty plywood mentioned earlier and had to many leaks. The next cut out was done with the chip board also to many leaks. I next welded a frame for around the top for the Sandwich mold to sit on seen in picture 18. Insulation was added around the bow and the missing front door. This door was easily removed and I found out that by quickly removing the door helped set the material and cool faster. (Trial and error method)

I first tried a kerosene heater but could not control the temperature as well as the propane one. Two small openings were cut in the control side of the oven, one for a visual area to see the hull forming and to control the air bursts into the mold and the other was to provide make up air for the heat and to adjust the control knob for temperature. (another trial and error spot). A post was built to gauge the depth of the form taken from the bottom side of the PVC. This would give me the outer hull dimension. The post also held the oven temperature gauge along with a rubber orange piece to show where each half would have to reach in order to be symmetrical. When the material is at about 350 F° it has the feel of chewing gum to it and will form to what ever touches it. So in order not to punch a hole in the PVC, a piece of rubber would bend as it touched. This also allowed me to control the air pressure by watching the tip so that each half would be the same 15 inches. The gas was turned off and the front door drop to quickly cool the form when the desired shape was achieved.

A drop light was set inside to watch the form take shape and to se the temperature gauge. In order to distribute the heat evenly a cast iron plate was placed on top of the heater for the first layer and an aluminum plate much longer was placed on top of the iron to distribute heat from front to back.

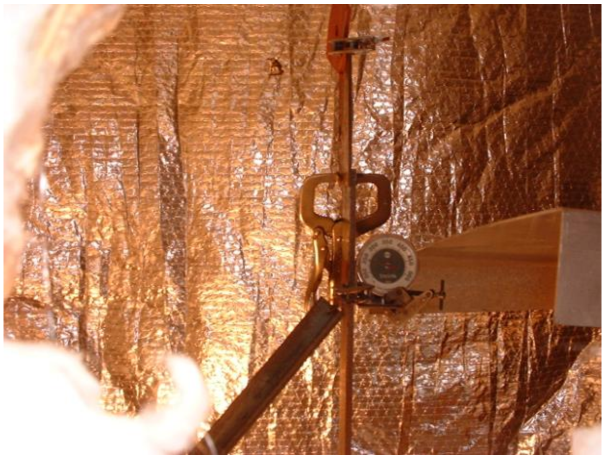
It should be noted here that Murphy’s Law was alive and well during the hull forming exercise. The six attempts to form the hull ranged from hot spots that blew out on the sides, air leaks in wood and seal, running out of propane at a critical point in the process to a lightning storm that did not give me a warm fuzzy feeling sitting next to a propane tank.

All in all I had learned a great deal about this sort of forming plastics and will use the oven for forming some acrylics and Lexan bubbles.

Picture # 18

Picture # 19

Picture # 20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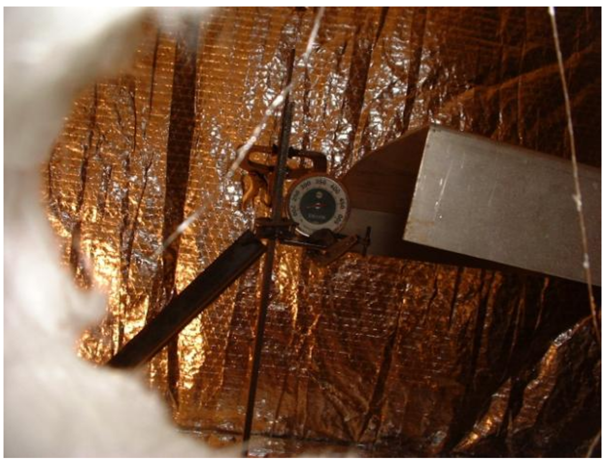
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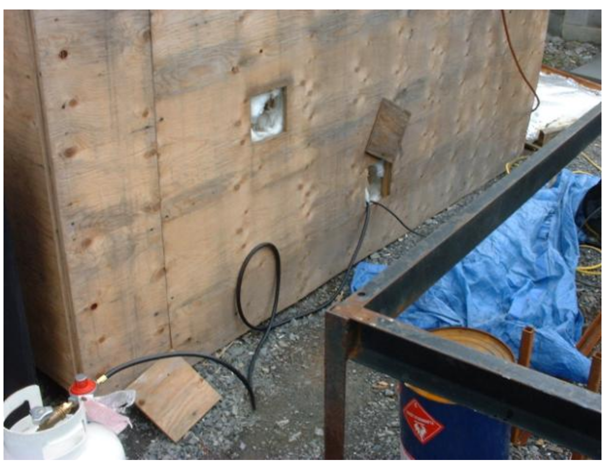
Picture # 23


Picture # 24


Picture # 25


Picture # 26

Life Support and Scuba Equipment

The life support equipment will consist of certified air tanks that have current visual and hydro safety inspections in order to be refilled at the races. The sub will carry 1 size 80 tank and will be mounted under the center line of the hull beneath thedriver , again keeping in mind that it will help in stabilizing the torque placed on the hull by the propeller. The Diver on board will also be carrying two spare air bottles, one will be carried on the diver and one will be on the steering bars in case of an emergency egress or if the on board regulator fails.
The diver will have the option of wearing a full wet suit (recommended) or if it's warm enough at the race to wear a short suit to make a run with out being in the water to long.
The air that is exhaled will be vented out through the top fin of the sub in order to prevent any ventilation in to the propeller. The blades will slip enough without air being sucked into the path.
The emergency buoy will be held by a bicycle hand break much like the one I had used in previous Subs. The buoy has 30 feet of high visible line that is required by the race manual.
A high visible strobe is placed on the top fin in order to be seen 360 all around

Picture # 27

Picture # 28

Picture # 29

Picture # 30

The Cost Estimate
The following page represents a cost estimate if I were to send out to a vendor to have the work done. An engineering group would provide the design and drawing documents and provide parts list for purchasing and bids. I used $45.00 an hour as an average estimate you could very well add more depending on where or who did the work. Having done the project myself the real cost is closer to the dollar

estimate of $2650.00. With scavenging and on line auctions the total for the project. $3200.0

Cost Estimate		
	Dollars	Hours
Design Hours		120
Drafting Hours		80
Purchasing Hours		20
Dive Site Testing hours		50
Research and Reference Hours		40
Rental Equipment		
Transportation	$350.00	
Dive equipment	$400.00	
Lodging/Food	$250.00	
Hardware Material	$500.00	
Welding Hours		25
Machining Hours		40
Assembly Hours		40
Fiber glass Hours		120
Sanding Polishing Hours		20
Painting Costs	$150.00	
Race Entry Fee	$1,000.00	
Sub Totals	$2,650.00	555
Rate — $45.00 per hour		x $45.00
		$24.975.00
Total Estimated Cost	$27,625.00	

When searching for human power information the WISIL HPVer's home page, http://www.wisil.recumbent.com was a very valuable source for recumbent information. Most noticeable was the fact a human powered recumbent bike was clocked at more than 80 MPH![7]. I read it several times to make sure I was including the right numbers.

By looking at the design I have presented in this paper, the real test comes from the actual contest at David Taylor Model Basin. The sub race will allow me to test whether my type of hull with the concave sides can be faster than the subs that have round cylindrical forms.

References

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[4] Burcher, R., Rydill, L., *Concepts in Submarine Design*, Cambridge University Press 1994, pp., 119-123.

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[6] Osse, James, *Low Drag Technology applied to Human Powered Vehicles,* Oceans 89, Volume 6, Human powered Submersibles, June1989, pp., 7-11.

[7] Beauchamp, Warren (2002) *WISL Human Powered Vehicle Web Site*, http://www.wisil.recumbent.com, (October 2002).

[8] Hill, Garrie (2002) *WISIL Human Powered Vehicle Web Site,* http://www.wisil recumbent.com/wisil/hill/garriehill.htm (October 2002)