University of Bath: Basic design report

ISR#12

Bath University Racing Submarine Team

Abstract

This paper forms the preliminary design report for a human-powered submarine entry from the University of Bath for the 12th International Submarine Races, USA. A brief summary of past submarine team designs and results are provided as background to the 2013 design. The report also covers activities and learning undertaken by the team in 2012 in dedicated technical design projects and at the inaugural European International Submarine Races. These are used as guidance for the 2013 technical design. Design methods for major subsystems within this year's vessel are described and explained and include the superstructure, propulsion system, control system and safety & life support systems. The report concludes with a preliminary design specification.

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1 Acknowledgements

BURST would like to thank their 2013 sponsors for their generous support which has allowed the team to undertake the challenging task of building a human-powered submarine. In particular BP and Rolls-Royce for their support of the University of Bath's Mechanical Engineering department and British Engineering.

They would also like to thank the Department of Mechanical Engineering at the University of Bath and its staff for providing facilities, time, effort and advice in all areas of the submarine build and project management. In particular Stuart Macgregor, Jens Roesner, Steve Dolan and Steve Thomas. Acknowledgement also goes to previous submarine teams that have come before for their work in setting the foundations for the 2013 team to build on.

Finally, the team would like to thank the ISR race organisers for putting on this unique and challenging event. This project has been an immeasurable education in engineering, management and what it takes to deliver such an interesting vehicle.

2 Introduction

Bath University's Racing Submarine Team (BURST) has been competing in the International Submarine Races (ISR) since 2003. This year, lessons learnt from previous submarine builds, academic projects and races have been incorporated into an entirely new vessel. With numerous senior year projects aimed at transmission design, reducing pilot task load through ergonomic design and guidance automation, BURST's commitment to innovation and improvement is evident. Figure 1 (a) and (b) show the 2012 and 2013 teams respectively (BURST 2013).


(a) (b)

Figure 1. BURST teams from (a) the 2013 inaugural European International Submarine Races (eISR) and (b) the 2013 team for ISR#12.

At ISR#12, BURST are aiming for an improvement on previous racing performance; they hope to set a team speed record and finish within the top five overall. Significant sponsorship deals from leading engineering companies such as BP and Rolls-Royce have provided BURST with the necessary resources to implement their designs and ideas that build on previous experience and academic projects.

The BURST project was previously run as a set of junior and senior year academic projects within the Faculty of Mechanical Engineering at the University of Bath. Students start a dedicated design project for a submarine in their junior year as part of a Group Design and Business Project, whilst a series of individual senior year projects realise and develop new designs and concepts. Manufacturing takes place throughout the academic year during racing years, however progress is traditionally slow and ramps up towards the races once academic studies have concluded. Figure 2(a) and (b) show BURST members in their workshop in 2013.

(a) (b)

Figure 2. BURST members manufacturing the 2013 submarine, (a) verifying the hull volume fits a human pilot and (b) checking vacuum-bag seals for the fibreglass hull.

2013 has been a mixed year for BURST; it marks the first time that a significant number of junior students remain in the team for senior year and bring with them design experience, and crucially racing experience from eISR#1. Unfortunately it also marks the end of dedicated junior year design projects, meaning that future teams will not benefit from this focused academic exercise.

BURST has kept several overriding design principles throughout the 2013 development cycle including simplicity, robustness and quality. These are discussed later in Section 4, however it is worth noting that the new 2013 design relies heavily on learning outcomes from previous design projects and racing experience. As a result of placing such trust in previous work, the need for detailed calculations has been reduced. Whilst this is a risky strategy for a technical design, it is very time efficient in the outset, and relies on testing and tweaking to achieve the desired performance. This is in line with the time pressure placed on the team to design and manufacture during the academic year; the results at ISR#12 will be telling.

2.1 Reading notes

This report will continue in the next section to briefly cover the past submarines that BURST have built and races, in order to provide the reader with an understanding of previous overall designs the team has explored in the past, and provide an indication as to why current design solutions have been chosen. Section 4 Lessons from 2012 will cover learning outcomes from the 2012 group design project and eISR#1. Following an explanation of the team's design principles and overall concept in Section 4, Section 5 will cover the technical design of the 2013 submarine's major subsystems in detail including the superstructure, propulsion system, control system and safety & life support system. Brief statements of intent with regard to testing and future work is provided in Sections 7 and 8 respectively. The report concludes with an overview of the final design.

3 Previous submarines

Since 2003, BURST have built and raced three distinct human-powered racing submarines: *Seabomb*, *Sulis* and *Minerva*. Brief descriptions of their designs and racing outcomes are provided below. The 2013 submarine design is based largely on Minerva. Figure 3 pictures the submarines' overall designs.

(a) (b) (c)

Figure 3. Previous BURST human-powered submarines showing (a) Seabomb, (b) Sulis and (c) Minerva.

3.1 Seabomb

Seabomb first put BURST on the map by finishing second in class at the ISR#9. The puffin-inspired biomimetic design won a bronze medal for innovation and finished fourth in overall performance.

3.2 Sulis

Sulis, an innovative design that broke convention came first in class in ISR#10. She featured a hybrid propulsion system that combined conventional propellers and flapping foils.

3.3 Minerva

A balance between speed and manoeuvrability, Minerva finished tenth at ISR#11. A redesigned propulsion system featuring counter-rotating propellers greatly improved her performance and she finished third overall at eISR#1 in 2012.

4 Lessons from 2012

This section will cover BURSTs experiences in 2012, leading to the 2013 manufacture for ISR#12. The 2013 team contains several students who have been involved in past projects; in particular the inaugural European races held in Gosport, UK, 2012. Additionally, half the 2013 team were involved in the junior year Group Design and Business project to develop a concept for the next generation submarine. This section summarises the key learning outcomes from the technical design project and UK races, and also how this has impacted the 2013 design.

4.1 Technical design project

This was part of a junior year Group Design and Business project involving ten undergraduate mechanical and electrical engineers over a three month period. It produced a conceptual design that concentrated on two areas (Morgan & Goode 2012):

1. Technical performance
2. Exploring new solution principles

The result of this project was a next-generation racing submarine design, pictured in Figure 4. The design features and rationale are listed in Table 1.

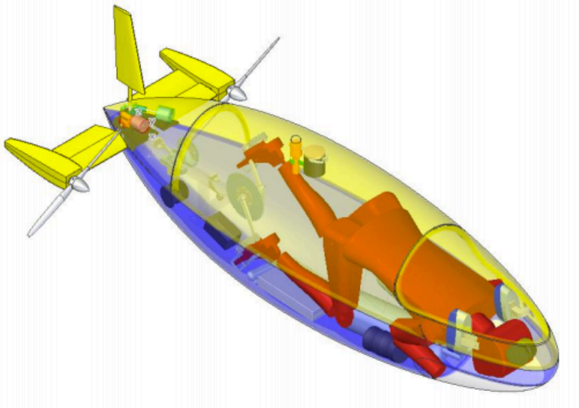

Figure 4. General assembly from the 2013 Group Design and Business project.

Table 1. Design features of the group design project and their rationale.

Primary design feature	Reason for choice and desired effect
Split counter-rotating propellers	To counteract torque roll from a single propeller; this propeller layout was explored as a single–rotational–axis design was in concurrent development as a separate academic project
Major hull volume reduction	Reduce hull drag and increase theoretical top speed
Major hull construction redesign	Improve past manufacturing quality for hull shape and drag reduction
Automated control system	Reduce pilot task loading and improve directional control

4.1.1 Learning outcomes from technical design

The length and breadth of the project allowed a complete iterative design for a racing submarine – this in effect provided a 'practice run' for a technical design and afforded the team an understanding of what is required should this be repeated in the future. The key bodies of work that were carried forward into the 2013 design and build are listed below and discussed later.

1. **Hull form** and **manufacture** method:
2. **Design principles**: simplicity, reliability
3. **Key technical areas**: drag reduction, thrust optimisation

4.2 Inaugural European races

BURST attended the inaugural European races in 2013 and placed third overall. The team raced their previous ISR entry *Minerva* with a brand new propulsion system – a pair of single-axis contra-rotating propellers. The race week allowed the team to experience first hand the challenges involved with operating a submarine and lead to the following learning outcomes.


(a) (b)

Figure 5. *Minerva* at eISR#1, (a) waiting on the starting line and (b) Go, Go, Go!

4.2.1 Learning outcomes from eISR#1

1. **Reliability is key**: more racing runs = more practice = better performance
2. **Simple is reliable**: if it can break, it will; reduce the failure modes
3. **Implications of working underwater**: everything takes more effort underwater, simplify and reduce tasks for the pilot and diving crew

5 Design principles and concept

Building on experiences from the technical design project and the eISR, BURST decided to adopt the following as their core design philosophies for the 2013 build:

Simplicity and **Quality**

The 2013 design is a combination of Minerva's design with aspects of the technical design project. Figure 6 illustrates the overall design concept that drove development and manufacturing activities in the build up to ISR#12.

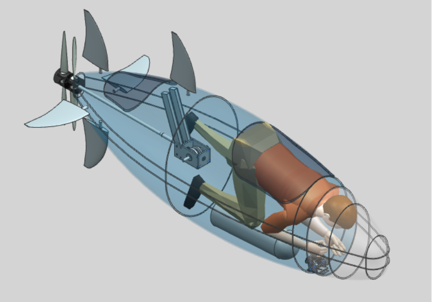

Figure 6. Overall design concept for the 2013 submarine.

In particular, the new build incorporates the successful contra-rotation propeller design from Minerva in eISR#1, and the significant hull volume reduction from the technical design project. This tackles the key performance variables of optimised thrust and reduced drag, and the remaining components and subsystems were design to accommodate these.

5.1 Subsystem definition

The 2013 design comprises of 4 major subsystems. These are the **superstructure**, **propulsion** system, **control** system, and **safety & life** support systems. The following section will detail the reasoning, development and manufacturing activities the team has undertaken for each. Figure 7 identifies each in a general assembly.

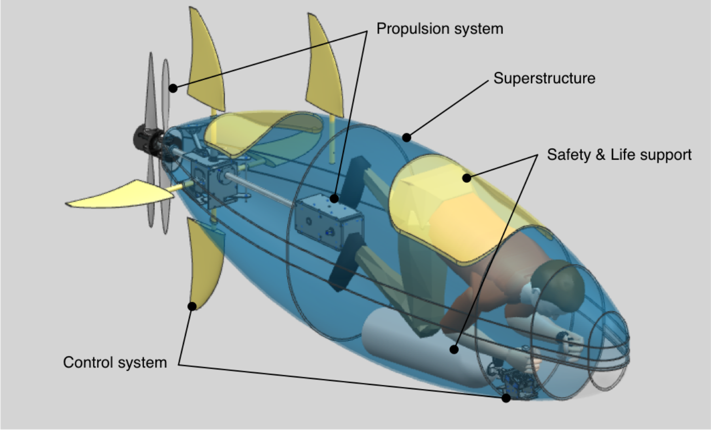

Figure 7. Definition of subsystems in the 2013 submarine's general assembly.

6 Technical Design

This section will provide detailed explanations behind the design rationale for various aspects of the submarine's subsystems as mentioned above. It aims to explain why certain solution principles were chosen, and illustrate the team's design and manufacturing efforts thus far.

6.1 Superstructure

The superstructure of the submarine is defined in this report as the static components that form the body of the submarine and include the hull and chassis. This section details reasoning behind the shape of the hull, buoyancy considerations in the composite structure and the materials and manufacturing techniques employed.

6.1.1 Hull form

The overall shape of the hull is based on a NACA-16 series foil. This symmetric foil was deemed closest to the ideal hydrodynamic shape with respect to the total form drag of the hull, a critical performance parameter. Figure 8(a) and (b) compare the ideal form and a NACA-16 foil respectively (Burcher & Rydill 1995, AirfoilTools 2013). To accommodate the pilots knees, and to minimise surface area, the chord height of the hull profile is different in the top and side views (Figure 8(c)). The 2013 hull design also represents a significant volume reduction in an attempt to reduce the submarine's drag. A comparison to *Minerva* is provided in Figure 9.

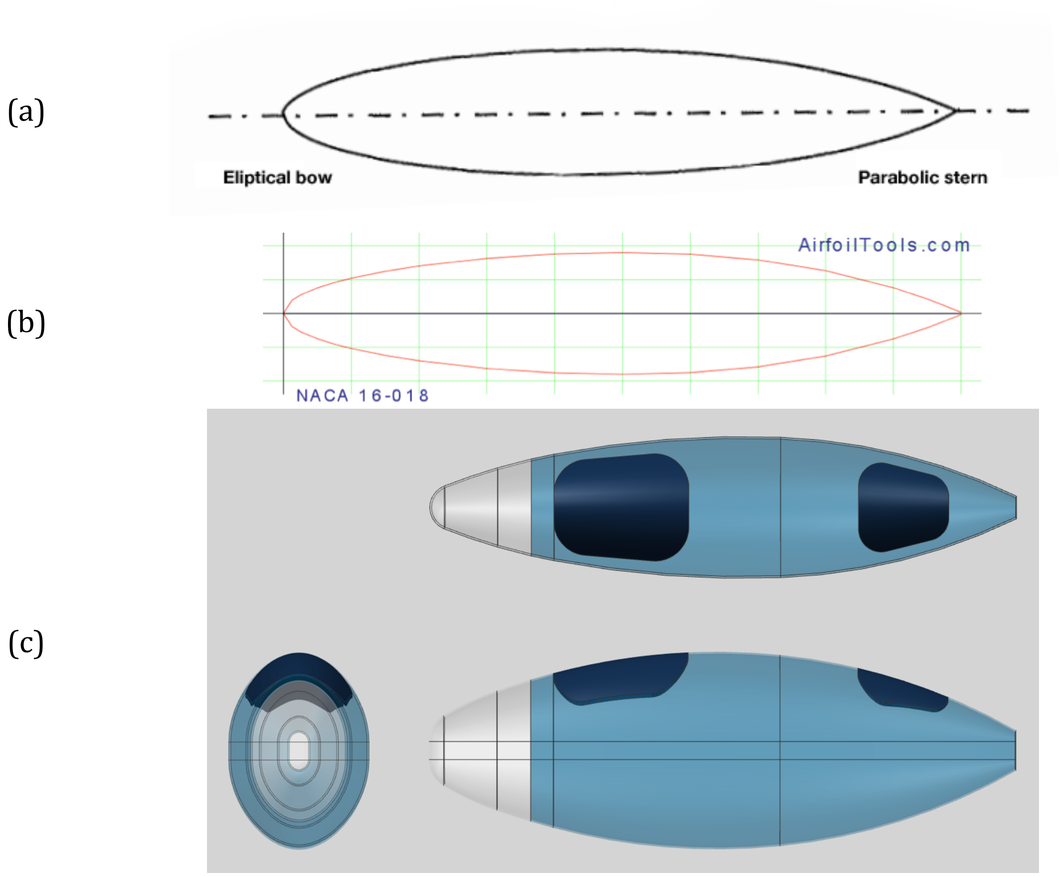

Figure 8. Comparison of (a) the ideal hydrodynamic form, (b) a NACA-16 series foil and (c) the hull shape.

Figure 9. Comparison of new hull design to *Minerva*. 612b

6.1.2 Manufacturing

Previous BURST teams have identified difficulties in manufacturing the hull's shape accurately and neatly, which in turn affected the vehicle's drag and thus top speed. The 2013 design aimed to tackle this by investing time, effort and money into the initial pattern designs and quality materials.

Fixtures: plug and mould

BURST adopted a three stage process to manufacture their Glass-Fibre Reinforced Plastic (GFRP) hull. Emphasis was placed on the initial forms and their surface finishes in order to create the best possible shape on the final manufacture and decrease the hull's drag. The process is described below and shown in Figure 10(a)–(c). The hull's symmetry allowed manufacture in two hemispheres and reduced the number of plugs and moulds required.

Male plug → Female mould → Final hull composite

(a) (b) (c)

Figure 10. The manufacturing process for the hull showing the (a) finished plug, (b) female mould and (c) manufacturing a half-hull.

Composite layup

The hull composite adopted a sandwich structure in order to increase its rigidity. The core material of this sandwich structure doubled as buoyancy material due to its low density, and reduces the volume of buoyant material required within the hull, saving space for other components. The materials and GFRP stacking sequence are described in Table 2. Figure 11 shows the vacuum bagging method adopted.

Table 2. Materials and manufacturing methods for the hull's GFRP composite structure.

Component	Description	Manufacturing
Glass Fibre	300g E-Glass	Stacking sequence: [0/90/-45/+45]s
Resin	Epoxy SR5550	Resin is infused during wet layup.
Core	5mm 3D-Core PET	Vacuum bagged to increase resin infusion through core structure and improve the composite shape.

Figure 11. Vacuum bagging the wet layup hull.

6.1.3 Buoyancy & trim

The extremely lightweight hull, buoyant sandwhich composite and redesigned transmission and control systems all contribute to a reduction in the total buoyancy required compared to previous BURST submarines. Figure 12 shows the 2012 theoretical design project's buoyancy locations (Hewson 2012). As the 2013 design is very similar in shape and size, this concept will be adapted to the new design once the detailed designs are complete.

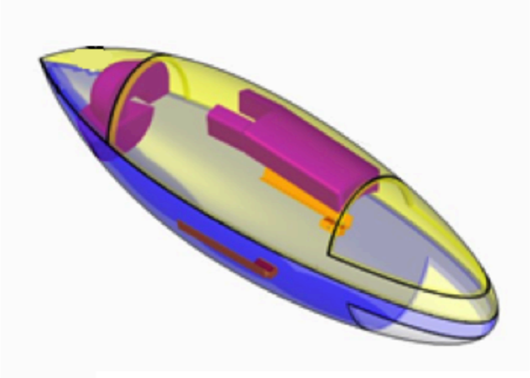

Figure 12. Buoyancy locations based on a 2012 theoretical design.

6.1.4 Materials

The GFRP adopts a quadraxial layup designed to provide optimal hull stiffness in both direct loading and torsion. The skin stiffness is 12.1GPa in the 0° and ±45° loading directions. The addition of a sandwich structure significantly strengthens the composite with minimal weight increase. This particular design, where the core is x4 the GFRP thickness, increases panel stiffness to approximately 450GPa (Petras & Achillies, 1998).

Due to the complex curvature of the hull a special core material, a honeycomb shaped thermoplastic (PET), was used and allowed maximum flexibility of the core during manufacturing as shown in Figure 13.

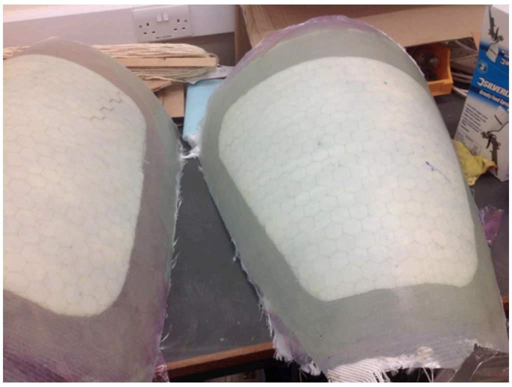

Figure 13. Honeycomb core conforms to complex curvatures in the hull.

This core structure also allows resin fusion between the two skin-layers, and results in further increased stiffness and strength compared to standard sandwich panels. Binding the two skin layers together like this will also help prevent one of the most common composite delamination mode, "skin-wrinkling", reducing the chance of water ingress in the sandwich structure.

As mentioned previously, the sandwich core provides buoyancy for the submarine. Due to the sandwich core the hull will provide approximately 11kg of buoyancy as shown in Table 3.

Table 3. Buoyancy contributions from the hull sandwich core.

Material	Density (kg/m^3)	Volume (m^3)	Weight (kg)	Bouyancy (kg)
Glass fibre	2700	0.0041	11.1	-7
Epoxy	1200	0.0032	3.8	-0.64
3D-core (PET)	200	0.0235	4.7	18.8
			Total	11.2

The combination of the materials above will ensure a stiff, lightweight composite with good mouldability, and will generate a positively buoyant hull structure.

6.1.5 Chassis

The critical subsystems that determine the submarine's performance are the transmission system, control system and hull shape. As a result the chassis is only indirectly linked to overall performance. It has been designed secondary to these subsystems. As a result, a simple design has been adopted and will be accommodated to other components once they are completed. The chassis will use 2x1in Aluminium rectangle section and will connect the gearbox to rear propeller bearings and hull mounting points.

6.2 Propulsion system

The previously mentioned pair of single-axis contra-rotating propellers from *Minerva* have been reused in the 2013 design (Vickers 2012). The original rationale for this design was to produce a propulsion system that keeps the submarine stable in roll. Figure 14 shows the assembled propellers on *Minerva*.

Figure 14. Single-axis contra-rotating propellers for the 2013 design (pictured on *Minerva*).

In addition to roll stability, contra-rotating propellers in theory provide an efficiency increase due to energy recovery from the first propeller's radial wake. The interactions of the blades are time dependent as the rotational location of the blades relative to each another is constantly changing. Only computational fluid dynamic methods account for this time dependence; other methods estimate time averaged axial and tangential velocity components, plus radial components to account for propeller wake contraction. Two sets of contra-rotating blades were designed using different methods. They are described below.

6.2.1 Propeller design: Larrabee and Openprop

The first set of blades were designed using the numerical method developed by Larrabee (Boor 2013). It included extension to off-design analysis and an estimate of propeller induced hull drag by means of a 'radially graded momentum theory'. The contra-rotating propellers were investigated and the Larrabee method extended using basic engineering principles (Table 4). The second method was computational, using 'Openprop' software, which allowed some method comparison and two designs to be produced.

Table 4. Parameters for theoretical contra-rotating propeller design.

Parameter	First set	Second set	Units
No. of blades	2	2	
EAR	0.079	0.071	
Diameter	0.55	0.495	m
Mean P/D	1.62	1.09	
ω	250	250	Rpm
Design C_L	0.40	0.62	
Design L/D	13.33	10.83	

The thrust and effective velocity were provided as constraints for the design. After considerations into human performance (input power 300W) and hull drag estimated to be 400N the power produced by the propellers was calculated to be in the region of 240N at 5 knots, with a desired speed of 250rpm. Figure 15 shows the CAD propeller alongside the manufactured blade.

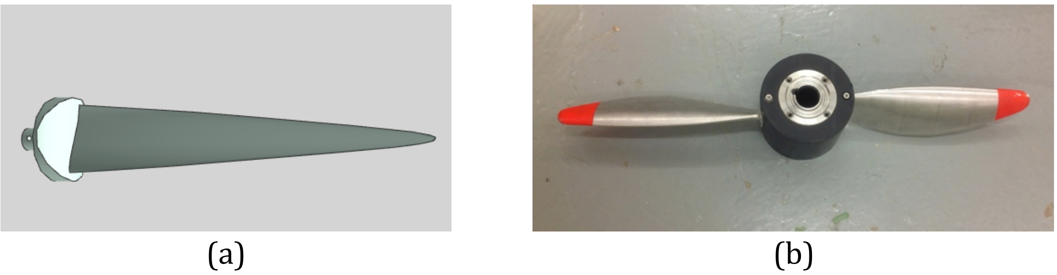

Figure 15. Comparison of (a) final propeller CAD and (b) manufactured blade.

6.2.2 Transmission

Previous academic studies have found that a comfortable cadence for human-powered submarine pilots is between 30-40rpm, reaching 50rpm with significant effort. The transmission system therefore requires a ratio of approximately 1:5 or more.

Keeping with the philosophy of simplicity, a two stage steel bevel gearbox was adopted, providing a 1:4 ratio (Figure 16). Whilst this is not the desired ratio, the time investment required to achieve a 1:5 design within the volume constraints of the hull (width no greater than 140mm) were too great. The performance sacrifice (200rpm instead of 250rpm) was deemed acceptable given the time constraints of the project.

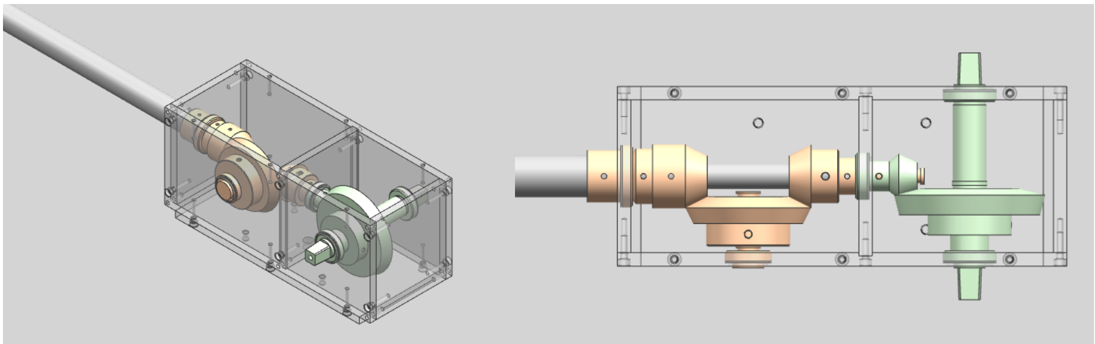

Figure 16. Bevel gearbox transmission showing two stages with a 1:4 ratio, and contra-rotating drive splitter..

6.3 Control system

The control system of the submarine has one job to do: to keep the submarine travelling straight and level to allow the shortest time through the timing gates, and thus a maximum speed. The control system for the 2013 build consists of 4 actuated control surfaces at the rear of the vessel, and a single, fixed vertical stabilising fin close to mid-ship.

6.3.1 Control surfaces schematic

The actuated surfaces are controlled manually by the pilot using a dual-axis joystick with push/pull cables. Figure 17 illustrates the system schematic.

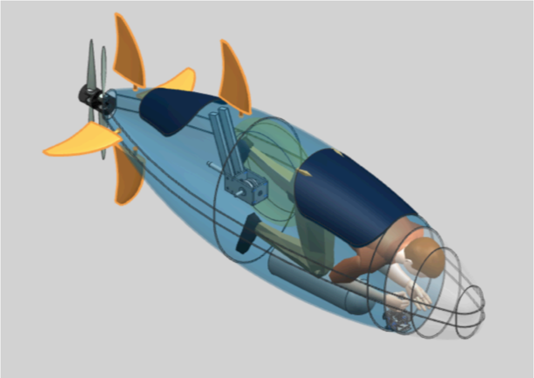

Figure 17. Control surface (orange) schematic for the 2013 design.

The control surface layout is taken directly from *Minerva* as this had proven successful in the past. A senior year specialist design project identified the joystick and cockpit as areas for improvement in the 2013 boat and developed them as a result.

6.3.2 Joystick design

The new design aimed to combine the yaw and pitch control of the submarine onto a single joystick. An exploration of existing gimbal mechanisms yielded a range of prototypes, developed sequentially and pictured in Figure 18 (Goode 2013). These resulted in a proof-of-principle test rig (Figure 19) to verify the design and inform the development for manufacturing.

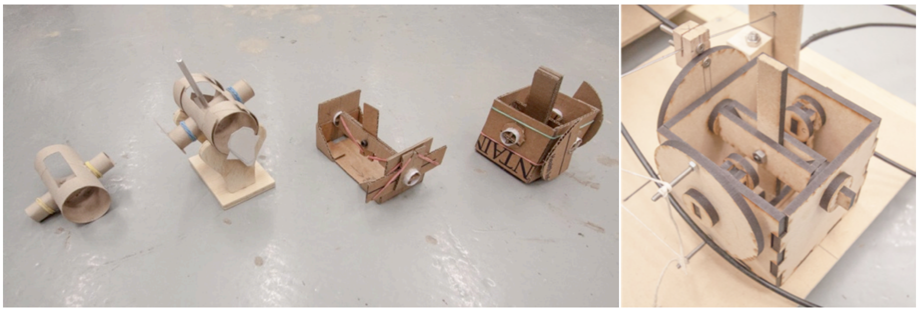

Figure 18. Prototype development for a dual-axis mechanical joystick.

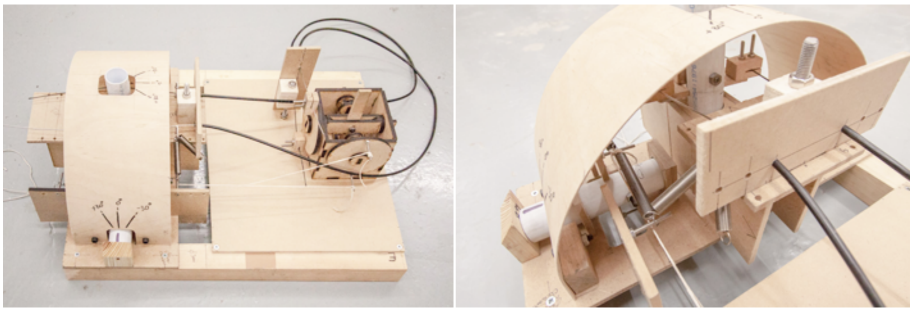

Figure 19. Joystick proof-of-principle test rig.

From conducting user tests with the prototype, the design was deemed acceptable with further development required as follows. Figure 20 shows the final design development at present.

- Volume reduction of the entire mechanism to fit within the cockpit
- Angled mounting to allow for pilot's hand/wrist orientation
- Redesign to allow manufacturing from Aluminium

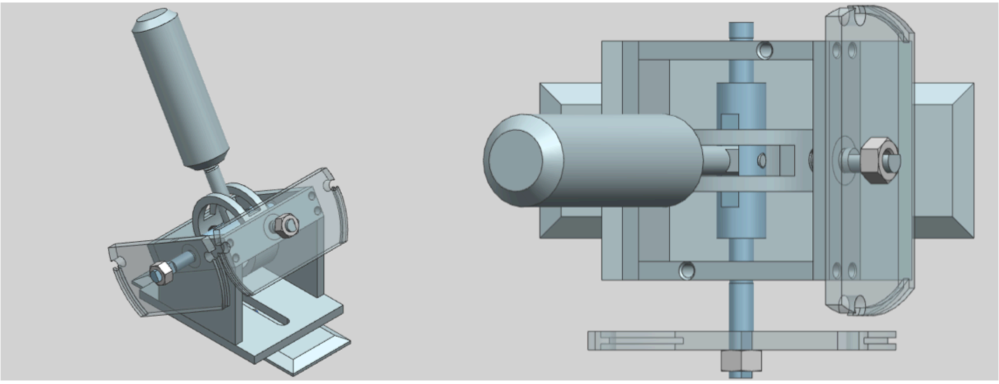

Figure 20. Final design development for the dual-axis mechanical joystick.

6.3.3 Cockpit layout

As the volume reduction in the new design was significant, a test-rig for the cockpit was produced and used in tests to determine that the hull size is adequate for a human and ascertain desired equipment locations within the cockpit. Figure 21 shows the cockpit test rig, and Figure 22 the desired equipment locations.

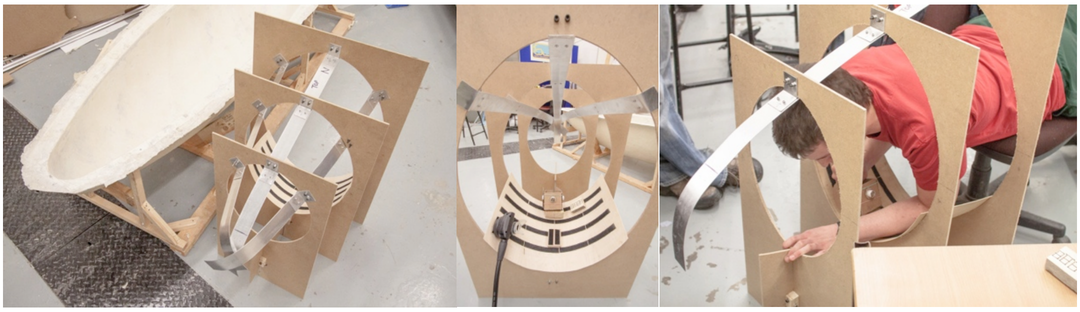

Figure 21. Cockpit test-rig design.

Figure 22. Cockpit equipment layout.

6.4 Life support and safety systems

This system includes the safety buoy & dead-man switch, strobe light and the pilot's scuba air supply. Again, BURTS have adopted very similar designs to previous years and minor adjustments explained below.

6.4.1 Safety Buoy

The key aspect of the safety buoy mechanism is the dead-man release mechanism. A bicycle brake type handle was chosen for a number of reasons:

- **Simple for the pilot to operate**: they simply grip the handle during the race, and release in the event of an emergency. Bike brake handles are also ergonomically designed.
- **Ease of manufacture**: Bike brake handles can be bought cheaply off the shelf, and are easy to maintain.
- **Past experience**: This type of handle has been used successfully by BURST in the past.
- **Ease of installation**: Bike cables can be flexibly routed to almost anywhere on the submarine, providing a reliable mechanical link.

The brake handle will be mounted on the control joystick, combining directional control with depressing the dead-man switch, thus reducing task loading on the pilot and allowing one hand to remain free to operate scuba equipment.

The buoy itself will be constructed from lightweight foam for buoyancy, to carry the buoy to the surface when released. The buoy will also have a chamfered fibreglass top to give a flush finish with the hull, minimising surface drag.

Figure 23 illustrates the safety buoy release mechanism. The buoy will be held in place by a small pin, held in compression against a spring by the bike cable attached to the handle. When the handle is release, the spring will pull the pin back, releasing the buoy. The buoy will also be held against a spring, which will propel the buoy away from the hull if the submarine is rolling, and help to overcome friction.

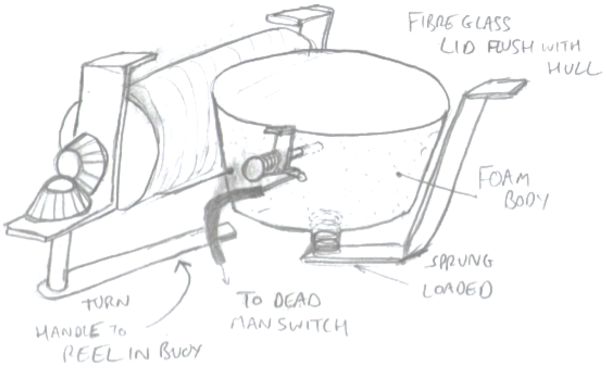

Figure 23. Sketch of the safety buoy release mechanism.

Drawing on previous experience

There have been two main faults with previous BURST designs for the buoy, both of which relate to the connection cord being wrapped around the buoy. The first problem is that at times the buoy would fail to release due to friction, as often the untidy winding would jam against the side of the housing. The second problem was that winding the cord back up was very difficult, and wasted valuable time in the water.

This year's solution, as shown above, winds the cord around a separate reel, which will give a tidier winding and therefore easier release. The reel will also have a handle to quickly wind in the cord.

6.4.2 Strobe light

Previous BURST teams have used a commercially available diver strobe light, mounted through the hull. The bulb protruded above the hull, inducing drag. In addition, the unit was relatively large. This year space and drag are to be minimised, so a new strobe was designed. The new strobe light will be built from scratch using super-bright LEDs. In order for the strobe to flash at a rate of 1Hz, a simple resistor-capacitor pair will be used to charge the circuit at a set time constant. The capacitor will then discharge through a transistor, causing the LED to flash. These components will be permanently encased in potting compound and powered by a 9V battery, which will be accessible for replacement.

The strobe will be mounted at the top of the hull for 360° viewing. It was found in previous years that the dorsal fin did not impede the view of the strobe from behind.

6.4.3 Primary Air Supply

The primary air tank will be positioned beneath the pilot's chest to maximise space. This location is also very easily accessible for removing the tank, and convenient for the pilot's regulators. Figure 24 illustrates the air tank location in the submarine.

Previous BURST teams observed that one full racing run used 20bar from a 12L tank. With a 232bar capacity, this means that the tank is more than adequate and far exceeds the 150% reserve as per race rules. If 70bar is deemed the minimum safe air pressure (an 'up at 70' rule), the minimum required pressure to perform one racing run with 150% reserve is 120bar. This means that if the air pressure in the submarine tank is less than 120bar the tank must be recharged before undertaking a racing run.

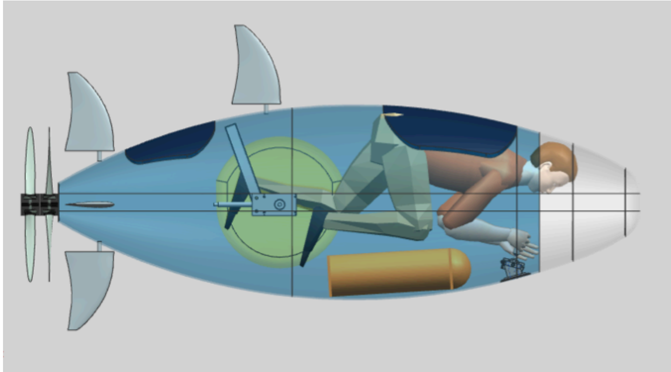

Figure 24. Air tank (orange) location within hull.

7 Testing

As mentioned previously, the 2013 design has relied heavily on past experience and design projects. This places greater importance on wet tests to verify that the designs function as intended and identify modifications that are necessary. Planned testing will include a minimum of three wet tests, more will be performed depending on time constraints. The tests will also include practice with BURSTs old submarine *Minerva* so the team can familiarise themselves with underwater operations, in particular loading/unloading pilots and race starting sequences. The tests will include:

1. Empty hull wet test to ascertain buoyancy of hull material and verify sea-worthiness of composite hull
2. First buoyancy & trim test with all internal components in the submarine
3. Final buoyancy & trim test with final adjusted buoyancy and ballast.

8 Further work

In order to compete in future ISRs (not including the eISR in 2014) a new submarine must be designed and built. The lessons learnt in this project will be important in achieving this, hence students from junior years at the University of Bath have been encouraged to take part in the design and manufacturing process as well as the administrative tasks required by the ISR.

Future technological improvements to the submarine include furthering the work done on pilot load reduction. This includes the development of ergonomic control interfaces and automation of the guidance system. The former is important to develop since the guidance system is still immature and will need a number of years of development before it may be deployed onto the submarine. The delay is due to the limited time allotted to the submarine project as part of the University curriculum and also the lack of experience with control systems which has historically plagued BURST.

9 Conclusions

The technical design of the 2013 submarine has been completed, however many changes will occur between this report and ISR#12 due to manufacturing alterations, availability of components and most importantly time constraints. In light of this, the following design specification (Table 5) is provided as a best estimate of parameters of the 2013 submarine. BURST are extremely excited to have completed the design and begin manufacturing, and look forward to delivering a successful craft for ISR#12.

9.1 Design specification

Table 5. Design specification for the 2013 technical design.

Parameter	Value	Unit	Comment
Overall dimensions			
Overall length	3.0	m	overall inc. fins and props
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
Stabiliser fins	1		Top mid-ship
Hatches	3		Top: Fore & aft, Bottom: aft
Window	1		Perspex, front 400mm
Superstructure			
Hull length	0.7	m	
Hull width	0.6	m	
Hull height	0.8	m	
Hull mounts	6		Top & bottom: fore, mid & aft
Chassis			Aluminium box section construction
Propulsion system			
Propeller speed	200	rpm	
Transmission ratio	1:4		
Drive input			175mm standard bicycle cranks
Drive output			x2 counter-rotating shafts
Bevel gears	4		
Control system			
Dive planes	2		aft
Rudders	2		aft
Control input			Dual-axis manual joystick
Transmission			Bicycle gear cables
Maximum pitch	±30	Deg	Stall angle ±18°
Safety & lift support			
Air supply	12	Litres	232bar SCUBA
Safety buoy			Cork construction, top mid-ship
Dead-man switch			Bicycle brake lever

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