Newcastle University Submarine Team

FINAL DESIGN REPORT

Contents

Mission Statement

The goal of the inaugural Newcastle University Submarine Team is to enter a competitive submarine into the 13th International Submarine Races (ISR) in June 2015. As of March, 33 teams (many with previous experience of the competition) had signed up for the race taking place at the David Taylor model basin in Washington, DC. Undoubtedly the competition will be tough.

For this first year, the main objectives are to produce a working submarine and to provide a base design which future teams can develop further. To this end the design was made as simple as possible with as few components as possible and the ability to easily exchange components which may fail.

The main work packages are:

- The complete design of the vessel (including hull, propulsion, and safety devices) and transport cradle.
- Gathering sponsorship and funding, for build and travel costs.
- Construction of the submarine.
- Planning and execution of the logistics.

Team Layout

Name	Role
Max Davidson	Team Captain, Finances, Hydrodynamics
Ubay Sohail	Power Transmission, Media
Alex Walchester	Structures
Paul Whitworth	Diving advisor, Main Pilot

OVERALL CONCEPT

The first iteration of design began using Autodesk Inventor to figure out the minimum spacial requirements, the general arrangement, and to achieve a basic understanding as to how the submarine will function (Figure 1).

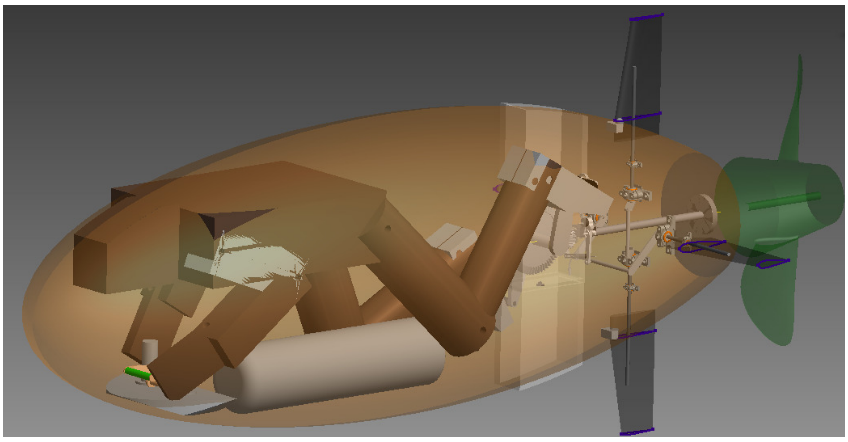


FIGURE 1: INVENTOR MODEL OF SUBMARINE

Where the submarines dimensions are thus:

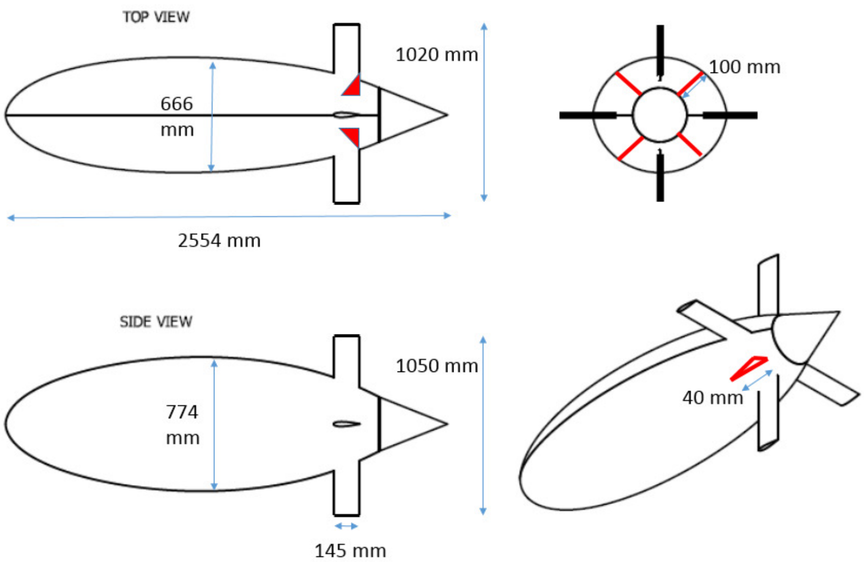


FIGURE 2 SUBMARINE DIMENSIONS

Hull form

A Computational Fluid Dynamic analysis using ANSYS Workbench (Figure 3) with the CFX module was used to calculate the form drag and the skin friction in order to find an optimized hull shape of the submarine. In order to optimize the performance of the submarine the nose shape, location of the maximum diameter and the tail shape were varied, the results showed that the individual optimums of these variations cannot be combined with the other optimum parameters to produce the least drag. The drag for the best performing submarine was found to be 76.24 N and was checked using the ITTC-57 formulations to show an error of 3.78% thereby showing a reasonable accuracy in the results. The drag is controlled by the wetted surface area and the hull form. It was found that at a length to beam ratios of around 5.2 the 'form drag' was the main component of resistance.

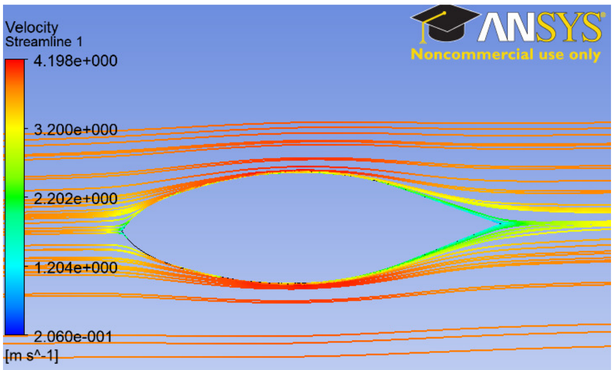


FIGURE 3: CFD ANALYSIS

Structures

The curvature of the submarine's hull gives it an inherent strength which means it can easily handle the forces involved however it was not known how well the materials used in construction could handle the local stresses around the propeller arrangement and the pedal box. To help distribute the stress a frame structure was originally designed (Figure 4). The location of the frames coincided with the bounding of the hatch and the placing of the pedal box.

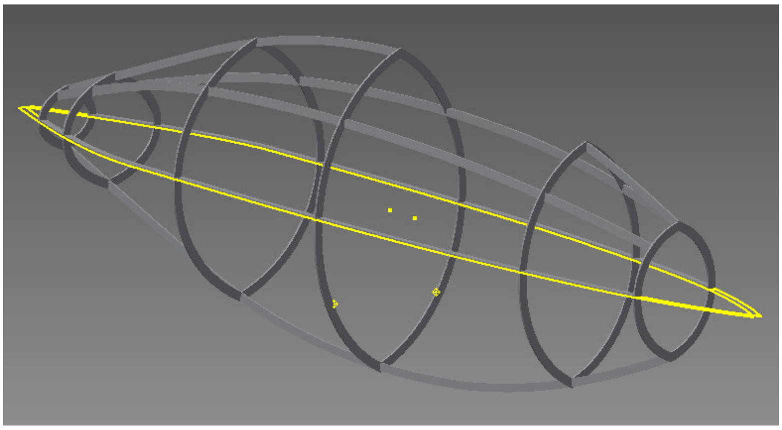


FIGURE 4: ORIGINAL STRUCTURAL FRAME

However, consultations with sponsors and industry experts suggested this would be unnecessary and would just increase the volume of the submarine thereby increasing the resistance. In light of this, the framing was dropped and the focus switched instead to calculating the stresses in the bare hull and pedal box.

Ideally a detailed Finite Element Analysis (FEA) would have been completed to best estimate the distribution and magnitude of the stresses but this would have been too labour intensive (especially as there is much uncertainty regarding the boundary conditions and forces). Instead values were calculated using equations detailed in “Roark’s Formulas for Stress and Strain” *(Young et al, 2002)* and PD 5500 *(BSI, 2014)*. Although the error is much greater, a much larger safety margin was applied to negate this.

The specific conditions looked at were as follows: when the submarine was being drained, the force on the thrust block due to the propeller, and the forces in the pedal box induced by ‘cycling’, among others. The calculated stress levels in all these conditions were well below the acceptable limit, with modal stress values of approximately 15MPa, verifying that (structurally) the design was fit for purpose.

Initially the design was meant to use a single skin structure however after creating calculating the buoyancy of the submarine it was realised that at a double skin was require to add a greater buoyancy which further increased the submarines strength.

Propulsion (Type)

Out of several concept ideas including, contra-rotation, hub-less and variable pitched propeller, it was chosen to use a 2 bladed fixed pitch propeller (Figure 5) for its simplicity. The propeller was designed to have an optimum speed of 120 rpm, this was decided so that with an effective gear ratio of 2:1 the pilots cadence would be at an optimum rotational speed of 60 rpm, focusing on low speed high torque reduces the vibration occurred while pedalling at a high cadence and the losses incurred by moving your legs through water.

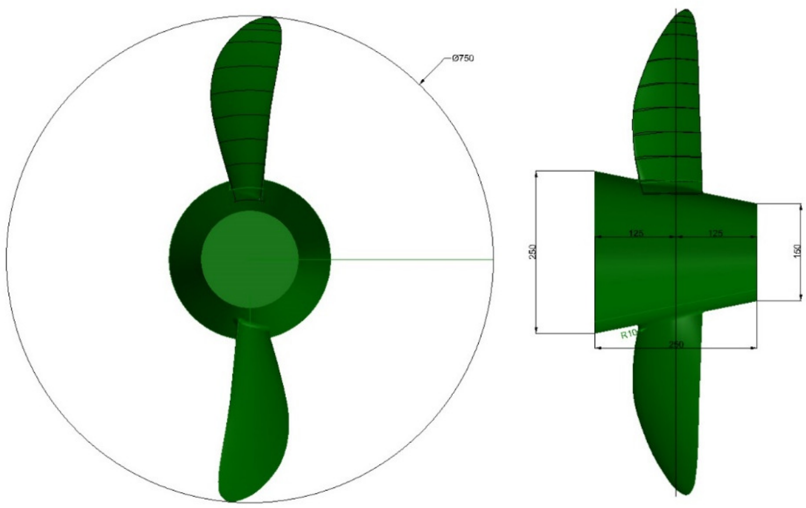


FIGURE 5: PROPELLER DESIGN

The propeller and the below theoretical expectations were calculated using blade element theory (Figure 6). One of the main assumptions was that a human produces an average of 0.6HP after an initial build up period. If we had the time we would have like to have measured the actual power output of the pilot so that a more accurate model could be built however this was not possible therefore this will be an aim for the next team.

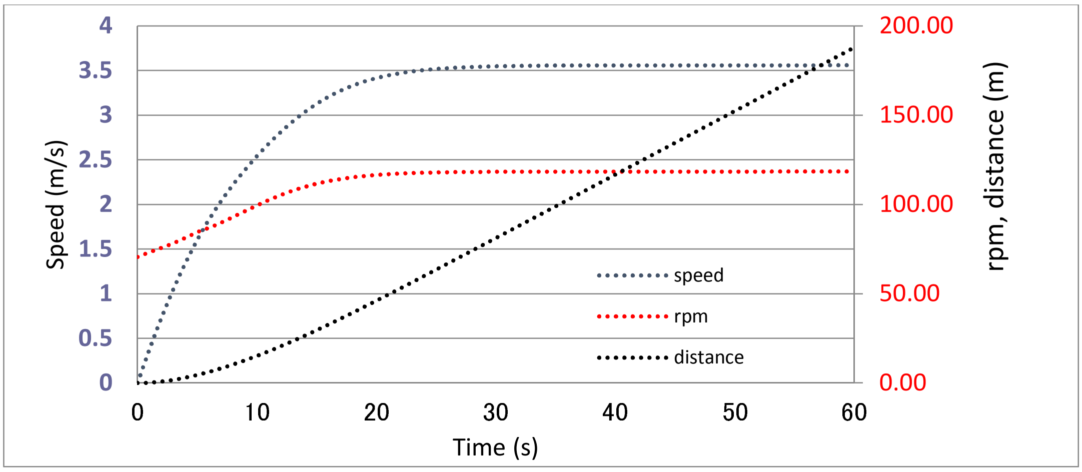


FIGURE 6: THEORETICAL OPERATING PROFILE

Controls

A submarine is affected by 6-degress of motion (Surge, Sway, Heave, Roll, Pitch, and Yaw) all of which must be controlled by the pilot. The motions that require controlling are roll, pitch, heave and yaw. To simplify the controls that the pilot has to deal with during the sprint, the propeller induced torque roll of the submarine is controlled by the fixed angle of attack anti-roll fins attached to the rear of the sub. Heave and pitch are controlled by attempting to make the submarine as neutrally buoyant as possible and through the use of twist grips (Figure 7) where one controls the fins which control the pitch of the sub and the other controls the fins which control the yaw.

FIGURE 7: INTERNAL MECHANICS

The fins were designed using the Nomoto stability criterion, from this an excel sheet was made where the height and cord lengths were made variables so that they could be adjusted until a point that the criterion was satisfied. The fins do not follow a specific NACA profile as they were handmade due to budget limitations.

Life Support

The pilot will be using a 12L air tank as well as a 3L pony bottle, as stated in the ISR rules the air in the submarine will remain above 75% of its capacity at all times, however in case a fault arises with the submarines SCUBA system the pony tank is available for the pilot to use.

Safety Devices

Safety of the pilot at all times is of utmost concern, and was at the forefront of our submarine design. The safety components can be broken down as follows:

Visibility

The propeller and fins are painted orange to ensure that they are visible under water. The SOLAS approved lights are automatically activated by water or can be manually turned on or off, they will be mounted in front of the fins on the top and bottom of the submarine to ensure they can be seen 360° around the sub. The hatch is clearly labelled where it can be removed as per ISR regulations. Furthermore the pilots face can be viewed from any point about the submarine.

Access

The large access hatch (Figure 8) ensures that the pilot has easy access to get into and out of the submarine. However, the access hatch holds some of the buoyancy of the submarine and with the door amiss the vessel will become less buoyant thus the hatch is affixed on to the sub allowing the buoyancy to remain unchanged. To prevent movement within the sub the pilot is affixed through the use of SPD pedals and arm braces, this is to ensure that maximum power can be delivered, both of these mechanisms are easily escapable from thus ensuring the pilot can exit safety.

FIGURE 8: ACCESS

Emergency Buoy

During the initial design it was decided to have a ratchet which would activate a brake to slow the propeller shaft and release the emergency buoy. As the design progressed it was decided that braking the propeller shaft would not be needed due to the direct drive, furthermore the design was not an "online" system therefore it did not meet the ISR requirements and a new system was put in place. The dead man switch was designed to be as simple as possible, the buoy is held onto the sub using friction from a rope cord (Figure 9) and while unpiloted a safety pin is utilised to ensure the buoy stays within its mount. By pulling the rope friction is increased which the pilot must do at the starting line of the race, hence releasing the rope reduces the friction on the buoy and it releases using its own buoyancy and an assisted push by bungee cords placed under the buoy thereby becoming an "online" system.

FIGURE 9: EMERGENCY BUOY

Cradle (for working on sub, and shipping.)

The cradle to house the submarine while out of the water has been designed using box tubes of galvanised steel, which have had drainage holes added as we believe that water ingress would be inevitable. The Cradles contact point with the submarine was created by laminating over the submarine with multiple layers of chopped strand mat thus creating the perfect fit. The trailer also comes with the recommended wheel size as per ISR regulations.

Training

For the Underachiever to function, the team were required to be SCUBA trained to a safe and competent standard. After this training process all members received certifications stating, they were competent and skilled to move forward with submarine training.

On the 3rd of March a proposal for the first trial of the Under Achiever was proposed for the 3rd of April, however we weren't able to test due to trying to organize a test with one weeks' notice and also due to the fact that the submarines safety mechanisms (such as the buoy) would not be completed in time, therefore the testing was delayed by a month as we wanted the submarine completed before organizing the test.

The submarine had its first test dive on Tuesday the 5th of May with a relatively large amount of success for our universities first ever submarine (Figure 10). Initially the submarine was set to a fair degree of neutral buoyancy without the pilot in, after this the pilot entered into the submarine with no problems, however this created a change in the buoyancy which caused the fore of the submarine to sink with the aft end remaining neutrally buoyant. Adding additional weights allowed a degree of control to the submarine however achieving neutral buoyancy was a problem. Due to the temperature of the test site the divers wore dry suits and gloves which made adjusting the trim difficult therefore we decided to get the submarine moving so that it could achieve some dynamic stability which would counter the non-neutrally buoyant static condition.

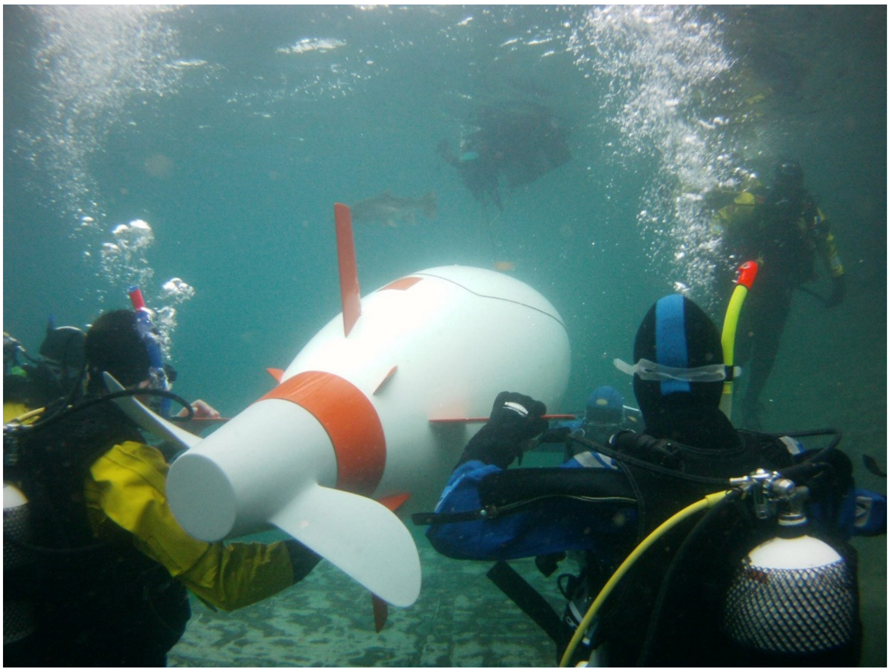


FIGURE 10 SUBMARINE TESTING

Several problems that occurred whilst moving; firstly the pilot was slightly buoyant which caused them to have to constantly pull on the steering handles to prevent an ascent and caused them to press against the door, thus continually opening the hatch. Secondly the pilot's feet would occasionally collide with the pedal box which limited smooth pedalling motion. Thirdly, we found that the rope attached to the buoy was far too long when it came out and due to the buoy buoyancy it proved difficult to pull down to the submerged submarine. To learn from these issues we moved the crank arms further apart so they no longer collided, added a hinge to the door so it is harder for it to open and we added arm braces so that the pilot didn't have to hold onto the controls to remain in the submarine. Due to the door coming off all the time we decided to cut the cord and let it float to the top hence Figure 11.

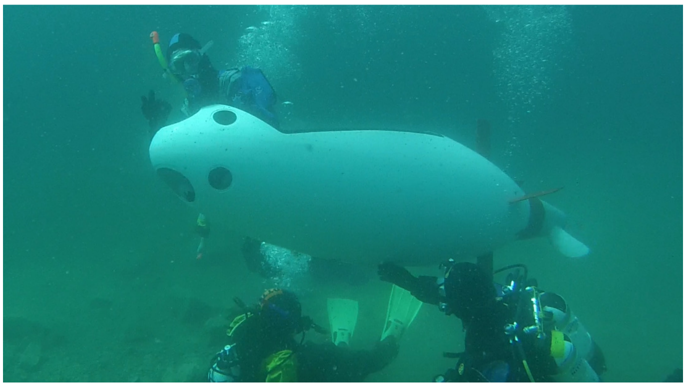


FIGURE 11 TRIALS WITHOUT THE DOOR

We also forgot to label which control handle did what and thought that 4th year university students would be capable of memorising which does what … however this was a mistake, therefore we have marked the handles functions which is why in Figure 12 the fins are being externally controlled and the pilot is simply providing the thrust which would allow the pilot to concentrate on power rather than what handles does what.

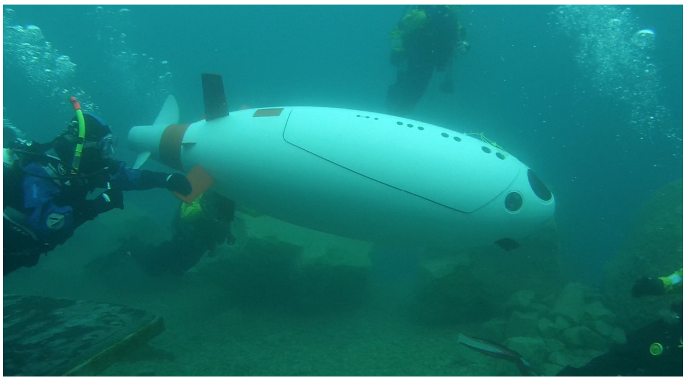


FIGURE 12 TRIALS WITH EXTERNAL CONTROL INPUT

We received a large amount of help from the universities diving society who we would not have been able to test without, from the divers who attended (Figure 13) we chose our 4th member (Paul Whitworth, 1st from the right in Figure 13) who was the most enthusiastic, most experienced diver and the fittest who will make a valuable addition to the team.

FIGURE 13 TRIAL TESTING TEAM

Team Development

Due to this being the first year, the team was developed by the captain who discovered the ISR by looking up submarine related topics for his dissertation, with some enthusiasm from the lecturers we formed a team which at first received a lot of interest but then due to it being our final year most of the interested people didn't join as they believed the time commitments would be too great. After this our team consisted of 3 people, all 4th year Masters engineers, the 3 of us also lived together which made it in some ways more convenient for communication. The next team has started to form and will be benefit from the lessons learned from the current team. We decided that a 4th team member was required in order to be able to operate self-sufficiently at the races therefore after the testing we selected our additional member who comes with a wealth of diving experience which was severely lacking as the original 3 of us had never dived before.

Responsibility

All of the responsibility lay with the students where the team captain took responsibility of the project. The team was supervised by a lecturer however they stated at the beginning of the project that there involvement would be non-existent due to other commitments therefore their involvement consisted of a chat every fortnight about the projects progress.

Finances

The finances were handled by the team captain where a personal account was created for the sole purpose of the submarine in order to purchase all of the submarine components. The university sponsored us at first so that we could afford the immediate costs such as the mould cost. It was easier and gave the sponsors more confidence to send the money so in all but one case the university held the money and we made our large purchases through them whilst we made the component costs and testing costs from the purpose setup account.

Our first sponsor (BMT Defence Services) was the company that 2 of our team worked at over the summer so we were able to discuss make contacts and attain sponsorship that way, the plan for the second prong of the fund raising was to call UK marine related companies however this proved to be unsuccessful as we were constantly redirected. Our third approach was to use the lecturer's contacts and to send out a sponsorship letter which described the event, our design and what we could offer them which proved to be more successful. The Marine school at Newcastle University does a lot of work for the research industry, when they came to meet at the University for updates and discussions we would gave a brief presentation on the submarine which had some success.

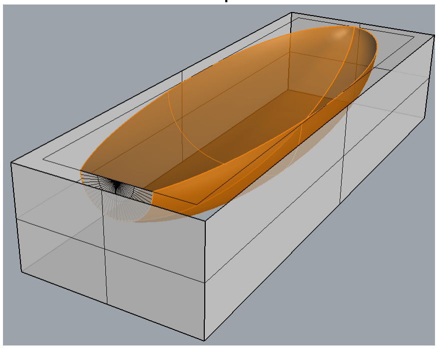
The overall income for the project so far was £12,300, £7,300 of which was donated by the Marine Science and Technology School at Newcastle University. £5,000 was attained from BMT Defence Services, SMD, and American Chemet who generously agreed to sponsor us which has assisted us in the following costs:

Item	Cost (GBP)
Submarine Manufacture Training/Materials/Build space	£6946
Test 1 and Test 2	£300
Race Costs (Travel/Accommodation/Scuba)	£2800
Diving Qualifications	£1100
ISR Entrance Fee	£900
Livery	£200
Shipping	£1800
Total	£14046

Manufacture

The Under Achiever has a sandwich structured composite hull form where most parts are stainless and a minority are galvanised. The university unfortunately had no space for us to build the submarine on site therefore we built the submarine at an ex graduates workshop who was able to show us everything we needed to know about composites and more. The process for manufacturing the submarine was thus:

1. We took the hull form which was made in Maxsurf and exported it into Rhino to get a negative of the submarine.



2. We got the mould milled out externally into a foam block.
3. We prepared the mould by putting a skin on it as the resin used to bond the fibres together would dissolve the foam block.

4. Fill the mould by and then fair it whilst slowly varying the grades of sand paper.

5. Additional layers of filler were used, each softer than the previous which allowed us to create a fair surface where after 2 days we reached the level at which we could polish and wax the mould.

6. Put window blanks in so that the submarine will have a depression in it where the windows will go by vacuum forming.

7. This lead to the final mould with the release tap on it ready for use.

8. Put first skins in.

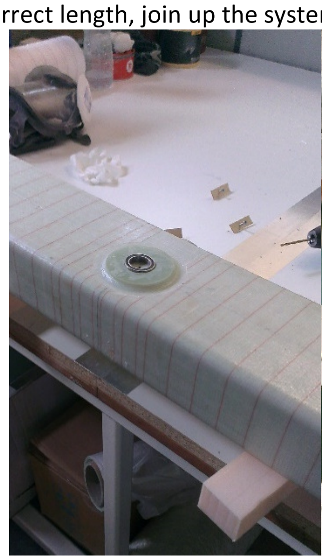
9. Put foam core in.

10. Put in plates so that the holes for the water drainage can later be drilled with precision rather than drilling through the composite skin.

11. Put final skins in. Where the blue stuff is the filler used to fill in any air gaps in the foam core.

12. Repeat for the other half and then attach the two halves together using a hot glue gun and some pieces of wood to hold it in places once aligned.


13. Cut all the shafts to the correct length, join up the systems, and assemble the pedal box and fins.




Conclusion

We have kept our design simple and modifiable every step of the way so that we can get to the races and give a good accounting of ourselves where we could simply and quickly correct any issues that may arise.

To conclude we have:

- Learnt how to use composites
- That designing a submarine and designing a submarine that needs to be built is a completely new and different situation with a host of unforeseen complexities that you don't learn at university.
- Made lots of contacts through the sponsors.
- Gained some valuable experience.