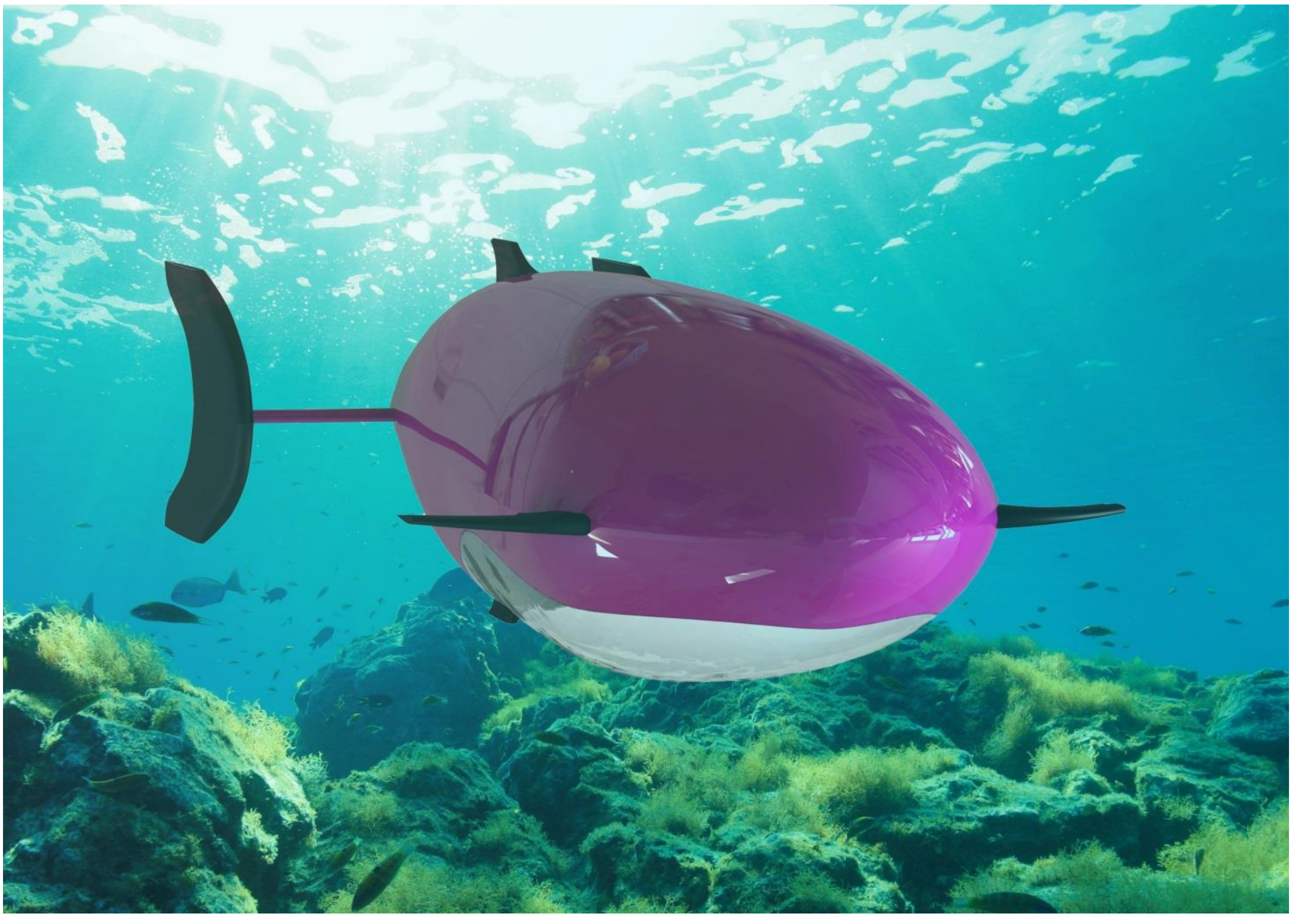
Argo

Human Powered Submarine



Team Argo
Date 6-18-2015

Initiated by: The Innovation Studio

Students from: Inholland University of Applied Sciences Delft, the Netherlands

Argo

Human Powered Submarine

Abstract

This report is about the human-powered submarine that is based on principles of biomimicry called Argo. Argo is a pink, 3 meter long, full carbon fiber submarine assembled with 3D printed parts.

Safety and sustainability are important factors during this project, that resulted as well in the product as in the process, the process of designing and collaboration with different exciting domains was time well spend!

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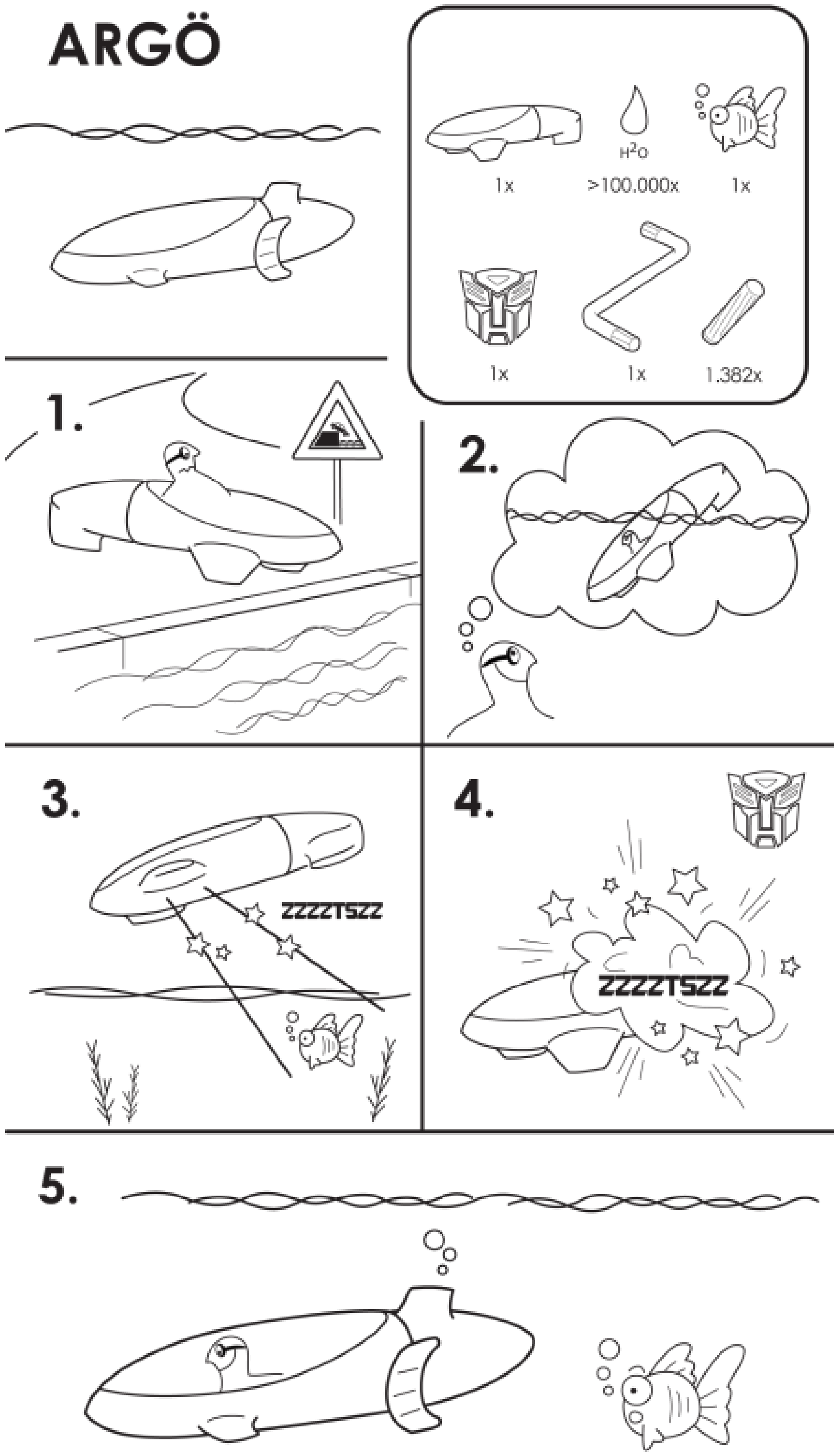
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1. Introduction

The International Submarine Races (ISR) are held since 1989 and is held every other year in the United States of America. During the race several academic institutions from various countries will race against each other with their personal built submarine. All submarines are human-propelled, thus the use of engines is not allowed. The goal for the ISR is to stimulate development in the nautical field of engineering. There are different categories in which a submarine can compete. These are one or two person submarines and propeller or non-propeller driven submarines. Also several awards are given to stimulate for example; innovation, spirit and the use of composites.

The Innovation Studio is a section of Inholland University of Applied Sciences, where students can develop and use their learned skills in engineering. The first project by the Innovation Studio was the Anemo, a wind powered vehicle which was first developed in 2008. After that the Anemo was improved and other new projects were done by the Innovation Studio. These are the Apollo, a high mileage vehicle; the Aquilo, a rocket made out of composites and since this year project Argo. The Argo is a new project in the Innovation studio. Until this year the TU Delft, with WASUB, was the only Dutch contestant to compete with the International Submarine Races. This year the Innovation Studio will compete with their own submarine in the ISR, named Argo.

The base of the project in the university is the collaboration between complementing domain. The two domains are Engineering and Agriculture, Food and Life Sciences. The Argo is based on a dolphin, where the two disciplines worked extensively togheter.

This submarine will compete in the category of a one person, non-propeller driven submarine. It means that one person will propel the submarine in a manner which is different than a propeller, which is generally used on boats and submarines. The submarine is made from scratch, and is completely developed by students. This consist of the design, calculations and eventually the entire construction of the submarine.

The goal of Argo I is to compete with a working man-driven submarine and to finish the race, the submarine must be designed by the sustainable engineering philosophy with a multi disciplinary team based on the principles of biomimicry.

The overall mission of the Innovation Studio is to facilitate students with challenging sustainable engineering projects to form the student with excellent skills, knowledge and personal competences

In Chapter 2 the requirements are listed, in Chapter 3 the fish propulsion is being discussed, Chapter 4 contains manufacturing stage of the submarine, Chapter 5 the propulsion system, Chapter 6 the safety requirements of the submarine and final chapter 7 an overall impression of the whole project in pictures.

2. List of requirements

The Argo has to fulfill several requirements to be able to compete in the ISR of 2015. For this several requirements have to be met. These two important parties have set their requirements, which are listed below. In the conclusion of this report the list of requirement are checked.

International submarine races:

For submarine:

1. High visibility colors
2. Emergency exits have 4 inch square orange patch with the word “Rescue” on it
3. Emergency exits have easy accessibility from in and outside
4. If there is a method of attachment, a clear visible release system should be visible
5. Face and head should be visible from the outside
6. Strobe(s) which is/are 360 degrees visible in horizontal and vertical plane
7. Strobe(s) should be approved by the USCG or SOLAS
8. Emergency buoy in sub
9. Dead man switch: when buoy is released all propulsion stops
10. Max width: 2.13 meter
11. Freely drain water
12. Launch cradle for movement of the submarine on land and into water
13. Possible a negative buoyant for sinking
14. Possible underwater communication
15. Can use wax on hulls and fins
16. Brake not necessary

For driver:

17. NAUI, PADI, YMCA or other license
18. Min age is 15 years
19. Own diving equipment
20. Scuba exhaust air can be trapped in sub. Better if it exits the sub.
21. Secondary air supply in the submarine
22. Air supply minimal: 1 speed run + 150% reserve for all diving crew (with provided calculations)
23. Clear pressure gauges during run. Pressure may not be lower than 500 psi

Innovation Studio:

For submarine:

24. Innovative design
25. Use of biomimicry
26. Completely made by students
27. Completely made by Innovation Studio
28. Design by students
29. Manufacturing by students
30. Testing by students

3. Biomimicry, the “new” sustainable engineering

Biomimicry is the art of nature, Argo is based on fishmovement, in this chapter, an overview is given about the way fish move. There are multiple ways of locomotion. First, the different types of fins are discussed. Then the different ways of locomotion are further discussed. After that, differences between fish are discussed. Finally, a choice is made for the type of locomotion and the type of fish that is going to be used.

Different fins

Fish have five different types of fins (Fig. 1). The first type is the dorsal fin (Simoens, 2009). Dependent on the type of fish, there are one, two or three dorsal fins. The second type is de caudal fin (tail). The third type is the pectoral fin. There are two pectoral fins, one on each side of the fish. The fourth type is the pelvic fin. There are also two pelvic fins. The fifth type is the anal fin. Some fish don’t have an anal fin, some have one or two.

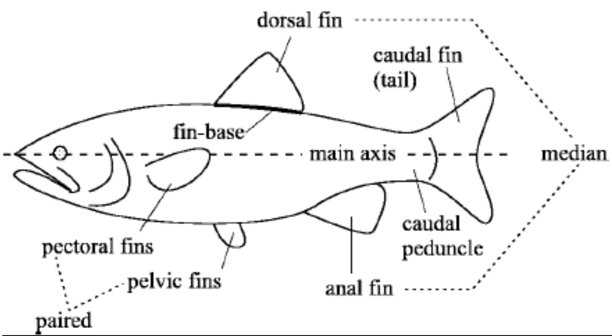


Figure 1: Terminology used in the text to identify the fins and other features of fish (Sfakiotakis, Lane, & Davies, 1999).

Fish swim by moving with their body and caudal fin, or with their pectoral fins (Sfakiotakis, Lane, & Davies, 1999). The pectoral fins are used when they swim slowly. These pectoral fins offer greater manoeuvrability, while the body and the caudal fin generate a lot of power and acceleration. Fig. 1 shows the terminology used to name the different fins of the fish.

Two modes of swimming

Because fish have a high density, every movement fish make, will set the surrounding water in motion (Sfakiotakis, Lane, & Davies, 1999). This works also vice versa. The density of water is almost the same as that of marine animals. The weight of the fish doesn’t have to be supported. The forces who are working on a swimming fish are weight, buoyancy and hydrodynamic lift in the vertical direction. Swimming locomotion can be classified into two types:

- Steady swimming – the same movements are repeated over and over. This type of swimming locomotion is used to cover longer distances and at a constant speed;
- Unsteady movements – movements that include quick starts and turns. These movements are used for a very short period of time and are meant to catch a prey or to escape from predators.

Most fish generate propulsion by bending their body (Sfakiotakis, Lane, & Davies, 1999). This causes a wave to form till the caudal fin. This type of swimming is classified under body and caudal fin (BCF) locomotion. Some fish use their pectoral fins. This is called median and paired fin (MPF) locomotion. A further division of types of movement can be made:

- Undulatory motion – formation of a wave along the propulsive structure;

- Oscillatory motion – no wave formation.

Fish use several modes of locomotion for accelerating, cruising and manoeuvring (Fig. 2). When BCF locomotion is used, this can lead to accelerating or cruising. When MPF locomotion is used, this can lead to cruising or manoeuvring. Depending on the using of undulatory or oscillatory motion, BCF or MPF locomotion is used.

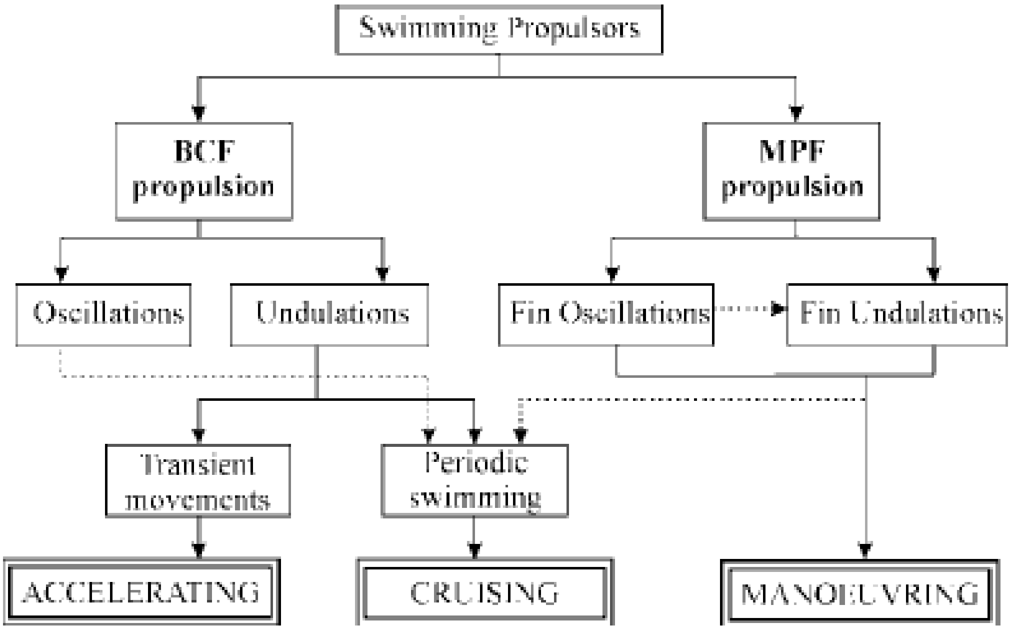


Figure 2: Diagram showing the relation between swimming propulsors and swimming functions (Sfakiotakis, Lane, & Davies, 1999).

Modes of propulsion by BCF locomotion

There are five modes of propulsion by the body or tail of the fish (Beamish, et al., 1978). All modes of propulsion are summarized in Table 1. The first form is the anguilliform mode. In this type of locomotion, all of the length of the body participates. The side-to-side amplitude of the wave is large along the whole body. An example of a fish who uses this type of locomotion is an *eel*. It has a long and thin body, this is also a characteristic of fish who swim in anguilliform mode. The caudal fin is small or absent. The young of most fishes swim in anguilliform mode. When they grow older, their type of locomotion can change. Fish with long, flexible bodies swim like this when they are adults. Fish who swim in anguilliform mode, can't swim fast. Most fish who swim like this, live close to the bottom.

The second mode of propulsion is the subcaragniform mode (Beamish, et al., 1978). The body movements made by this type of propulsion are the same as those in anguilliform mode. Compared to fish who use anguilliform propulsion, the body is heavier and anterior more rounded. The caudal fin is flexible. An example of a fish who uses this type of locomotion is a *cod*.

The third mode of propulsion is the caragniform mode (Beamish, et al., 1978). In fish who use this type of locomotion, only the posterior part of the body is capable of wide flexure. The formation of a wave (undulations) is limited to the last third of the body length. The impulse is delivered from the stiff tail. Fish who use caragniform swimming are faster than fish who use anguilliform swimming. Recoil movements are reduced by concentrating the mass and the body depth toward the anterior. Stiff median fins help resist sideways movement of the body. An example of a fish who uses this mode of propulsion is the *mormyridae*. This fish has paired longitudinal bones which provide rigidity to the caudal part of the body. The caudal fin is also stiff, to permit little dorsoventrale bending. A disadvantage of the caragniform mode is that fish who use this mode of propulsion can't turn and accelerate fast, because they have a rigid body (Sfakiotakis, Lane, & Davies, 1999).

The fourth mode of propulsion is the thunniform mode. This is the most efficient way of propulsion (Sfakiotakis, Lane, & Davies, 1999). Propulsion is generated by the lift-based method. By this method, lifting forces are generated. Because of this lifting forces, high speeds can be maintained for longer periods of time. Fish who use this mode of propulsion have a high stiff caudal fin who generates the thrust (Beamish, et al., 1978). The body is streamlined and is heavy toward the anterior. An example of a fish who uses this mode of propulsion is the *tuna.* This fish is the fastest of all fish. Some sharks swim in thunniform mode. They have a high stiff dorsal fin, who reduces recoil. Near the front, the body is heavy and streamlined. Just as the tuna, the *Lamna* and *Isurus* sharks are all heavier than water. The whale shark *Rhineodon* has a body shape that looks a lot like that of the thunniform swimmers. Some sharks use the thunniform mode for locomotion, but most sharks have a highly flexible body and use anguilliform or subcaragniform mode.

The last mode of propulsion is the ostraciiform mode (Sfakiotakis, Lane, & Davies, 1999). Fish who swim like this, can't bend their body laterally. They only use their tail to move. They do this by rotating their tail. The caudal fin is flexible. The body is poorly streamlined. Compared with caragniform or thunniform swimmers, fish who use ostraciiform mode are very slow. This mode of swimming is not described in any living fish.

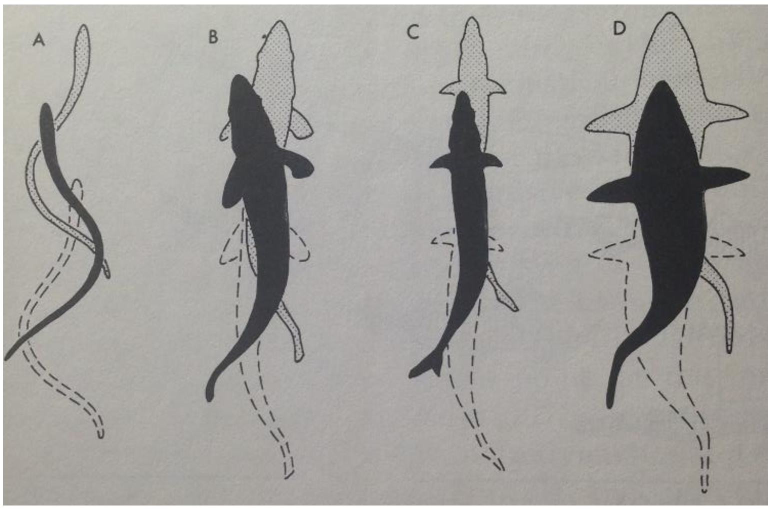


Figure 3: Gradation of swimming modes from (A) anguilliform, (B) subcaragniform, (C) caragniform to (D) thunniform (Beamish, et al., 1978).

Table 1: Summary of modes of BCF locomotion.

	Mode	Image	Properties	Advantages	Disadvantages
1	Anguilliform	See Fig. 3 A	Whole body length participates Wave-like propulsion	Flexible body	Not a fast way of locomotion
2	Subcaragniform	See Fig. 3 B	Whole body length participates Wave-like propulsion	Flexible body	Not a fast way of locomotion
3	Caragniform	See Fig. 3 C	Undulations are limited to the last third of the body length	Faster than anguilliform and subcaragniform mode	No fast turning and acceleration
4	Thunniform	See Fig. 3 D	Streamlined and stiff body	Fast way of locomotion Streamlined body	Stiff body No fast turning and acceleration
5	Ostraciiform		No lateral body movement Tail rotation	Flexible caudal fin	No lateral body movement Not a fast way of locomotion

Selected mode of propulsion

The mode of propulsion that is chosen, is a combination between the caragniform and thunniform mode. These modes of propulsion are chosen, because they are both a fast way of locomotion (Beamish, et al., 1978). Because of lifting forces, high speeds can be maintained for a longer period of time. The high stiff caudal fin is used to generate the thrust. The body of fish who use caragniform or thunniform locomotion is streamlined, which is a characteristic that is reflected in the *Argo*.

There are several fish who use caragniform locomotion. Examples of fish who use caragniform locomotion are some scombroidei fish. Examples of scombroidei fish are tunas and mackerels. Scombroid fish swim quickly and continuously. Species of this family of fishes don't all have the same speed of sustained swimming. What they do have in common, is a streamlined body. The body is stiff and the caudal tail is used for generating the thrust. The caudal fin generates a lot of power and acceleration. The pectoral fins are used for manoeuvrability. Whales, dolphins and some sharks use thunniform locomotion (Beamish, et al., 1978).

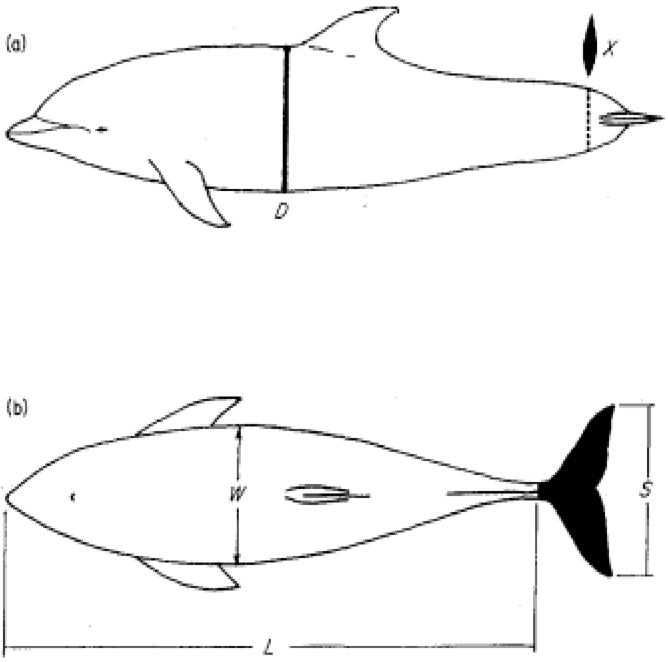
Differences between fish

A combination is made between several fish. The mackerel has a body shape that looks like the *Argo*. A chub mackerel, *Scomber japonicus*, has a length from 20 to 26 centimetres (Nauen & Lauder, 2001). A study shows that the kawakawa tuna uses thunniform locomotion, while the chub mackerel uses caragniform locomotion (Donley & Dickson, 2000). There are two criteria used to determine if thunniform or caragniform locomotion is used. This is based on the length of the propulsive wave during steady swimming and on the portion of the body that undergoes lateral undulatory movements.

Tuna

Tunas use thunniform locomotion and this is considered to be the most efficient way of locomotion (Donley & Dickson, 2000). Because of the streamlined body, frictional drag is minimized (Fig. 5). The body has the shape of a tear-drop. Rotation around intervertebral joints in tunas is limited (Dewar & Graham, 1994). The caudal peduncle is rigid, only the pre- and post-peduncular joints can bend. Most lateral motion takes place over the caudal region of the tuna. The high stiff caudal fin generates the thrust and therefore it oscillates fast. (Beamish, et al., 1978). This is also to generate lift-based propulsion. Compared to the mackerel, who is discussed in the next paragraph, tunas have to beat their caudal tail at a high frequency to maintain the same speed. However, tunas use lower caudal tail beat amplitudes. They also move a smaller distance per caudal tail beat than mackerels.

Figure 6: Side view and top view of a dolphin (Fish & Clifford, 1994).



Mackerel

The mackerel is characterised as a caragniform swimmer, because of the length of the propulsive wave that moves along the body during steady swimming. In fish who use caragniform locomotion, propulsive wavelengths are rather greater than body length. The body mass is concentrated in the front portion of the body of the fish (Beamish, et al., 1978). Because of distribution of body mass and body profile, the lateral movement of the body or recoil from forces exerted by the caudal fin is reduced.

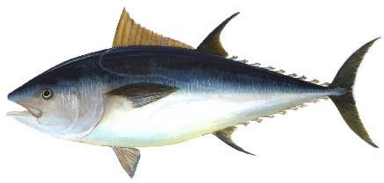


Figure 5: Atlantic Bluefin Tuna Fish (www.wikipedia.org, 2015).

Dolphin

Dolphins and whales have a caudal tail that is flat instead of standing. In the *Argo*, a standing tale is used. However, the features of the dolphin can be adapted to what works the best for the *Argo*. The dolphin has a body that looks a lot like the shape of the *Argo* (Fig. 6). Dolphins have a fusiform, streamlined body (Fish & Clifford, 1994). The thickest part of the body is found at 34-45% of the body length (Zyga, 2006). Because of this, the water can flow with ease from the anterior part of the body to the caudal tail. This minimizes drag. The flippers (pectoral fins), dorsal fin and caudal fin (all together called the appendages) are used for stability, manoeuvrability and the production of thrust. They also reduce drag and generate lift, when needed. Propulsive movements are made with the posterior one-third of the body. The greatest amplitude takes place at the caudal fin. Dolphins are characterized as caragniform swimmers.

The dolphin has mechanisms to reduce drag (Fish & Clifford, 1994). As mentioned before, the fusiform body and the appendages reduce drag. There are more mechanisms who are supposed to reduce drag. These mechanisms are based on modifying the boundary layer. In the first place, the component of the drag force can be minimized by maintaining the boundary layer in a laminar condition. The second mechanism minimizes the pressure component of drag by inducing turbulent conditions in the boundary layer. At the position of the shoulder (34-45% of body length) turbulent flow and boundary-layer separation is probably developed. The skin of the dolphin also reduces drag.

The appendages are streamlined (Fish & Clifford, 1994). The leading edge is rounded and the trailing edge is tapered. The effect of the appendages on total body drag is greater at low speeds than at high speeds. This is because at high speeds the flow is turbulent.

Trade-off

In table 2, a trade-off of the most important features is made. Each weight factor is ranked on a scale from 1 to 5, in which 1 is the least important and 5 is the most important. This means the higher the weight factor, the more important it is. The same goes for the different features. The tuna, mackerel and dolphin are scored on all features. For example, the dolphin scored a 5 on the feature '*streamlined body*'. The weight factor of this feature is 5, so that comes to a total of 25 points. The fish with the highest total score is chosen.

Table 1, Trade-off of the most important features

Feature	**Weight factor**	**Tuna**		**Mackerel**		**Dolphin**	
		Score	**Total**	**Score**	**Total**	**Score**	**Total**
Streamlined body	5	4	20	4	20	5	25
Fast way of locomotion	4	5	20	4	16	5	20
Fast turning and acceleration	2	4	8	2	4	4	8
Stiff median fins	3	2	6	2	6	4	12
Stiff caudal fin	5	4	20	3	15	5	25
Maintaining high speed for longer period	4	4	16	4	16	4	16
Body mass concentrated at the anterior part	3	4	12	4	12	5	15
Total			**102**		**89**		**122**

The fish with the lowest score is the mackerel. The mackerel scores low on the features '*stiff median fins*' and '*stiff caudal fin*'. On the second place comes the tuna. The tuna also scores low on '*stiff median fins*'. At other features, the score of the tuna is comparable to the score of the dolphin. The fish with the highest score is the dolphin. The dolphin scores high on all features. This means that the dolphin is the most suitable fish.

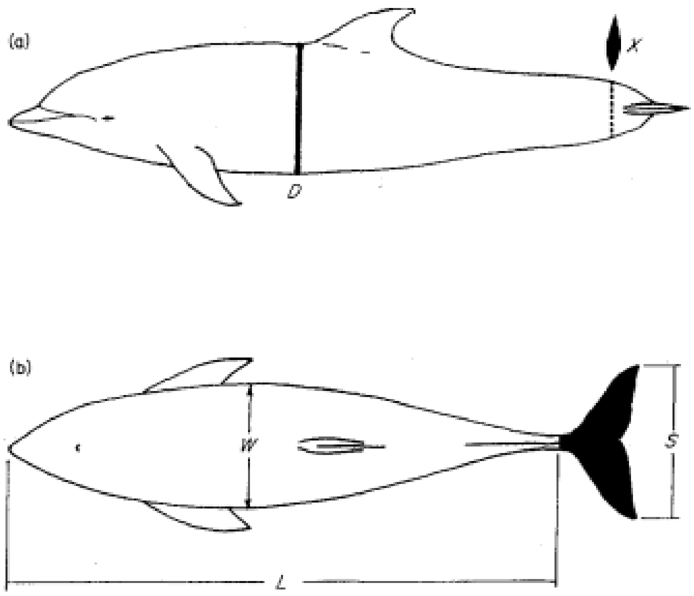
Conclusion

From the trade-off can be concluded that the dolphin is the most suitable fish. Therefore, the dolphin is the fish that is going to be used as an example for the *Argo*. The dolphin has many positive features. The dolphin has a fusiform, streamlined body (Fig. 7). This helps to reduce drag. The body mass is concentrated at the anterior part of the body. The appendages are used for stability and for generating lift when needed. They also help to reduce drag and provide quick turning and acceleration. The caudal fin is stiff, which is important for the *Argo*. These are all features that need to be used in the *Argo*.

There are also points that need to be adapted. These points need to be adapted in order to improve the *Argo*. The first feature that needs to be adapted is the position of the caudal fin. The dolphin has a caudal fin that is flat instead of standing (Fig. 7). In the *Argo*, a standing tale is used. It needs to be examined if it is possible to change the position of the caudal fin from a flat till a standing fin. Another point that needs to be adapted is the position of the flippers and dorsal fin. This should be looked at to determine the best position for the flippers and dorsal fin. It should be examined if the best position for the flippers is either higher or lower along the body. The dorsal fin can be placed more at the anterior or more at the posterior part of the body.

In short, the dolphin is the best fish to use as example for the *Argo*. Some features of the dolphin can be used immediately. Some features need to be adapted before they can be used. After examination they can be adapted and used.

Figure 7: Side view and top view of a dolphin (Fish & Clifford, 1994).



4. Composite production

In this chapter the production phase is discussed.

Hull

The hull is made and designed by the Innovation Studio itself. It is made out of carbon fibers with an epoxy resin. The lay-up which is used is [0/90 +45/-45 cork -45/+45 90/0]. The multiple layers of carbon fibers in different direction give a higher strength. The cork core gives the hull a very high stiffness and buoyancy.

The production of a composite laminate is very difficult. Carbon fiber and epoxy resin are noxious and therefore require careful handling. The raw materials also require careful handling, because all flaws are visible in the end product and reduces the strength and stiffness of the hull. The production of the body is split in two steps. First the upper and lower halves of the body are made, and after that the two shells are connected to each other. This chapter describes the production of the complete hull for Argo.

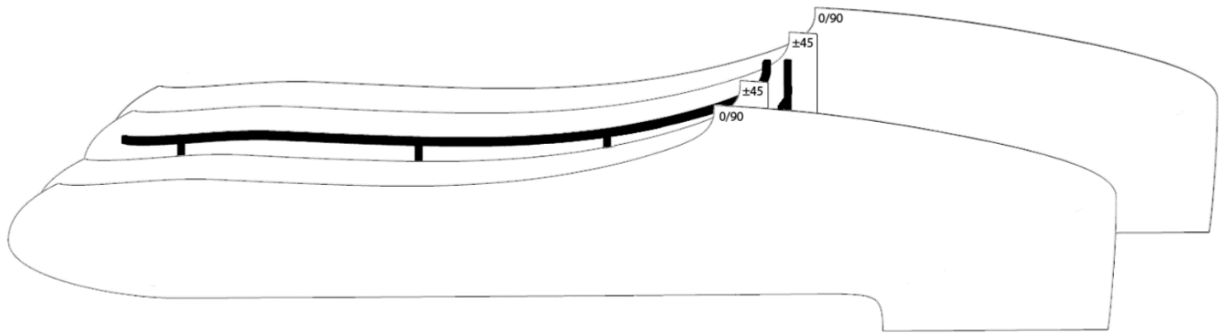


Figure 4.1 The lay-up of the carbon fibers

4.1 Laminate techniques

There are two methods of lamination of a product under vacuum pressure. These are vacuum bag molding and vacuum infusion. Vacuum bag molding is a wet lay-up technique. It is the easiest production method for composite products. The carbon fiber is positioned in the mold, and a resin is rolled or brushed in. This step repeats for all layers. When all plies are saturated, the product is put under vacuum. This sucks all the air and excess resin out of the product. Vacuum infusion uses the vacuum to let the resin flow through the product. This means the lay-up of dry carbon fibers is already put under vacuum before the resin is poured into it.

Vacuum infusion is a more complicated way of lamination, but the Innovation Studio has more experience with this technique, therefore this is the method which is used for Argo.

4.2 Vacuum infusion

Vacuum infusion has a number of advantages over other production methods. A higher fiber-to-resin ratio is obtainable with this technique. Resin rich areas are normally eliminated by the vacuum. Less resin in the product means a higher fiber volume percentage, and this means a lower weight. Therefore a resin with a shorter potlife, the time the resin is usable for lamination before it gets too viscous, can be used. The lamination takes half an hour when using vacuum infusion, compared to the wet lay-up which takes up to two hours, this is very fast. There is also no time pressure when building the lay-up.

4.3 Production preparations

The production starts with the preparation of the molds. The molds are wet sanded with a grain up to 2000. Polishing is therefore not necessary, because this results in a hardly noticeable difference in the end product. Next, the carbon fiber and cork is prepared. Because of the complex shape of the mold several small pieces of carbon fiber are used per layer. The final step in the preparation consists of degreasing the mold surface and applying the mold release wax. This is done to fill micro holes on the surface of the mold. After this step the lay-up can be made.

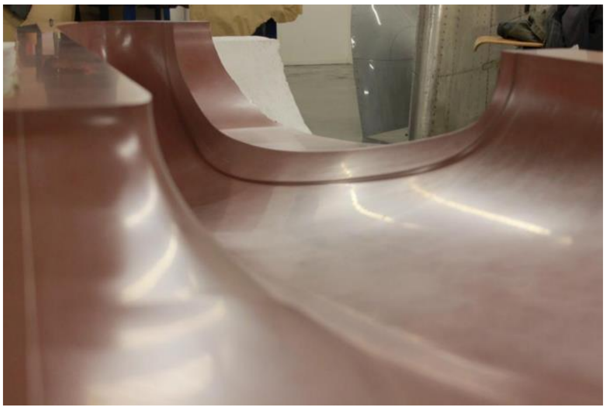


Figure 4.2 The mould after being waxed

4.4 Injection strategy

After the fibers and cork are in place, the laminate is covered with peelply. Peelply is a nylon cloth designed to not bond with resin so that it can be peeled off easily after production. On top of the peelply comes the resin flow mesh. This mesh is designed to aid in the flow of the resin. It is a technique to make sure that the resin gets to the vacuum hose simultaneously. One of the most important decision that has to be made is the positioning of the vacuum and resin hoses. Well placed hoses cause a more equal distribution of the resin. And therefore an end product with a higher quality.

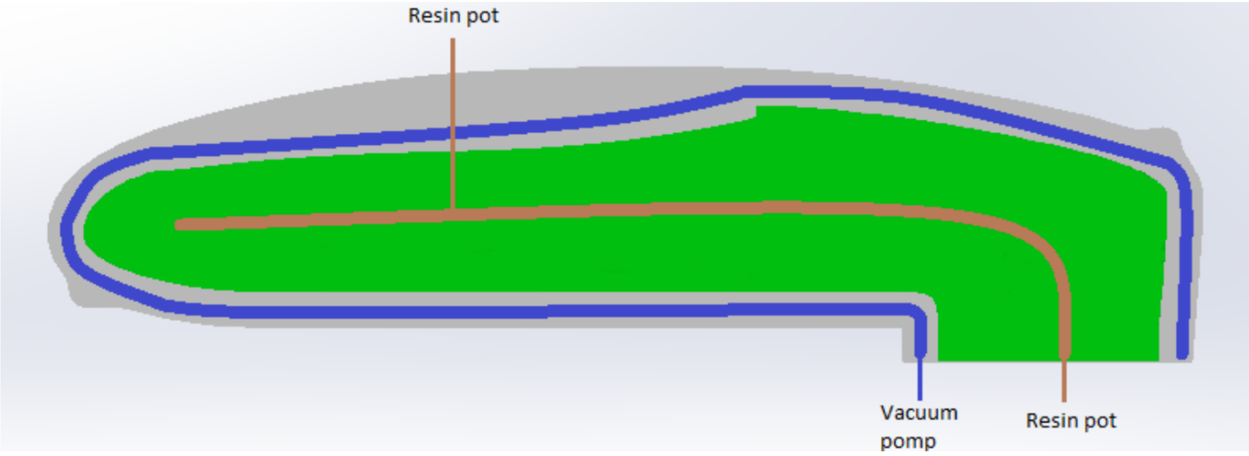


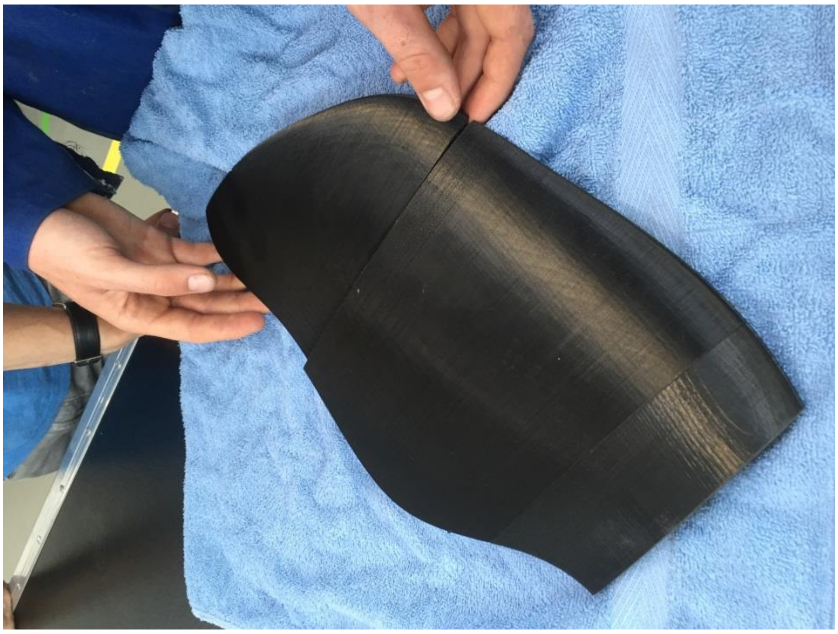
Figure 4.3 The distribution of the hoses in the mold

Apollo to Argo

Due to sustainability resource management the same mould is used used the for the Argo as we did for the Eco-marathon vehicle Apollo. The hydrodynamics characteristics of the submarine proved in a positive result. Shown below the Apollo and the Argo to see the similarities. The Argo is two time the upperhalf of the Apollo to have a symmetric profile in the water.

3D printing with composites

Next to the hull several more components are made of composite materials. To be able to make double curved and highly complex shaped fins a new way of composite manufacturing is used. With the CAD software SolidWorks the fins of the Argo are designed. These are based on the fins of a dolphin combined with a extreme low drag hydrofoil. This combination makes the fins of the Argo a complex shape to produce. For this the 3D printer was necessary to make the curved surfaces. With the 3d printer the core of the vin was printed. This ensures the shape of the fin. To strengthen the fin carbon fibers are made around the fins with the use of handlaminating and vacuuming. The advantage of this production method is that no complex and expensive moulds are used. The following pictures show the production of the horizontal fins.



5. Propulsion

In this chapter the propulsion mechanism of the submarine is described. The propulsion mechanism consists of several major parts. The first part of the mechanism is the input, this is the driver of the submarine. After the input of the system the transmission comes. This will transfer the loads by the driver to the actual propulsion mechanism. The next part in the system is the crankshaft. This part is of great importance, and the efficiency of this part will have a large effect on the complete system. The last parts on the propulsion mechanism are the fins. The fins will transfer the loads of the driver on to the water, which will cause the submarine to go forward.

5.1 The driver

As mentioned the first step in the propulsion mechanism is the driver. In Argo one driver will be propelling the submarine. This means that the maximum power input of the system is equal to the maximum power our driver can deliver. Thus a stronger driver results in a faster time during the International Submarine Races, and selecting a strong driver is therefore very important.

5.2 The transmission

The transmission is used to transfer the loads which are generated by the driver. It consist of normal pedals (like the ones on a bike), a NuVinci (which is a transmission without steps (CVT), so a smooth gear change) and a bevel gear (to transfer the plane in which the axles rotate. The transmission should be as efficient as possible, because a high loss of energy is bad for the whole system.

5.3 The concepts

For the final manner of propelling Argo, there were several concepts discussed. One of the criterion which had to be met is that the Argo will move without the use of propellers. Therefore a study on different types of sea creatures was performed. The animals that were selected for further research were the jellyfish, the manta ray, the squid and a general fish. These movements are also described in the subchapters below.

5.3.1 Concept 1 – Jellyfish

The jellyfish is the most energy efficient swimmer of all animals. This fish propels itself by contracting and expanding its belt. When the muscles are contracted, the water is forced to go out of the body. And when the muscles expand, more water is allowed to go into the body. This results in vortexes, which gives the jellyfish its thrust. Another important aspect of this fish is its radial symmetry. This gives the fish a low drag, compared to other sea creatures. The downside of this efficiency is that it only works at low speeds, and small bodies.

5.3.2 Concept 2 – Manta ray

The manta ray is one of the largest species of rays. Their span can reach a size of 7.6 meters, and their top speed is 11 km/h (or 3.06 m/s). These fish also have a very energy efficient way of propulsion, because they have the ability to glide for long distances in the water. The movement is also very similar to birds; they flap their ‘wings’ and then glide on the free streams, which results in a low energy input by the fish.

5.3.3 Concept 3 – Squid

The squid uses a similar way of propulsion as the jellyfish. Water gets into its head, and when it is full of water the squid releases it through the back of its body. The difference squids make is the pressurization of the water, which is then accelerated via a funnel. The jet stream coming out of the funnel has a high velocity and allows the fish to move forward. A negative property of this jet is its unsteady flow. This immediately gives the fish instability which results in a lower efficiency, because of the compensation for the direction of the fish.

5.3.4 Concept 4 – General fish

The general fish has a lot of shapes and sizes, but about 85% of the fish species use a caudal fin for its propulsion. This fin (on the aft of its body) provides the fish a fast and efficient way of swimming. The fish generates thrust by making sinus movements with the caudal fin. But the fin also causes large vortices in the water, and this results into a higher drag force acting on the body.

5.3.5 The trade off

Each concept is scored on its expected way of moving, size, efficiency and propulsion speed. In the table below, Table 5 1, the trade-off is performed. The weight factors and the scores are valued between 1 and 5 points. For the weight factor a higher amount of points means a criterion of more importance, and for the score a higher amount of points means that the concept is better in a criterion. The concept with the highest total score wins the trade of and is therefore the best solution for our chosen concepts.

Criterion	Weight Factor	Concept 1 Jellyfish		Concept 2 Manta ray		Concept 3 Squid		Concept 4 General fish	
		Score	Total	Score	Total	Score	Total	Score	Total
Efficiency	4	5	20	4	16	4	16	3	12
Complexity	3	2	6	4	12	2	6	4	12
Speed	5	1	5	3	15	2	10	5	25
Size	3	3	9	1	3	3	9	5	15
Total			40		46		41		64

It is clear that the best concept is concept 4. This concept achieved the highest total score in the trade-off. The efficiency is lower than the other concepts, but the speed and size compensate for that. Now the detailed design can be made. Therefore this concept will be further designed and sized.

5.4 The final design

The final design is a fishtail propelled system. A SolidWorks render is shown in Figure 5.1 below. This gives a clear visualization on how the propulsion system looks. The axle that goes through the box is driven by a spur gear and this goes to the transmission. In the box a crank will rotate. This will cause a linear movement which moves the fins in and outward of the submarine. The fins will also change angle of attack, this is done in order to finish the wave movement, just like a real fish does.

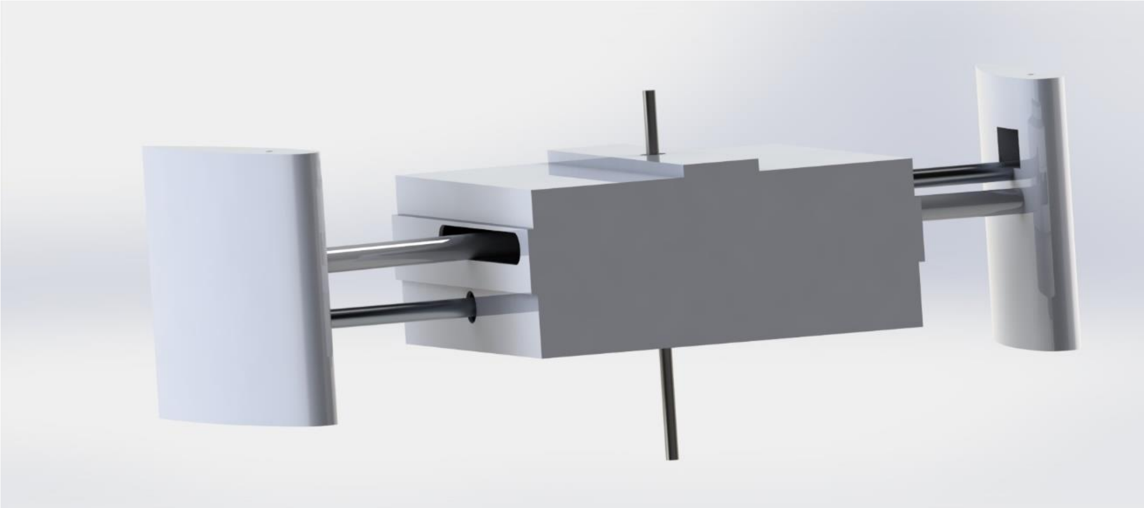


Figure 5.1 Render of the propulsion system

5.5 The fins

The fins’ size and their shape have a great influence on the drag and thrust of the system. A NACA airfoil is used for the shape of the hydrofoil. One of the important requirements for the hydrofoils is its symmetry. Since the hydrofoil moves in an in- and outward direction relative to the submarine an asymmetrical foil would cause more drag. The fin also needs to be thin, a thin foil means less lift but because of the low speeds this has no large effect on the thrust. Therefore a NACA 0012 profile is chosen for our hydrofoil.

6. Safety

Air Supply calculation

To ensure the safety of our driver some calculations of the air supply have been done. The race committee of the ISR set a requirement of 100% + 150 % needed during the race. Below this calculation is shown.

Pressure on 10m depth	2	bar
Usage above water	35	liter/minute
Usage on 10m depth	70	liter/minute
Race distance	130	meters
Speed	0,514	meter/second
Racetime	252,9183	seconds
Racetime with safetyfactor	632,2957	seconds
Racetime with safetyfactor	10,53826	minutes
Total usage	737,6783	liters
Capacity tank	7	liters
max Pressure tank	200	bar
Total liters of air	1400	liters

The submarine is therefore equipped with a 7,2 liter steel tank.

Dead man switch

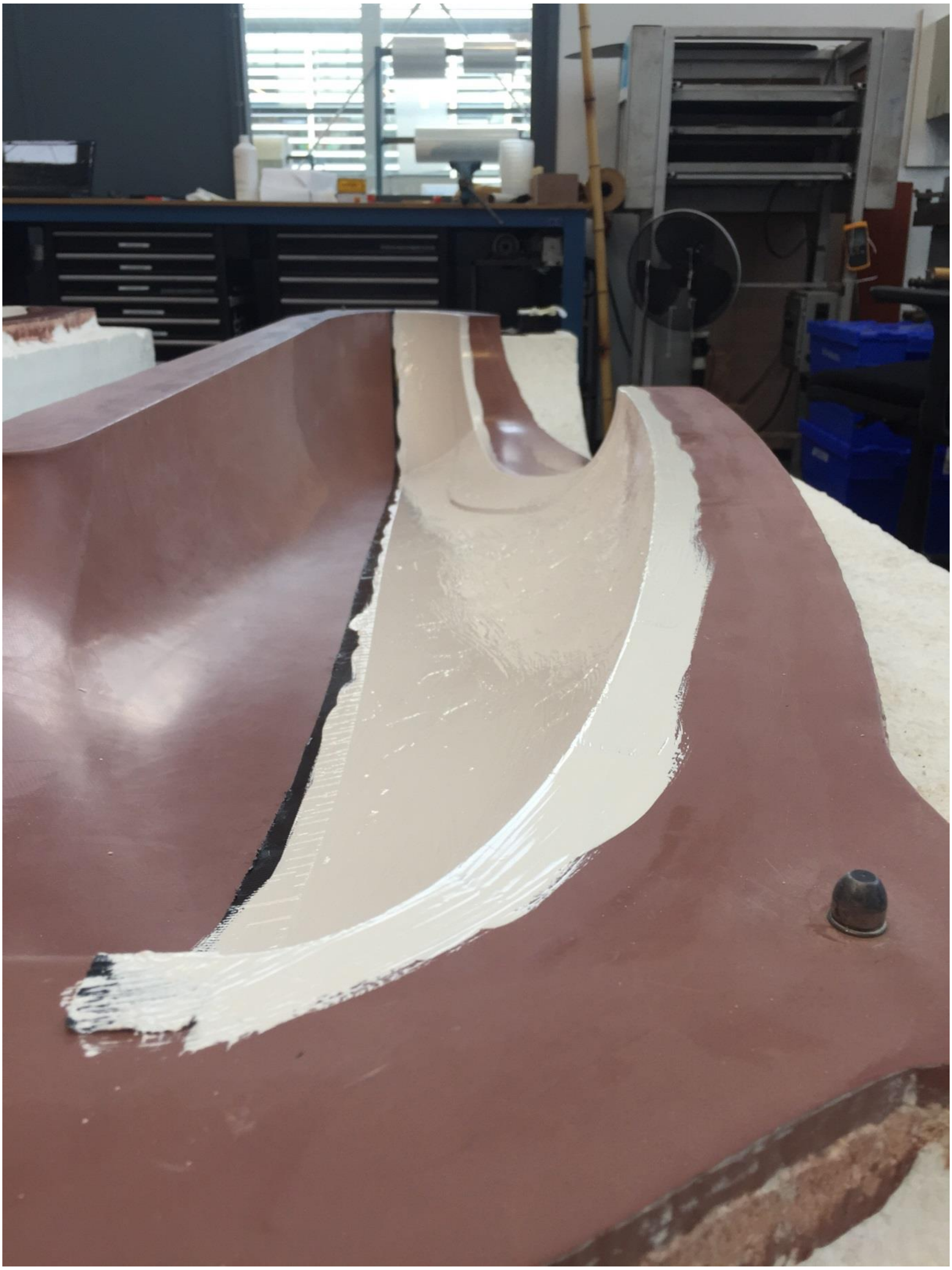
To show the safety divers that the driver of the Argo has issues and wants to be rescued. He has to pull the dead man switch. This switch consist of a rope which opens the rear door. Due to the buoyancy of the buoy the rear door will open. The buoy is made of high density foam which is able to sustain high pressures. The buoy is connected to the Argo with a highly visible, red colored dyneema, rope of 10m long. The buoy is painted acid green.

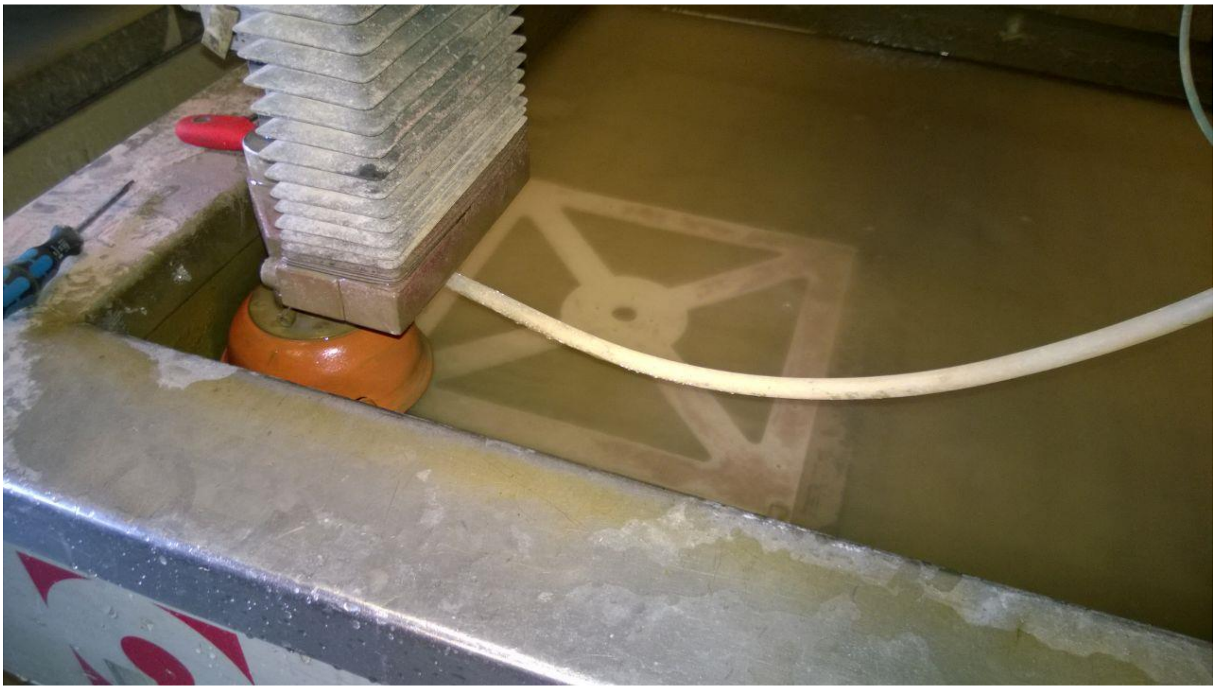
Air supply onboard

The main tank of 7 liters is located in the rear of the submarine. With the use of a custom made yellow regulator hose of 4m the regulator is able to reach the front of the submarine. In case of failure of the main air supply a backup system is installed. This backup systems consists of a spare air cylinder with regulator which holds enough air for 40 inhales at 10 meters. This is sufficient air to slowly and safely reach the top of the basin.

7. Overall impression during process

This chapter shows the highlights of the whole project in pictures. Concept testing, production of the hull, production of parts, fitting diver, assembling and finally full scale testing statically and dynamically.






de meeuw
de meeuw
Windturbine
ANEMO


TEAM
sonic


Sub·Lub
THE GLOBE
EEKHOUT
spuiterij
Elcee
SCABRO
IDEEËN KRIJGEN VORM
13TH Concepts
FOLIESPECIALIST
HOOYMANS PRODUCTS

GOUDA

Geslaagde proefvaart onderzeeër

Het grote wedstrijdbassin van het Goudse Groenhovenbad was gistermiddag niet in gebruik, maar anders waren alle zwemmers waarschijnlijk in een mum van tijd op de kant geklommen. De onderzeeboot *Argo* van studenten van Inholland, die een proefvaart maakte in het Goudse zwembad, zag eruit als een vervaarlijke haai en de visbewegingen waren ook levensecht.

FOTO PETER FRANKEN

8. Conclusion

To conclude this memorandum report the checklist is checked if the team has met the listed requirements as stated in the start of the project

Requirement		**Checked**
For submarine:		
1. High visibility colors		V
2. Emergency exits have 4 inch square orange patch with the word “Rescue” on it		V
3. Emergency exits have easy accessibility from in and outside		V
4. If there is a method of attachment, a clear visible release system should be visible		V
5. Face and head should be visible from the outside		V
6. Strobe(s) which is/are 360 degrees visible in horizontal and vertical plane		V
7. Strobe(s) should be approved by the USCG or SOLAS		V
8. Emergency buoy in sub		V
9. Dead man switch: when buoy is released all propulsion stops		V
10. Max width: 2.13 meter		V
11. Freely drain water		V
12. Launch cradle for movement of the submarine on land and into water		V
13. Possible a negative buoyant for sinking		V
14. Possible underwater communication		V
15. Can use wax on hulls and fins		V
16. Brake not necessary		V
For driver:		
17. NAUI, PADI, YMCA or other license		V
18. Min age is 15 years		V
19. Own diving equipment		V
20. Scuba exhaust air can be trapped in sub. Better if it exits the sub.		V
21. Secondary air supply in the submarine		V
22. Air supply minimal: 1 speed run + 150% reserve for all diving crew (with		V

provided calculations)		
23. Clear pressure gauges during run. Pressure may not be lower than 500 psi		V
Innovation Studio:		
For submarine:		
24. Innovative design		V
25. Use of biomimicry		V
26. Completely made by students		V
27. Completely made by Innovation Studio		V
28. Design by students		V
29. Manufacturing by students		V
30. Testing by students		V