Leviathan

Seacoast International Submarine Race Team (SISRT)

Technical Report

as required by the

International Submarine Race #12

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Team Members:

Original six

Joe Allen
Matt Crist
Michael Cargill
Sean LaMontagne
Langdon Tarbell
Sean Connor
Matt Notaro

New members

Tyler Dutile
James Kalowski
Eliza McDonough
Theresa Kalowski
Ryan Forbes
Connor Pearson

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Introduction

In January of 2011, the Seacoast International Submarine Race Team (SISRT) was founded by Annette Young. In June 2011, the team participated in the 11th International Submarine Races (ISR) with a borrowed boat named Scuba Doo, built by Ed Leibolt, and a propeller designed and built by the SISRT. This year, since we have had the whole two years, we designed and built a completely new submarine. During this process we learned about fluid dynamics, Computer Aided Design (CAD), buoyancy, submarine design, and much more. The team meets every one or two nights a week for two hours at Seacoast School of Technology (SST), Exeter, NH to design and build the submarine. Some fabrication work requiring more sophisticated equipment was performed for training purposes at the Portsmouth Naval Shipyard, Portsmouth, NH. SST was our original fiscal agent for the 2011 races. The Seacoast Science Center, Rye, NH is our fiscal agent for the 2013 races. Our team members vary in age, gender and the schools they attend. Our youngest member is thirteen years of age and our oldest member is nineteen. Our team leaders are Norm Messa, Pre-Engineering and Computer Science Department Head at SST, and Annette Young, Nuclear Engineer at the Portsmouth Naval Shipyard. The purpose of the team is to educate ourselves on the engineering process.

Safety Systems

Bringing a human below and then returning them back to the surface safely has been the primary objective of submarine designers ever since the creation of the submarine itself. The nature of taking a human out of their natural environment and giving them the ability to explore one that is much more hostile to them is an extremely dangerous idea on its own. Creating a vehicle to complete this task without the risk of failure is extremely difficult. On full scale nuclear submarines, creating a pressure resistant, watertight, and especially quiet human-friendly environment is a daunting task for drafters and engineers. Although the 10-15 foot long, pedal-powered wet subs present at ISR are not even close to being as complex as, for example, the USS NEW HAMPSHIRE (SSN 778), the same basic principles behind life support and safety come into play.

The primary means of life support on SISRT's **Leviathan** consists of an 80 cubic foot, 3000 psi tank attached to a standard SCUBA regulator which feeds air to the single operator. The system's exhaust exits the submarine through ventilation holes located on the top of the hull.

Safety Buoy

Safety is a major concern when It comes to dealing with homemade machines of any kind especially ones that take you into a environment in which on your own you cannot survive. There must be a quick and reliable system of safety provisions in place to aid the pilot in escaping on his own and notifying safety personnel of a potential problem so that they may aid you in your accent to the surface.

To signal rescue divers in case of emergency, the **Leviathan** will be equipped with a positively buoyant, fluorescent colored safety buoy as per ISR requirements. Following the concept of a dead man switch, the pilot holds onto the buoy's cord during normal operation. To release the buoy, all the pilot needs to do is release his grip on the chord to send up the SOS.

A timely escape by the pilot can be executed easily with use of the quick release latch for the main hatch. A large lever on the left inside of the hull allows for the pilot to "pop" the hatch while exerting only minimal effort to save air in case of emergency.

Hatch

The style of hatch mechanism that we used is called an egress hatch. It is a large buoyant hinged hatch with a hatch release that can be accessed by the pilot and the rescue team. Additionally it is marked with a four inch patch of orange sticker labeled rescue. The hatch release will be tested in shallow water before the race to ensure that it is operating correctly. The pilot can choose to have bracing blocks for his/her shoulders to push against when pedaling. The pilot will also be in toe straps to hold their feet on the pedals when propelling the sub.

Buoyancy Control

When the submarine is submerged, it displaces a volume of water. To make the submarine neutrally buoyant, the weight of the submarine is to be equal to the weight of the displaced water. The pilot is neutrally buoyant so he or she does not factor into the equation. For the hull volume, we used iProperties in the CAD program, Autodesk Inventor. To get our total displacement of the shell of the sub we simply switched the material to be water and used that to find the weight of the water displaced. The volume of the submarine's hull is 4,511 cubic inches. The fiber glass portion of the hull is 1,519.5 cubic inches. The weight of 1,519.5 cubic inches of water is the same weight as the fiberglass so it is negligible. Multiplying the amount of water displacement from the foam by the weight of water is the amount of weight we added to make the submarine neutrally buoyant. Final adjustments will be made at depth to ensure a neutrally buoyant submarine.

Bow-Dome

The pilot will be able to safely navigate the course by looking through an acrylic dome on the nose of the sub. This dome is designed to offer a 180 degree view left and right as well as up and down, depending on the location of the pilot's head. The dome is mounted with two fiberglass rings, one fiberglassed directly to the forward edge of the sub, and the other integral to the after dome perimeter. The rings meet flush and are bolted together. The dome is removable for maintenance and or repair. The leading surface of the bow dome is blunt to optimize hydrodynamic The hull of the submarine is made out of a foam core with a fiberglass shell inside and out. In order to create a consistent shape, the sub was crafted with a frame. flow over its surface. A Portsmouth Naval Shipyard apprentice and a graduate of the apprenticeship program practiced their craftsmanship by industrializing our design and constructing of the entire assembly. Dome viewing panels were constructed from 6 smaller panels to create the compound-curved shape we desired and accommodate replacement of a damaged panel. Figures 5 – 11 document bow dome design and construction.

Control Surfaces

The control surfaces of the SISRT's submarine are similar to the ailerons of an air plane. The purpose is generally the same. The planes move up or down depending on the intended path of the submarine. The use of the controls surfaces is mainly for course correction.

The control surfaces were constructed with a wooden plank to provide structure. The wood plank was wrapped in a1/4" thick home insulation and then the empty spaces were filled with expanding foam insulation. Prior to the expanding foam's addition the foam was wrapped in a layer of duct tape to keep their hydrodynamic shape consistent. After the foam had cured, the entire body was wrapped in two layers of 1/16" fiberglass. After the fiber glass was cured and sanded a hole in the hull was cut to accommodate the plane.

The plane was inserted into the hole and fiber glassed into place. The outer part of the plane was cut off and a shaft was fixed to the side so that it could pivot when the shaft was rotated. The plane is rotated using a cable system. The cables are actuated by levers operated by the pilot's hands.

Hull Construction

We used a hull design identified in an internet search by one of our team members. A formula for a "perfect hydrodynamic shape" was found in a hydrodynamics paper, "Computation of Turbulent Viscous Flow around Submarine Hull Using Unstructured Grid", by Karim, Rahman and Alim. The formula we used to design our hull is:

(i) The nose can be represented by:

$$\frac{r_1(x)}{l} = \frac{d}{l}\left[2.56905\sqrt{\frac{x}{l}} - 3.48055\frac{x}{l} + 0.49848\left(\frac{x}{l}\right)^2 + 3.40732\left(\frac{x}{l}\right)^3\right] \quad ;0 \le \frac{x}{l} \le 0.2$$

(ii) The mid body (circular cylinder) is given by:

$$\frac{r_2(x)}{l} = \frac{d}{2l};0.2 \le \frac{x}{l} \le 1 - \frac{3d}{l}$$

(iii) The tail is represented by:

$$\frac{r_3(x)}{l} = \frac{d}{2l} - \frac{l}{18d}\left[\frac{x}{l} - \left(1 - \frac{3d}{l}\right)\right]^2;1 - \frac{3d}{l} \le \frac{x}{l} \le 1$$

Source: Karim, M. M., M. M. Rahman, and M. A. Alim.; Tech. N.p., n.d. Web. 20 Mar. 2012. http://teacher.buet.ac.bd/mmkarim/jst.pdf

For calculation results see Figure 1-2013 Hull Diameter Calculations and Figure 2-2013 Hull Profile Graph. Our submarine has a 30 inch diameter. A drawing of our hull is in Figure 3-CAD Drawing of 2013 Hull.

The sub frame was made of circles cut out of ½" plywood. The circles then had 2" holes drilled in the center in order to be threaded onto a long metal pole. The circles were spaced 6" apart from each other. The pole was used to create a level and stable support around which to build the hull.

The wood circles were then covered with thick paper and wrapped in duct tape to provide support and a surface to which fiberglass would not stick. Following the tape is 5 layers of 1/16" sheets of fiberglass. Each layer of fiberglass was wrapped in opposite directions (clockwise, counterclockwise), for strength. The foam is ¼" Pink Panther™ home insulation sheets that were bent to the shape of the hull. The fiberglass is three layers of 1/16" fiberglass sheets. A final layer of resin was applied to the hull to seal the hull. The plywood circles were extracted through the hole for the hatch. In case of a drive system failure, a small hole was cut in the after section of the hull for easy access to the drive system for faster repairs.

Propulsion System

Power to our propulsion system is created by the sub driver using a modified bicycle power train. A single set of crank arms and chain ring are mounted to the hull and transfer power via a bicycle-type linked chain to a single sprocket. The sprocket is mounted on a shaft coupled to a right angle drive unit input shaft. The right angle drive output shaft is coupled to the propeller shaft. Propeller shaft bearings are Teflon blocks. Our propulsion system involves two propellers. An interior, smaller diameter propeller uses the after section of the hull as a duct to supply flow to a larger diameter propeller exterior to the trailing edge of the hull.

The propeller is a basic two bladed design. We spoke to a propeller designer at the last race and he mentioned that the two bladed design was the most efficient number of blades for our purpose. We started with a basic model of a two bladed design in Auto Desk Inventor and then modified it to fit our design needs. After some research we decided that for our practical purposes our estimated RPM would be between 60 and 120 RPM. With the given RPM, we used the spreadsheet calculator obtained from <mvvs.nl/prop-power-calculator.xls> that we should use the following specifications for our prop. We decided that we should have a blade length of approximately 12 inches with 45 degree pitch.

Then, one of our former members found a design on the internet and printed a 1/3 size scaled model on a 3D printer. We decided to use this model for our basic design instead. See Figure 14-MeshLab drawing of Propeller, View A and Figure 15-MeshLab drawing of Propeller, View B. We had planned to have the propellers printed on a 3D printer and covered in epoxy resin for strength purposes. At the time of this writing, we are unable to locate a large enough printer within our budget. We came up with alternate construction ideas.

Two methods are being used to construct our propellers. The first method is to shape the blades and rotor manually from wooden blocks. Wood Shop students at the Seacoast School of Technology, Exeter, NH are using this method. The other method will be mechanical construction from a solid material by Portsmouth Naval Shipyard apprentices to train on the Shipyard's new 5 axis milling machine.

Testing

The sub will be dry tested to make sure all the mechanical features work. We plan to perform test dives at the University of New Hampshire's (UNH) Department of Ocean Engineering test tank in Durham, NH.

Project summary

The SISRT completed the design of **Leviathan** and the basic hull construction. The process has taken almost two years. We have some remaining work to be accomplished prior to dive testing in UNH's engineering test tank and racing this summer at the 12th ISR in Bethesda, MD. These tasks include installation of the power train, completing construction of the propellers and installing them, construction and grooming the interior and exterior of the hull, fitting up the bow dome, installing control surface actuators and the emergency buoy, and christening the sub.

	A	B	C
1	x	r(x)	
2			
3	Nose Section		
4	0	0	
5	6	7.483159	
6	12	10.40223	
7	18	12.47338	
8	24	14.06537	
9	30	15.33176	
10			
11	Mid Section		
12	30	15	
13	36	15	
14	42	15	
15	48	15	
16	54	15	
17	60	15	
18	66	15	
19	72	15	
20	78	15	
21	84	15	
22	90	15	
23			
24	Tail Section		
25	90	13.93333	
26	96	13.33333	
27	102	12.6	
28	108	11.73333	
29	114	10.73333	
30	114	10.73333	
31	120	9.6	
32	126	8.333333	
33	132	6.933333	
34	138	5.4	
35	144	3.733333	
36	150	1.933333	
37	156	0	

Figure 1-2013 Hull Diameter Calculations

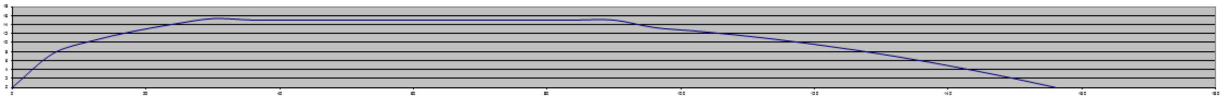

Figure 2-2013 Hull Profile Graph

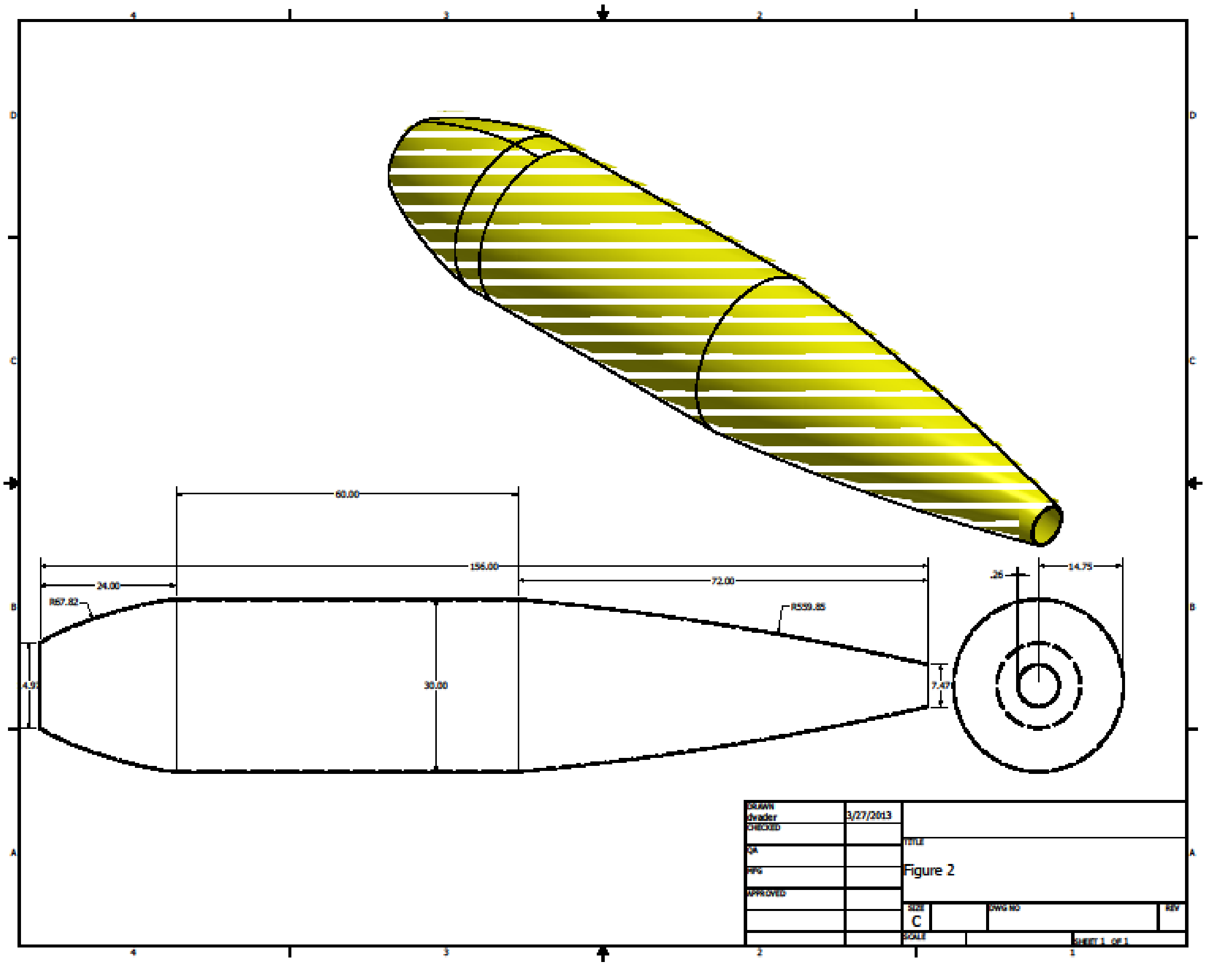

Figure 3-CAD Drawing of 2013 Hull

Figure 4 and Figure 5-SISRT Members Prepare Hull Skeleton for Fiberglass

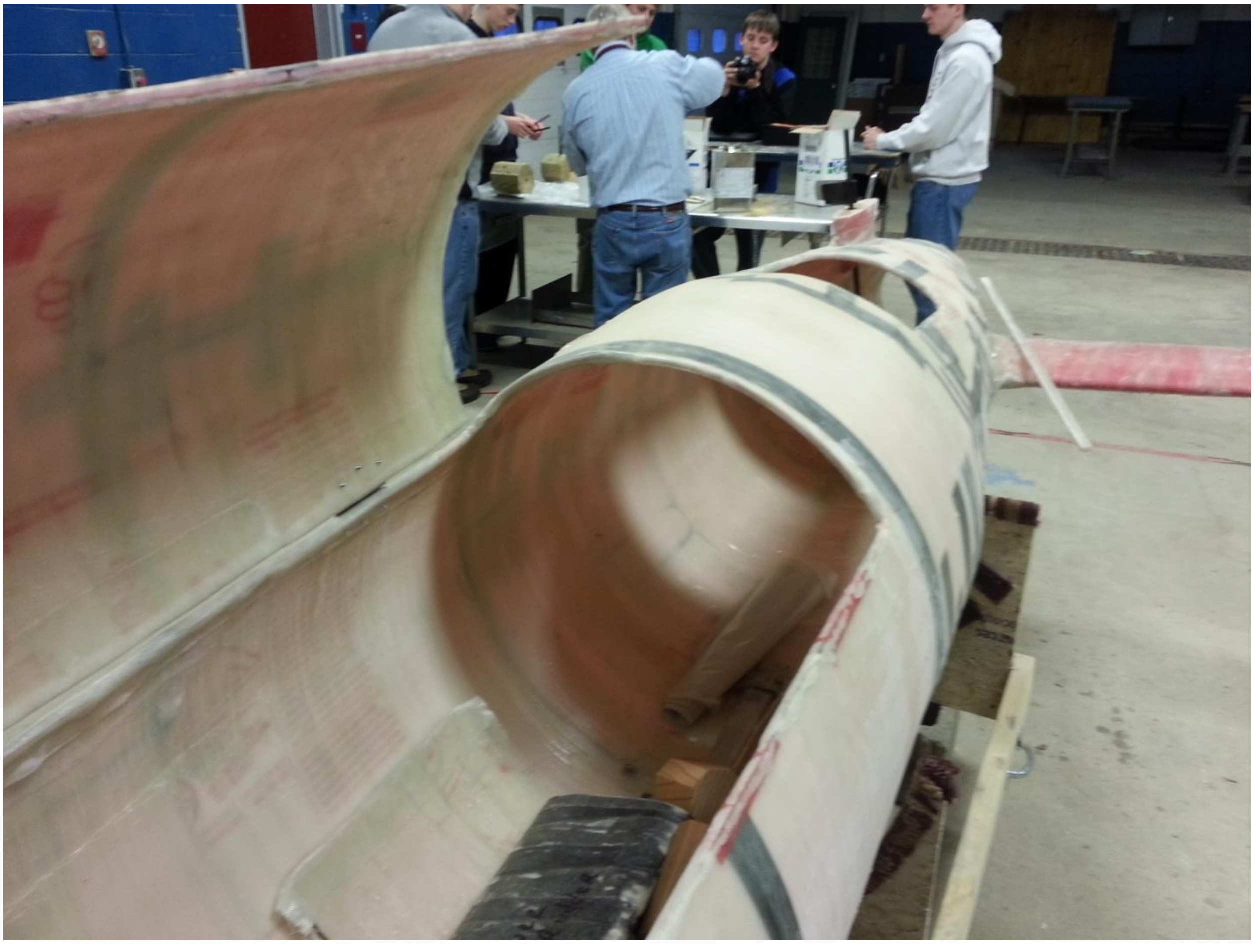

Figure 6-Fiberglassed Hull

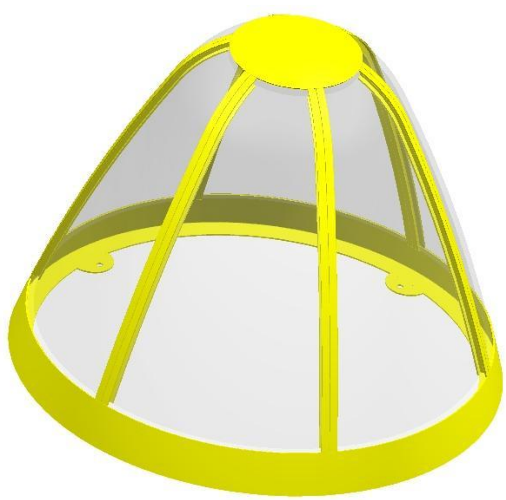

Figure 7-CAD Drawing of Bow Dome

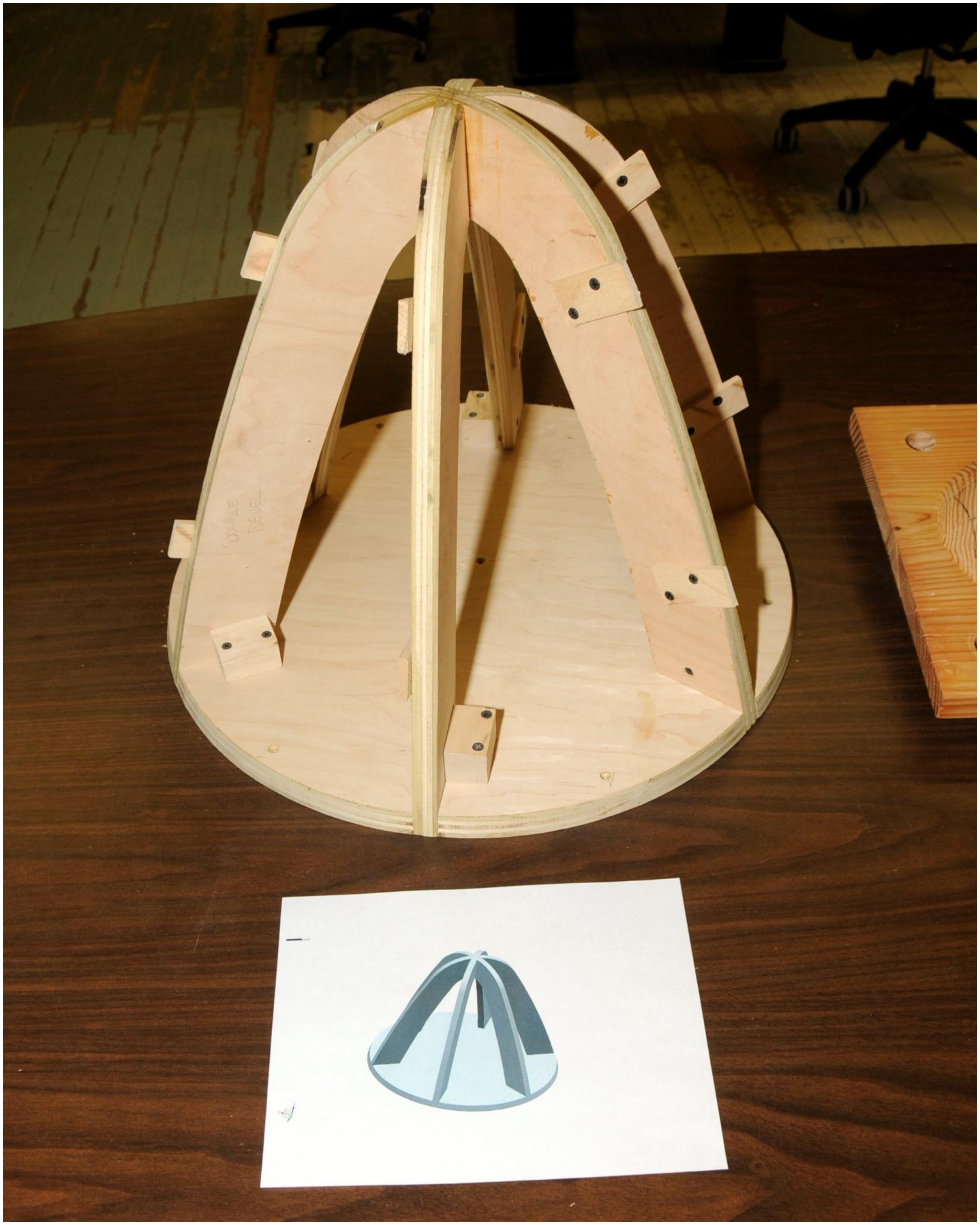

Figure 8-Bow Dome Frame Mandrel

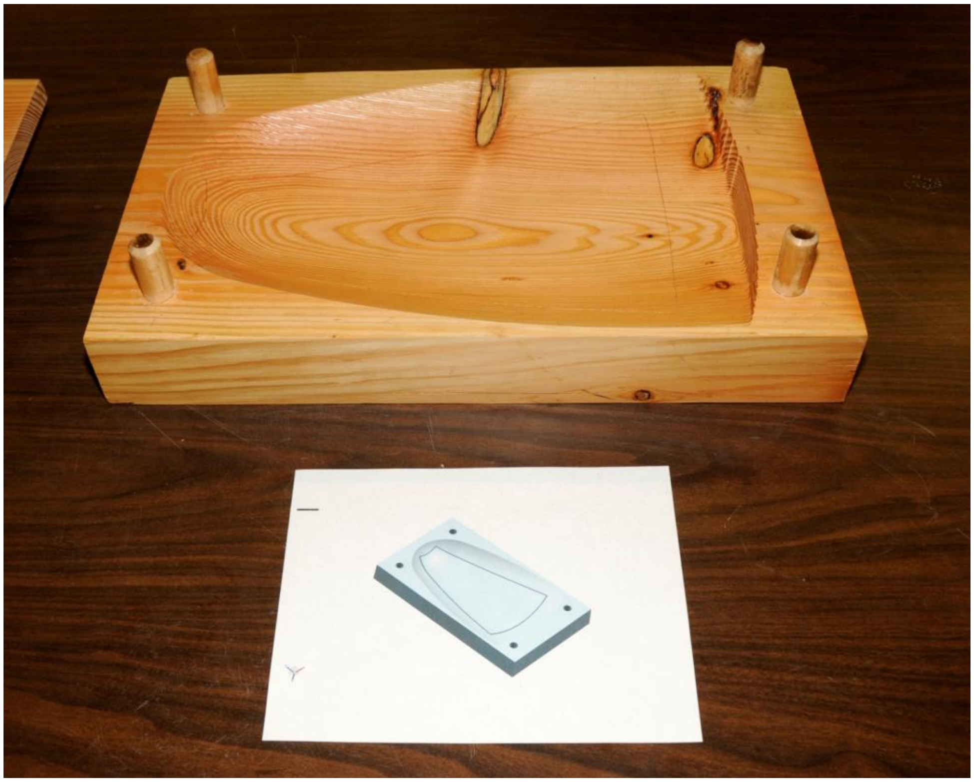

Figure 9-Bow Dome Viewing Pane Mold, Female Half

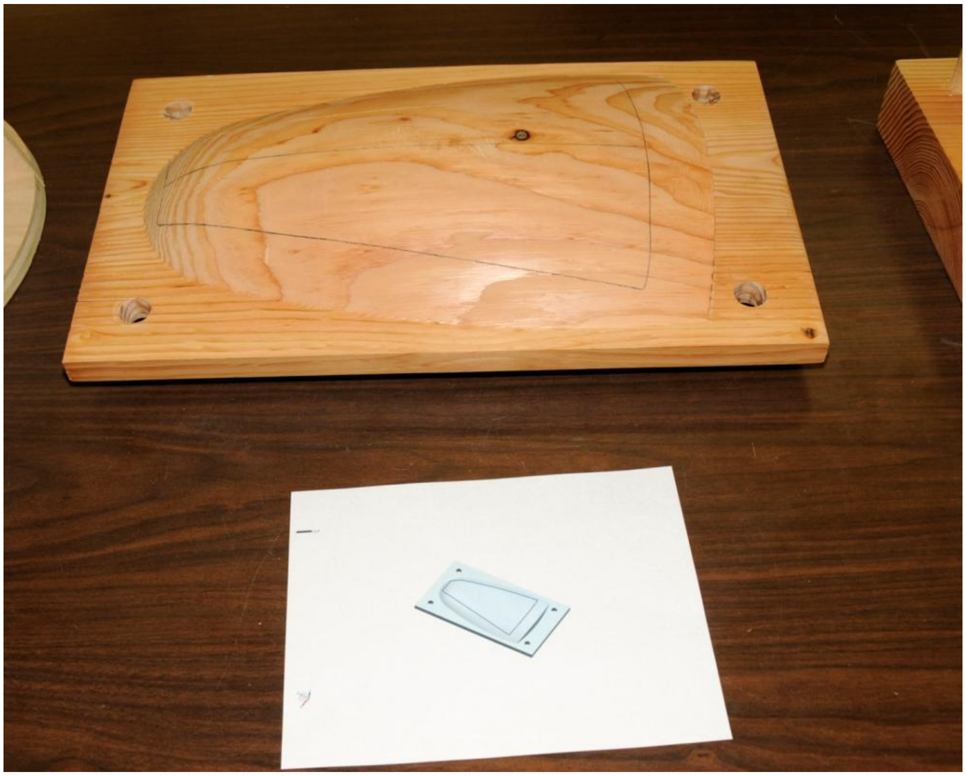

Figure 10-Bow Dome Viewing Pane Mold, Male Half

Figure 11-Mold Designer Demonstrates Bow Dome Viewing Pane Mold

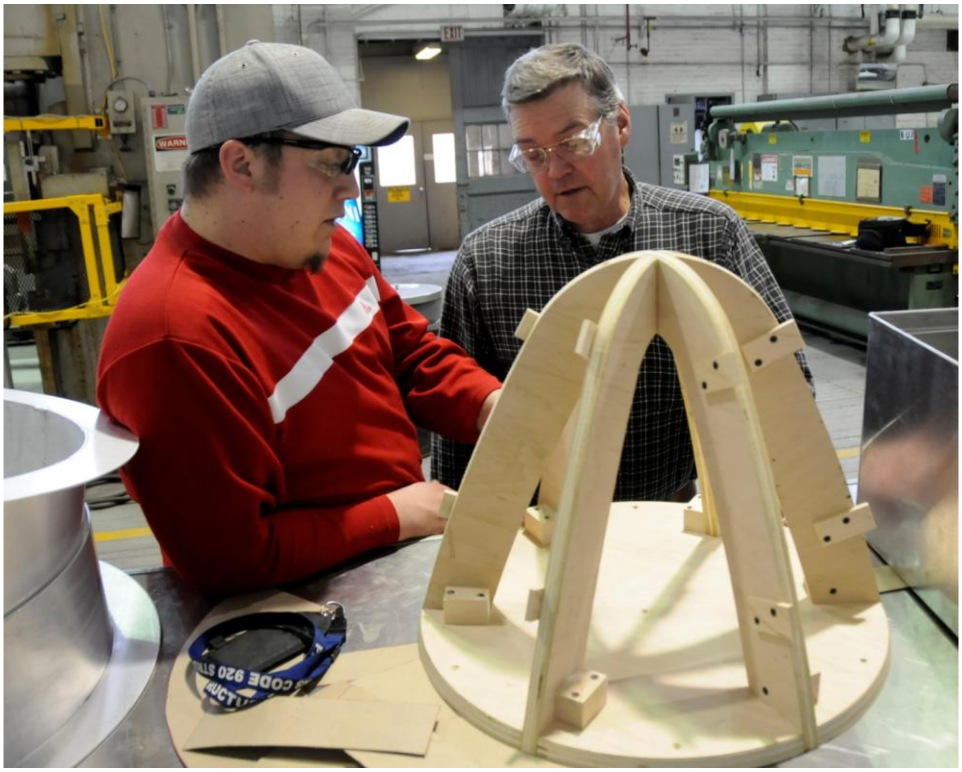

Figure 12-Mold Designer and Sheet Metal Shop Supervisor Plan Bow Dome Fabrication

Figure 13-Sheet Metal Shop Apprentice Fits Up Bow Dome Assembly

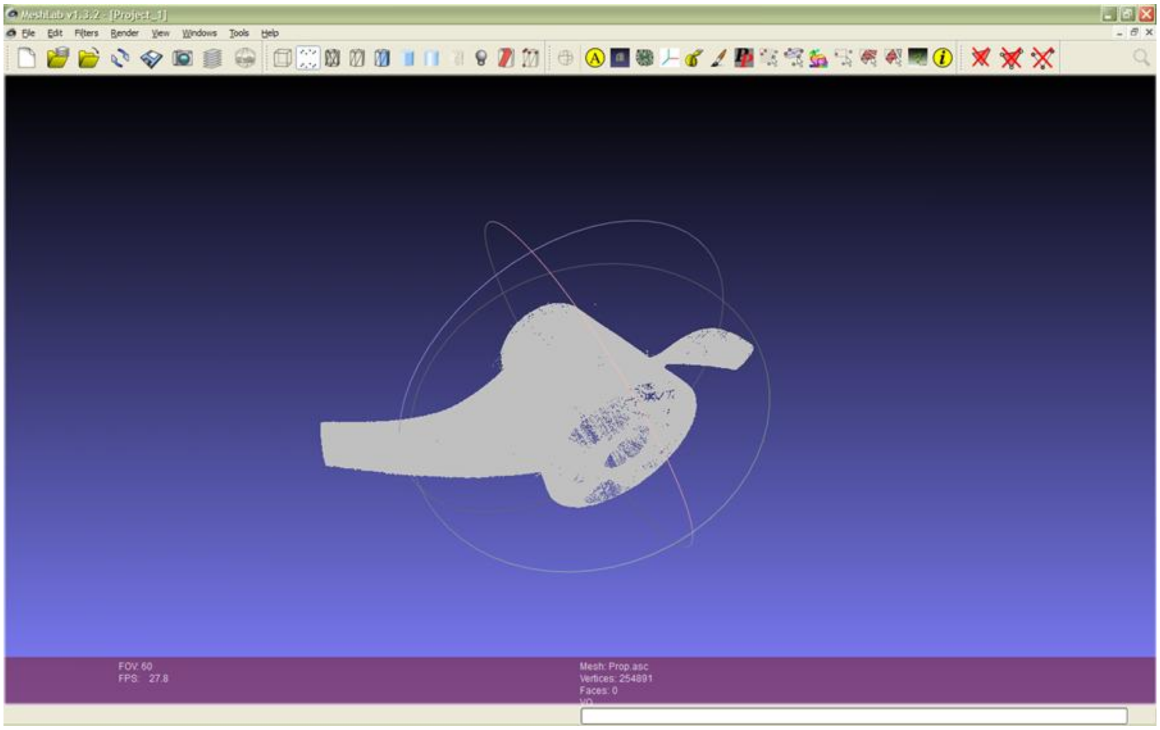

Figure 14-MeshLab drawing of Propeller, View A

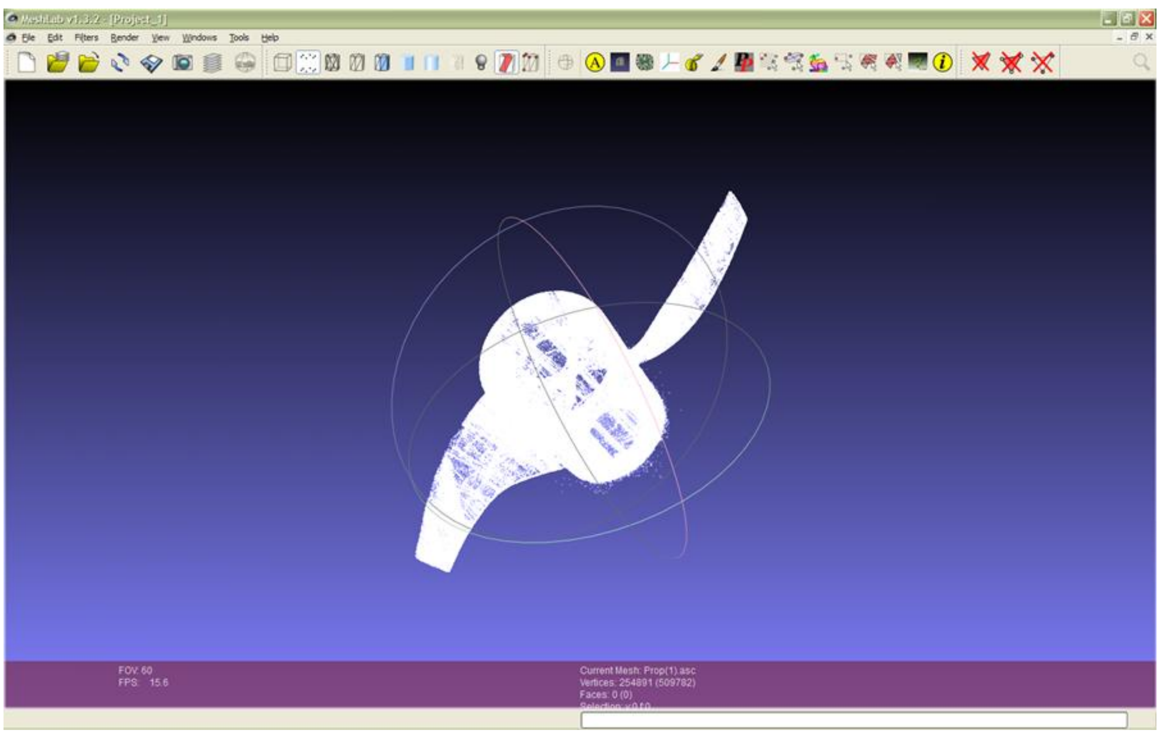

Figure 15-MeshLab drawing of Propeller, View B