University of Bath: Final Design Report

May

2015

Abstract: This is a design report for the Bath University team of students that have designed and hope to race a human powered submarine at the International Submarine Races 2015.

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List of Abbreviations

Abbreviation	**Meaning**
BURST	Bath University Racing Submarine Team
eISR	European International Submarine Races
GFRP	Glass Fibre Reinforced Plastic
ISR	International Submarine Races

Acknowledgements

The team thanks their generous 2013-2014 sponsors for having contributed to the highest sum of sponsorship funds the human powered submarine project has seen until this date. This support will allow the team to send more junior members to the ISR. Our racing performance will be strengthened and the longevity of the project ensured as the junior members gain valuable racing experience. In addition the team also thanks those sponsors who contributed to the project by offering their technical design assistance; their expert input has allowed us to develop technical solutions to problems which we would otherwise have been too inexperienced to handle effectively.

The team also thanks the University of Bath's Department of Mechanical Engineering for its continued support of this project. The learning outcomes for the team members are invaluable and will strengthen our understanding of engineering. We will take this experience with us as we progress into our various careers, adding to the engineering reputation of the University. Dr Stuart MacGregor and Mr Steve Dolan deserve particular recognition for their roles in supervising this project.

Finally the team thanks the ISR for presenting this opportunity for us to challenge our capabilities and enhance our education.

Introduction

BURST has been participating in the ISR and eISR for the past 9 years. The events challenge teams of University students to design, manufacture and race human powered submarines on a yearly basis. They provide a unique opportunity for students to be exposed to the practical sides of engineering design and management. This year BURST will be manufacturing a new hull, Salacia, and fitting it with a slightly modified version of the drivetrain from the previous submarine, Menrva.

The goal for this race is to beat the top speed achieved by Menrva at the ISR 2013, which was 4.05 knots. This ambitious technical feat will be achieved by designing a hull with a smaller surface area than previous, and fitting the improved powertrain (gearbox and propellers) from Menrva. In addition to these design changes the team will also prepare for the upcoming races through a longer period of rigorous, in-water testing. Finally, BURST is also focusing on building the team's experience and ensuring that the junior members will be able to carry the project forward for future competitions. Figure 1 shows the team at the eISR in 2014. Seven of this team will be returning for the ISR, along with three new members.

Figure 1 - From left to right: Mr Steve Dolan, Francis Stanton, Kevin Mountford, Vishwa Rai, Arnaud Doko, Mark Bleakley, Catherine King, George Balkwill, Sophie Orlans, David Thompson, Bryn Cameron, William Ainsworth, Grace Gipson and Josh Evans.

Report Aim

This report aims to describe the design and manufacture of the Salacia submarine by BURST for the 13th ISR, held in 2015. It also provides information of BURST's experience at the eISR 2014. It will be of interest for the judges of the ISR competition and any future University of Bath students who want to get involved with BURST.

Previous Submarines

The current submarine Menrva was preceded by several different designs over the years. We will only describe the two most recent generations.

2012 - Minerva

Minerva was designed for both manoeuvrability and speed. She finished third overall at eISR 2012, due in part to the new contra-rotating propellers. Figure 2 shows Minerva at the eISR 2012.

Figure 2 - Minerva at the starting line

2013-14 – Menrva

Minerva served as the main source of inspiration for Menrva. The team members who had built and worked with Minerva as juniors were now seniors and applied their experience to the Menrva design, delivering the fastest submarine which BURST has yet seen. Figure 3 shows Menrva during the ISR 2013. The drivetrain from Menrva fitted for the eISR in 2014 will be retrofitted into Salacia for the ISR.

Figure 3 - BURST sets up for a race run with Menrva

Lessons from the eISR 2014

The lessons learned from the eISR 2014 are recorded here, so that future members of BURST can benefit from the experiences of the 2014 team.

Technical Issues

Control System

During running, it was noticed that the propeller shaft and bearing supports were generating some excess friction in the drivetrain. During the solution of this issue, which was completed by realigning the control system box at the rear of the submarine, the mounts for the control surfaces were shifted, creating a situation where the friction in the mechanical control system prevented smooth manoeuvering of the submarine. Solution to this involved realigning the control box, and replacing the tandem brake cables used as the method of transferring pilot input into control surface output. This was hugely detrimental to the team's performance at the eISR, and is something that the new design aims to eliminate.

Hatch Securing System

During the final runs the team were given the chance to attempt at the eISR, the alternative pilot was given the opportunity to give it a go. Unfortunately, with him being four inches shorter than the primary pilot, there was more room in which for him to move inside the hull. The latch used to secure the hatch to the submarine is opened from the inside using a sliding lip. The axis along which this slides is along the length of the submarine and the pilot's movement unlatched the hatch each time. It also loosened the latch from its mounting system, so that when the unintentional release problem was resolved, the latch itself rotated and the hatch opened, ending the run. This will be resolved with the new design, both of hull and latching system.

Teamwork

Communication

While working underwater the divers and the pilot cannot speak, so the team developed a routine for communicating silently to trim the submarine and load the pilot. To begin with the team practiced this routine on land, first speaking to each other, then communicating silently. Getting the divers and the pilot familiar with this routine improved the efficiency of the race setup and allowed the team to squeeze more runs into the allotted time.

Task Allotment

The jobs were split evenly between the team members, taking into consideration that the junior members didn't have much time to work on the manufacture of the submarine because they (unlike the senior team members) had exams to revise for. The junior members were also less experienced with the manufacturing techniques and so were given organisational tasks such as researching cheap flights and car rental services.

A clear assignment of responsibilities/jobs (e.g. onshore manager, pilot, dive master etc.) allowed the team members to know what was expected of them and what to expect of others. This improved the efficiency of our teamwork.

The project manager's style of team leadership proved to be effective. The team remarked on how he listened to all team members' points before making a decision and committing to it. He also knew when to raise an issue for discussion. This decisiveness was key to the team's performance.

ISR 2015 Submarine Design

Design Principles

This year BURST continues to build on the designs used for Menrva in 2014. With Menrva having completed race runs at the ISR in 2013, a new hull design was required as part of the race rules. This hull will be named Salacia, after the wife of Neptune, the Roman god of water. The following section details the hull design process, along with the key subsystems.

Subsystem Definitions

Figure 4 shows the different subsystems of Salacia's design.

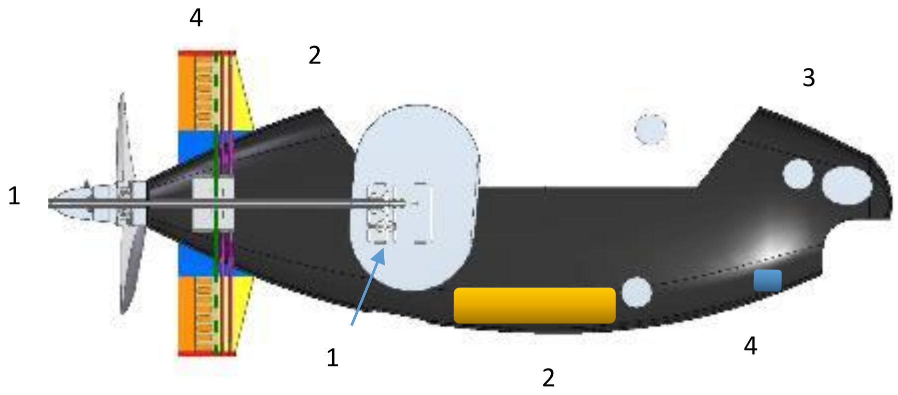


Figure 4 - The submarine's subsystems

1. Power Train

The pilot drives a gearbox via bicycle cranks with SPD pedals. The gearbox is designed to rotate two shafts in opposite directions; one shaft is hollow and axially aligned with the other, forming an envelope. Each shaft is also connected to a separate propeller. This contra-rotation minimises torque roll on the submarine and allows some of the energy from the first propeller's radial wake to be recovered. Both of these benefits increase the efficiency with which the pilot's power is converted into axial thrust.

Menrva's 2013 gearbox required modification for the eISR 2014. The previous design had been rushed, due to time constraints, and did not provide the optimum gear ratio as a result. The propellers had been designed for a rotational speed of roughly 250rpm, with a pilot top cadence of 50rpm. A 5:1 ratio would thus have been required – the gearbox provided a 4:1 ratio. Figure 5 shows the previous gearbox design.

Figure 5 - The previous gearbox design

The new gearbox again uses the contra-rotating principle. It has a larger depth than the previous design, but will require less maintenance because of the stainless steel gears used. The first stage remains identical to the previous gearbox design, with a 4:1 ratio from the crankshaft. The second stage has been modified – it now uses spur gears and lay shafts to reverse the direction of rotation whilst maintaining the same rotational speed. This arrangement is easier to disassemble and less sensitive to misalignment than the initial bevel design, which required precise spacing for optimum efficiency without gear binding. This arrangement also eliminates the need for a large, bulky boss on the side which, in the previous design, was too close to the rotating cranks. Having learned from the shaft failure at the ISR 2013, the diameter of the shaft connecting the first and second stages was increased. Keyways, rather than pins, will now be used to transmit the torque from the gears. The top speed cadence of the pilot has now been assumed to be 60rpm for propellers designed for 240rpm, so the 4:1 gear ratio is now optimal. Figure 6 shows the CAD model of the new gearbox design.

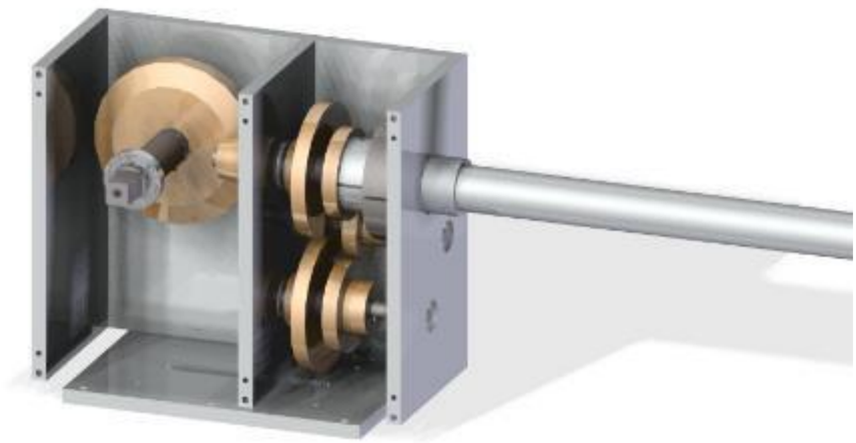


Figure 6 - The new gearbox design. Note the top and side walls have been removed for interior visibility

The propellers have also been redesigned for the ISR 2015. The previous propellers used at the ISR 2013 were machined from aluminium in the CNC machining centre of the Department of Mechanical Engineering. Doubts about the capabilities of this CNC machining centre at the time meant that the propellers were manufactured thicker than the optimum design. One of the old propellers is shown in Figure 7.

Figure 7 - Aft bladeset of the old contrarotating propellers

The new propellers use the same contra-rotating principle as the old set, which minimises torque-roll on the submarine. With technical design assistance from Rolls Royce, experts in this field, the literature on the B-Series Wageningen nautical blade was explored. This design has been heavily researched in academia, for example by Rachwalik (2013), and was found to be highly efficient. Using the gathered data the team was able to calculate the propellers' ideal sections at certain radii. Obtaining the optimum blade-area ratio for a particular rotational speed became the design-driving criterion. From this ratio it was possible to predict the torque and the speed and verify that they were acceptable. The propellers are designed for a top speed of 240rpm. The propellers were again machined from aluminium by the Department of Mechanical Engineering, but working more closely with them to ensure maximum quality. Figure 8 shows the new propeller design on Menrva during testing prior to the eISR.

Figure 8 - The new propellers shown on the old hull during pre-eISR testing

A few modifications will be made to the propeller hubs before the ISR, including adding a taper to the hubs to smooth fluid flow, and a hub cap to allow for better separation of flow aft of the propellers. These are shown in CAD form in Figure 9.

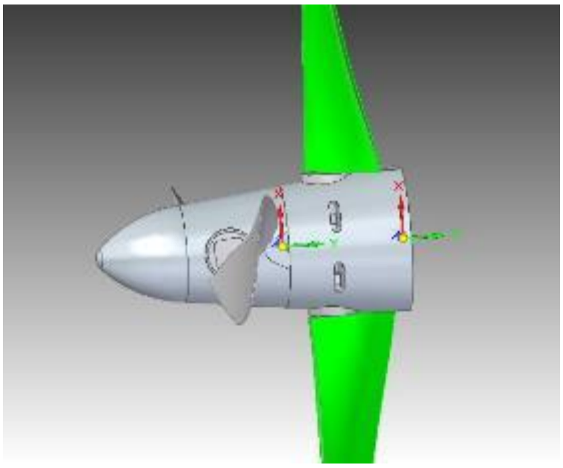


Figure 9 - CAD model of tapered prop fairings and hubcap

Since BURST will be relying on different pilots throughout the race, some of whom will not be able to output the power required for the designed top-speed, it is be useful to vary the pitch of the propeller blades before a race run. This is done by machining a boss on the base of the propeller blades, which then mounts into a tapered cylinder on the bottom of each blade, to be accepted into a cylinder with a receiving taper mounted in the hub. This allows the blade to be positioned and then locked in place using a grub screw. The blades will be removed for adjustment using a shim as in tool-setting. A fairing will be fitted over the assembly to minimise losses from rotating the cylindrical hub section. This will allow for experimentation in finding the optimum top speed/acceleration compromise and also cater to the capabilities of each pilot.

2. Safety and Life Support

Salacia has the mandatory safety buoy. It consists of a buoyant foam core, wrapped in fibreglass and connected, via a string on a reel, to the submarine. The buoy is brightly coloured for easy visibility from the surface.

This year the submarine will feature the inclusion of a pneumatic system for the release of the hatch and safety buoy in an emergency situation. This will be charged off of the BCD connector hose on the internal air supply within the submarine, then separated, as per the regulations. The pneumatic actuators used will be single acting, with the spring acting to open the hatch and release the buoy in case of loss of pressure in the system. The dead-man switch will be a pneumatic valve integrated into the pilot's control joystick. A sketch of the proposed circuit, being developed further by our sponsors at SMC Pneumatics, is shown in Figure 10 below.

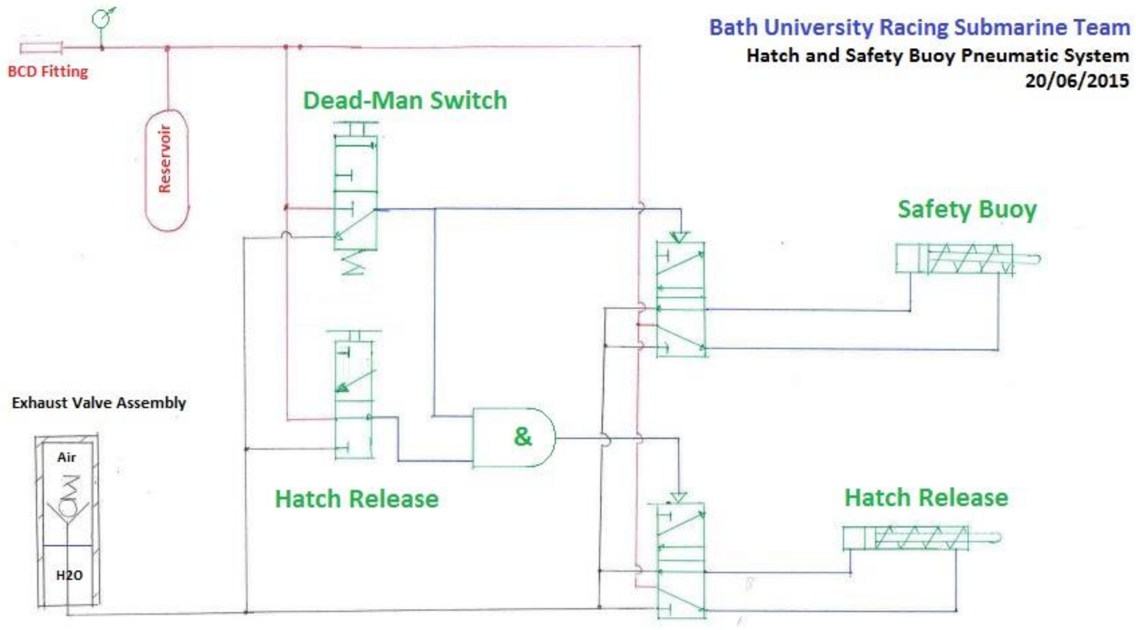


Figure 10 - Schematic of pneumatic hatch and safety buoy release system

There will continue to be a mechanical override, both internally and externally accessible, by use of a sliding latch mechanism.

A safety strobe is also incorporated into Salacia's design. For the ISR 2015 the team will be utilising a purchased strobe which matches the requirements of the ISR Manual. This strobe is shown in Figure 11.

Figure 11 - The safety strobe

As previously mentioned in the powertrain section, the pilot will be using standard Shimano SPD cleats and the appropriate footwear to drive the gearbox. These can easily be twisted free of the pedals, and the heels of the shoes will be marked in the high-visibility orange so that rescue divers would know how to aid the pilot should it be required. The external hatch release point will also be marked as per the regulations once the hull has been painted.

The primary air supply system has not changed since our previous submarine Menrva competed at the ISR in 2013. The 10L primary air cylinder is conveniently positioned underneath the pilot's chest and has a capacity of 232 bar, as shown in Figure 12. The pilot will also carry an emergency 4L (2x2L twinset) supply as a backup to the primary air supply. The gauges will be positioned for the pilot to view during race runs.

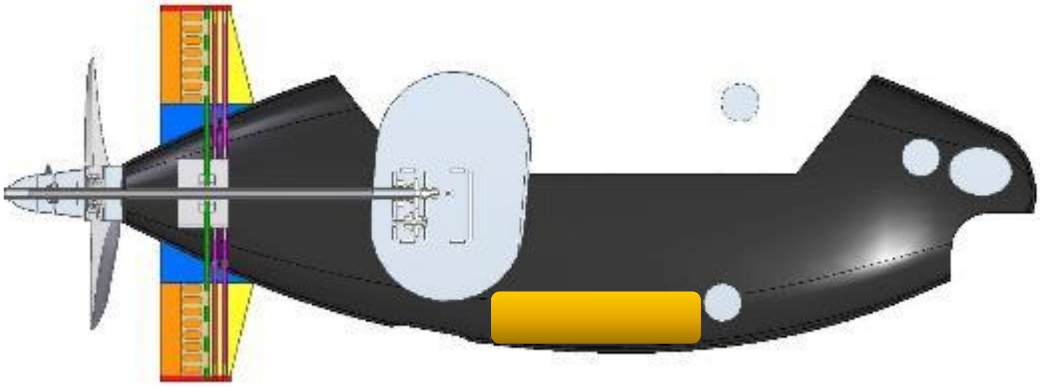


Figure 12 - The air cylinder is shown in orange

3. Superstructure

The term "superstructure" in this context describes the submarine's hull and chassis, both static components. Salacia's hull dimensions are based off of our main pilot's anthropometric measurements. During the summer prior to the ISR competition, the team created a rig from which his measurements could be taken. This rig is shown in Figure 13.

Figure 13 - Main pilot using rig

The design was then created around these dimensions, and tested in Ansys CFX, a piece of CFD software available on the University's computer systems. The results for this are shown below in Table 1, including a 13.8% reduction in drag force compared to Menrva's hull at our target speed of 6 knots.

Velocity/knot	5	5.5	6	7	10
Drag Force/N	93.55	110.92	131.01	175.41	346.53

Table 1 - Drag force results from CFD analysis of Salacia hull

The hull was manufactured from GFRP in three stages. Salacia's axisymmetric form allowed the team to produce one mould for both halves of the final hull, saving considerable time. First a male plug was built and sanded down. Significant attention was paid to the quality of this initial form and its surface finish, since those properties would carry through to the female mould and the final-hull. After the male plug was complete, a female mould was built and the final hull laid up inside. Figures 14 and 16 show the stages of this process.

Figure 14 - The male plug (left), female mould on plug (centre), female mould (right)

The team laid the composite in a quadraxial sandwich structure for high stiffness in both direct loading and torsion. A closed cell foam, Rohacell®, four times as thick as the GFRP, was used as the core of this sandwich. This flexible sandwich core complied well with the curvature of the hull and also allowed the epoxy resin, used in the wet layup, to fuse the two skin layers. This increased both the stiffness and the long-term robustness of the composite panels. The Rohacell® core also provides significant buoyancy due to its low density of 75 kg/m³. Overall the hull provides approximately 28kg of buoyancy. Figure 15 shows the structure of the Rohacell® core.

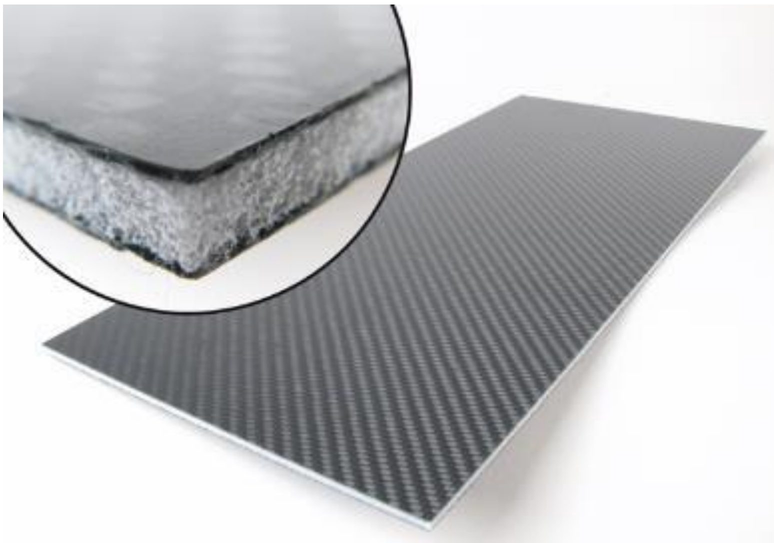


Figure 15 - The Rohacell® core in a carbon composite panel.

Figure 16 shows images from the layup process for Salacia

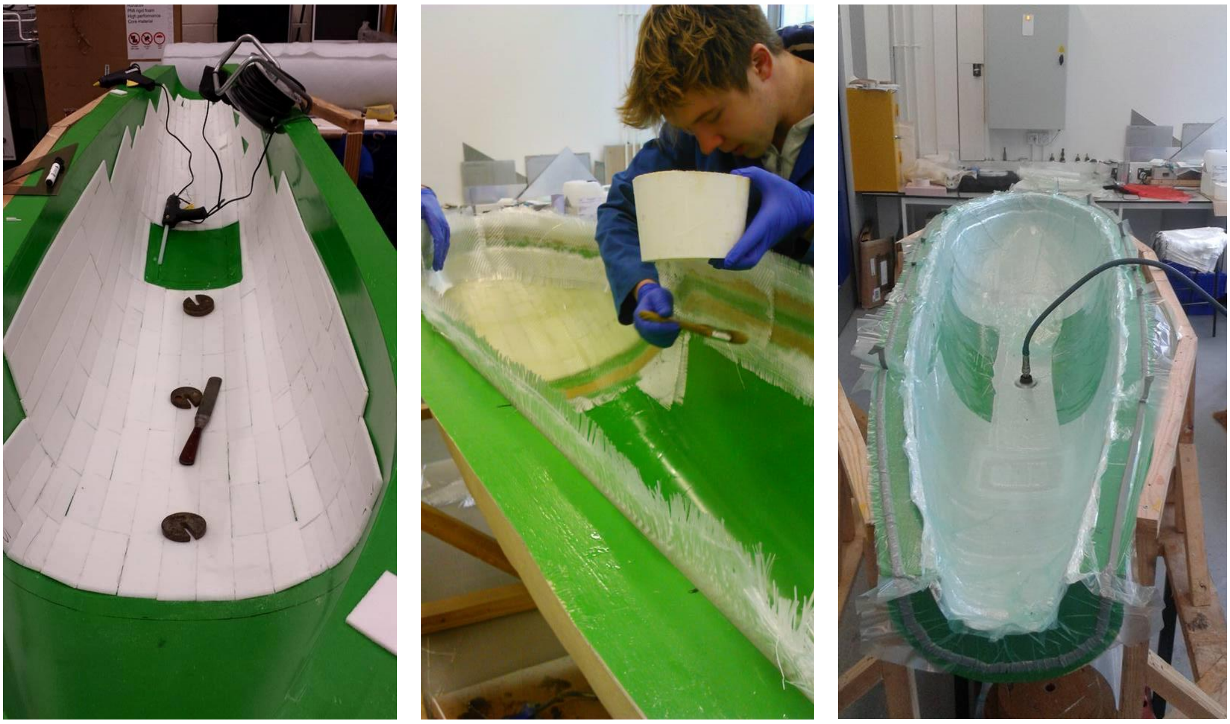


Figure 16 - Core preparation (left), layup of GFRP in mould (centre) and vacuuming of finished layup (right)

The submarine also contains a chassis, constructed from aluminium bars of 2”x1” rectangular cross section. The gearbox and propulsion system is mounted to the structural hull using it, as shown in Figure 17.

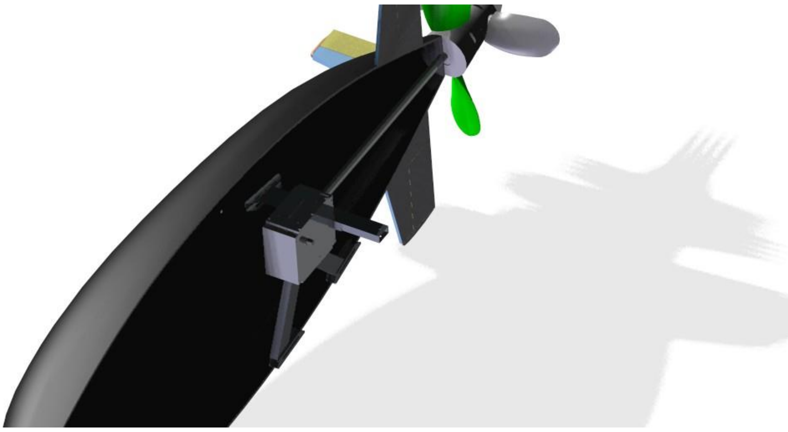
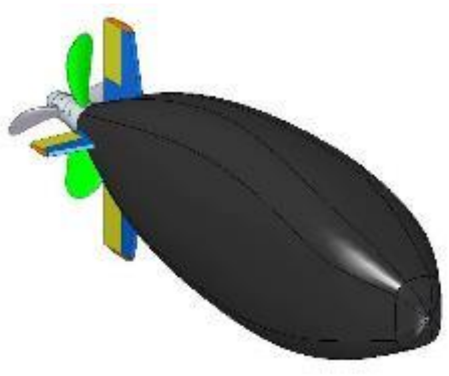


Figure 17 - CAD screenshot of gearbox chassis

4. Control System

The pilot controls the yaw and pitch of the submarine using a joystick. The joystick itself is connected, via push-pull cables, to the control surfaces at the rear of the submarine. Figure 18 shows the control surfaces and the new mechanical joystick design.



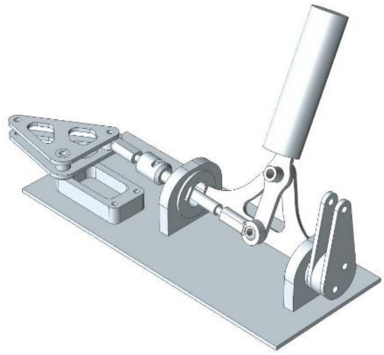


Figure 18 - The control surfaces are highlighted in yellow with stationary skegs in blue (left) and a close-up of the new joystick is shown (right).

With the hull redesign, the control surface mounting system has been changed to make it both more rigid and less likely to seize. To do this, the stationary skegs have 2 support rods up through them. The top of each one of these tubes will have a threaded insert in it, onto which the top skid of the fin will be mounted and secured. Aft of this the steer tube will protrude, set into a plain bearing in the skid. This allows for easy removal and replacement of the fin if needed, along with minimal maintenance. This is shown below in Figure 19.

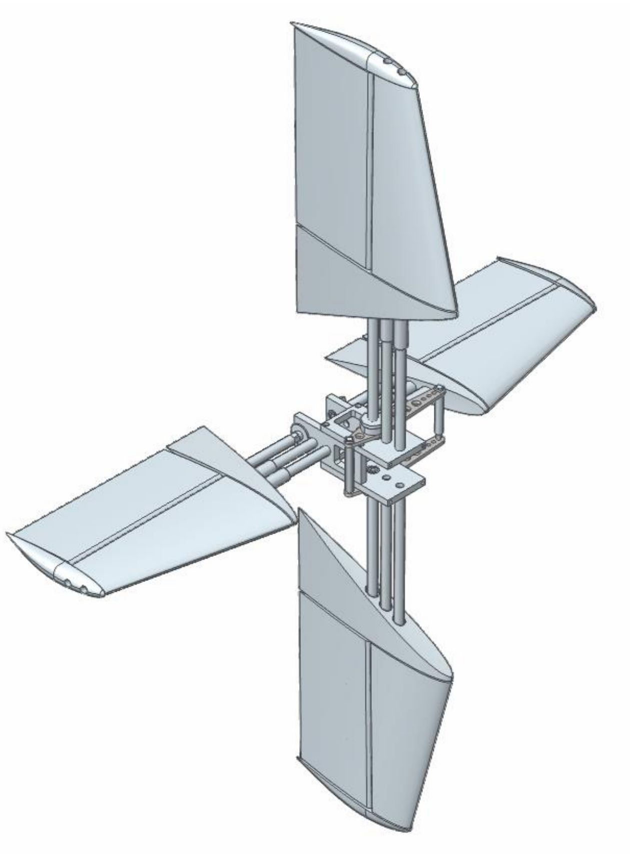


Figure 19 - CAD model showing skeg support tubes, steering tube and associated fittings

Buoyancy and trim

At the ISR 2013 Menrva's buoyancy was controlled through foam buoyancy modules which were installed on the inside of the hull. Salacia will use a similar system to adjust the trim. Figure 20 shows these modules highlighted in purple. Due to the design changes made for the ISR in 2015, and the associated weight changes, BURST will adjust the buoyancy module distribution once Salacia is underwater during setup and testing.

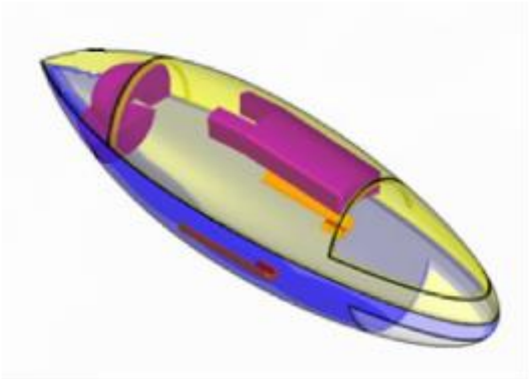


Figure 20 - Theoretical buoyancy module distribution for Menrva from a 2012 design report by Hewson

Electrical Systems

There is a plan to include some electrical sub-systems into Salacia. These systems are not critical, but will be simply supplying the pilot with feedback on where the submarine is heading in pitch, and where the diveplanes and rudder are pointing, allowing for the necessary corrections to be made without putting further strain on the pilot in what is an already stressful environment. There is also a plan to measure and store shaft velocity for recovering after the run, allowing for adjustments to be made to the propeller's pitch to increase the submarine's efficiency. Initial concepts for these are outlined below, with further development ongoing.

Measuring Shaft Speed

Detecting Shaft Angular Velocity

Rotary Encoder

In this concept, a rotary encoder is attached to the shaft and outputs a signal which is collected by a microcontroller. The encoder would have low resolution and therefore provide very precise speed readings, which is probably unnecessary. The difficulty would be in attaching the encoder and then waterproofing it.

Dynamo

In this concept, a wheel contacting the shaft is driven by friction, in the same way that a dynamo bike light works. This would be simple to implement and could be quite easily waterproofed, but would require sufficient friction between the shaft and dynamo to turn it. In order to get an accurate reading, the dynamo would have to be tightly pressed against the shaft.

Figure 21 - Dynamo detecting shaft speed

Tachogenerator

This concept would provide the greatest accuracy and is commonly used in industry, however would require a substantial electrical system to support it, as it generates electricity. It would have to be mechanically linked to the shaft at some point also.

Magnetic Pick-Ups Detecting a Rotating Magnet
In this concept, a magnet is attached to the shaft and a magnetic pick up such as a reed switch is placed nearby. As the shaft turns, the reed switch outputs a digital square waveform that will allow a microcontroller to count the pulses and hence the turns. This would be low resolution unless more magnets were placed around the shaft but would be robust and would be mechanically isolated.

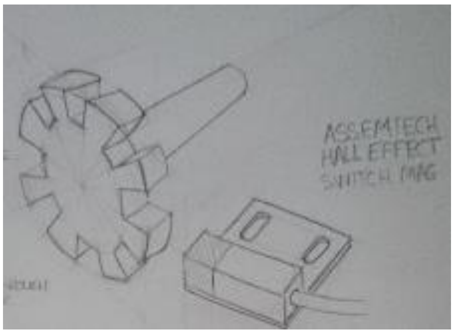


Figure 22 - Magnetic Pickup detecting cog wheels moving past it

Reflecting Light Strip
An LED shines light from a stationary circuit board, the shaft has a reflective strip attached to it that rotates, as the strip moves past the LED, it reflects some of the light back which is picked up by a photo resistor, shown in Figure 23.

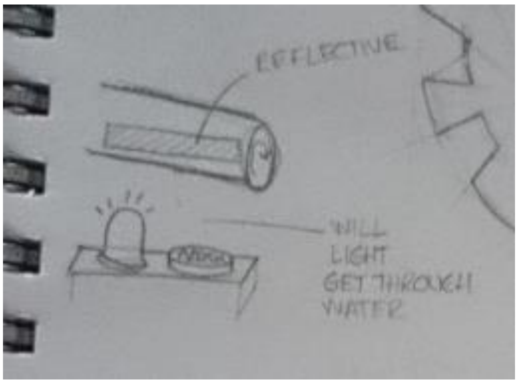


Figure 23 - Reflective strip on shaft which reflects light from LED

Detecting Hydroplane Position
Development ongoing

Feeding Hydroplane Position Information to Pilot

LED Grid
A set of LED's in the shape of a cross, one green one in the middle and 2 red ones either side and up/down. The up/down LED's indicate dive plane positions, green is level, red going up means the hydroplanes are pointed up and vice versa. The left/right LED's would be for the rudder. This is quite an intuitive design and would be easy to implement. Sketch shown in Figure 24.

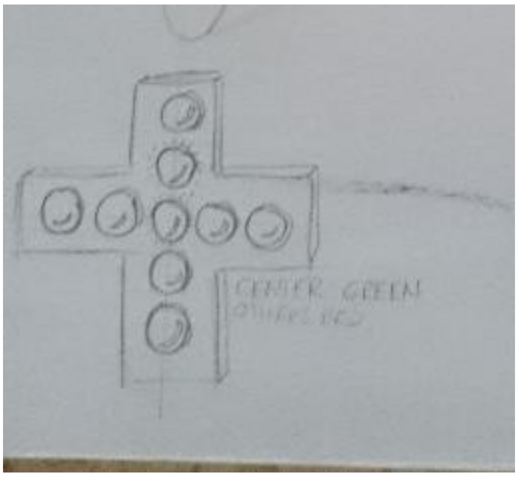


Figure 24 - LED grid in the shape of a cross for pilot feedback

LED’s Surrounding Pilot Head

The idea is that the LED’s are in the pilots peripheral vision, he sees nothing if everything is lined up. As the dive planes are tilted up, a red LED appears somewhere in the top of his vision, he sees it in his peripheral vision, letting him know what correction needs doing.

Measuring Submarine Pitch

Detecting Submarine Pitch

Two Depth Sensors

In this concept, a microcontroller gets depth information from a depth sensor at the back and a depth sensor at the front. It then calculates the difference between these to get submarine pitch.

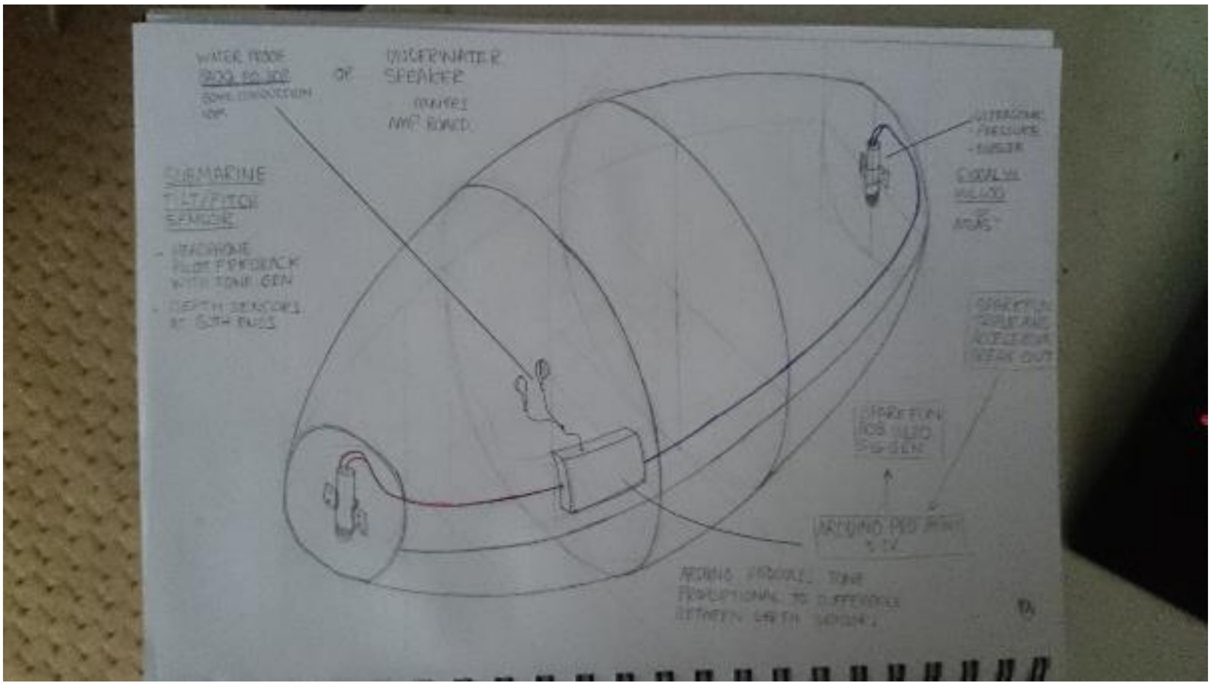


Figure 25 - Submarine pitch detection concept with headphones and depth sensors

Accelerometer

A simple accelerometer is used to get pitch information, very quick and easy and can be in the same place as the microcontroller which drives the display.

Feeding Submarine Pitch Information to Pilot

Tone Generator

A tone is generated by a microcontroller, where the pitch of the tone is related to the pitch of the submarine. The tone is then transmitted to a hydrophone near the pilots head or a pair of underwater headphones. This technique is apparently intuitive and used in gliders as an automatic way of telling the pilot the pitch of the craft. Underwater headphones can also be bone conducting, which don't require being inserted into the ear. Horizontal submarine position could be recognised as a blipping noise.

Seven Segment Display

A seven segment display could feedback absolute angle of the submarine in degrees, this would be easy to implement and driven directly from a microcontroller. The displays would have to be waterproofed however and also, this might be too much information for the pilot to handle, having to look at a number display.

LED matrix of lines

A set of LED's to form a grid can be used as a display, each line has 5 LED's and there are 17 lines, the middle line horizontally is green and the others are red. When the submarine is horizontal, the green line lights up, as the submarine tilts up, the lit up line starts to move upwards into the red zone and vice versa. This would be intuitive and very similar to the hydroplane feedback system would not be too taxing on the pilot.

Testing

Full Submarine

BURST has planned a full week of testing before taking Salacia to ISR #13. This is significantly more time than BURST had at the ISR 2013 and will allow the divers to familiarise themselves with handling the submarine, culminating in better racing performance, and team efficiency.

Specialist Coating Testing

The team investigated the use of several different permanent, paint-like coatings on the Menrva hull form in order to reduce her skin friction drag. The University's water tunnel provided the environment in which BURST could test small-scale Menrva models for this purpose. After some calculations it became clear that, although the models could be manufactured to be geometrically similar to Menrva, the test conditions would only be dynamically similar to the life-sized operation of Menrva for her lowest velocities. Nevertheless the team decided to see what effect the coatings would have.

Six small-scale models of Menrva were laser-cut from slices of MDF and glued together. The edges were sanded down to achieve a smooth hull finish. The models were painted and given different surface coatings. Figure 26 shows the small scale models next to the previous Menrva propeller. BURST designed a simple rig, which was laser-cut and assembled from MDF board. It incorporated a long lever which held the models at one end and exerted a tensile force on a force-gauge at the other. Figure 27 and 28 show the rig set up.

Figure 26 - Scale models of Menrva hull with different surface coatings

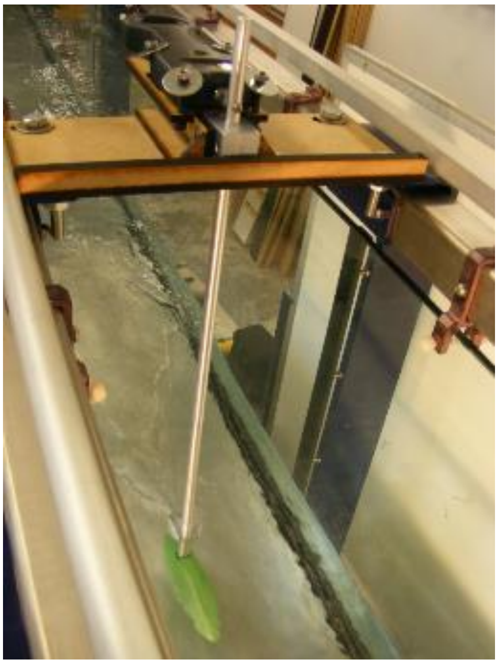


Figure 27 - The test rig in the water tunnel

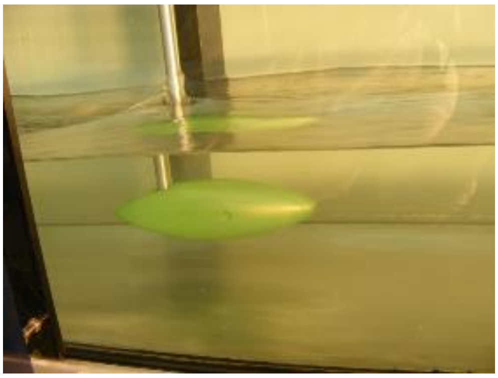


Figure 28 - Close up of model in water flow

The results showed that none of the coatings significantly improved the drag performance of the submarine over its existing automotive-grade coating finish. The exception was the rubberised coating – it significantly worsened drag performance compared to the other coatings. Based on this result BURST decided to refinish the submarine in the most convenient coating recommended by AkzoNobel, the sponsor providing the team with this.

Team Organisation

Name	Uni Year	Course (all Engineering)	Team Role
Steve Dolan	Staff		Technician
Mark Bleakley	4	Mechanical	Project Manager
Josh Evans	4	Mechanical	Project Manager
Tym Pakulski	3	Mechanical	Safety Systems
Arnaud Doko	3	Mechanical	Sponsor Liaison Safety Systems
Kevin Mountford	2	Mechanical	Pilot Support Systems
Grace Gipson	2	Electrical and Electronic	Electronic Systems
Bryn Cameron	2	Electrical and Electronic	Electronic Systems
Daniel Evans	1	Electrical and Electronic	Electronic Systems
Jake Williams	1	Mechanical	Cradle

Project Management taken on by two final year students in order to spread the load. Both have experience from the eISR in 2014, and have used it to further build on BURST successes and problems. A number of the design tasks were taken on by Josh, while Mark focussed on the financial and logistical tasks.

Further electronics are planned for future inclusion, hence the inclusion of a large contingent of electronic engineers for the ISR, in order to determine ways in which to improve further on BURST performances in the future.

Finances

All of the income to the project is from sponsors, whether that is monetary, technical or the form of in-kind materials. Below is a detailed breakdown of income and outline expenditure.

Sponsors	BP (primary sponsor)	Formax (material)
Atlas Elektronik (monetary, technical)	University of Bath (financial, technical)	Emkay Plastics (material)
BMT Defence Services Ltd (technical)	Vac Innovations (material)	Matrix Composite Materials Company (material)
AkzoNobel (material)	DSM Resins (material)	sia Abrasives (G.B.) Ltd (material)
Rolls Royce (technical)		

Conclusions

For BURST, this academic period has been very successful. All of the major design ambitions were fulfilled and the BURST team experienced an influx of new, junior members. The record amount of sponsorship and the professional design assistance has allowed the team to manufacture what will likely be Bath's most successful submarine yet. BURST has also made good use of this academic period to explore value-adding innovations and improvements to the old Menrva designs. We're excited to see what Salacia will come out with at the 13^{th} ISR in June 2015!

Solution Specification

Parameter	Value	Unit	Comment
Overall dimensions			
Overall length	2.7	m	Overall inc props and control surfaces
Overall width	0.9	m	
Overall height	0.9	m	
Propeller sets	2		Contra-rotating
Blades per set	2		
Control fins	4		4 compass points aft
Hatches	2		Top (access), Bottom (drainage): both midships
Window	1		Perspex, front 400mm
Superstructure			
Hull length	2.4	m	
Hull width	0.58	m	
Hull height	0.8	m	
Hull mounts	4		Bottom half: fore, mid & aft
Chassis			Aluminium box section construction
Propulsion system			
Propeller speed	240	rpm	
Transmission ratio	4:1		
Drive input			175mm standard bicycle cranks
Drive output			x2 contra-rotating shafts
Bevel gears	2		
Spur gears	5		
Control system			
Dive planes	2		Aft
Rudders	2		Aft
Control input			Dual-axis manual joystick
Transmission			Marine push-pull cables
Maximum pitch	±15	Deg	
Safety & lift support			
Air supply	10	Litres	232bar SCUBA
Safety buoy			Foam core wrapped in fibreglass, top, slightly aft of mid-ship
Dead-man switch			Pneumatic valve

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