KrUSer53 presents

SMASH

UNIVERSITÉ DE SHERBROOKE

Synopsis

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The main objective of project SMASH is to beat the previous speed record established by the École de Technologie Supérieure of Montreal, in the one-person propeller submarine category. Our purpose was to compete at the HPS competition in California. Since the HPS competition was cancelled, we decided to move forward and subscribe the SMASH submarine to the ISR #11 competition.

1. Hull

The submarine's hull is constructed out of fibreglass and rigid foam, issued from two different NACA profiles linked by smoothing. These two dimensions are optimized to reach the best ergonomic and hydrodynamic performances while providing the maximum security level for the pilot.

1.1. Main structure

Concerning the hull's main structure, a composite material formed by rigid foam of 12.7 mm, covered with three layers of fibreglass on each side, is used to minimize the deformations and the constraints due the pilot's efforts. Moreover, in order to split up the efforts and offer a resistant joint, the components' fixations are glued and laminated to the hull. With this kind of heavy duty composition, the hull got a safety factor of 7 for the worst case of applied strength. The hull composition is shown in the figure 1.

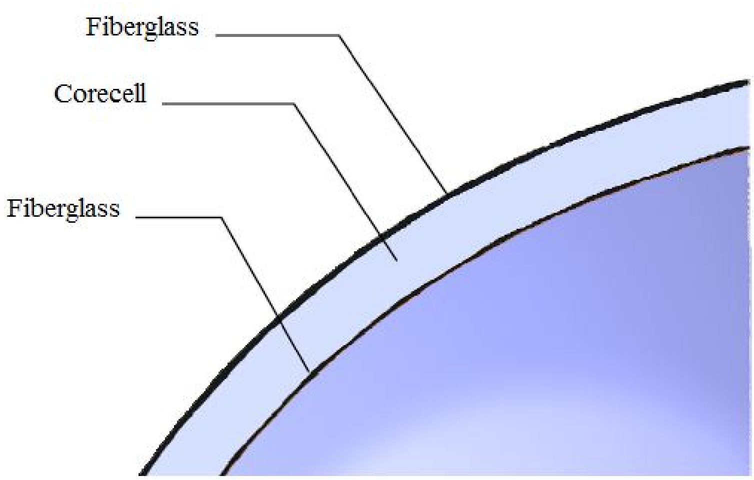

Figure 1 - Hull composition

1.2. Hydrodynamics

The hull is composed of two different NACA profiles. These two profiles are the ones who match best with the physiognomy of the pilot while pedaling. Each profile is used to form the hull, one horizontally and the other, vertically. The horizontal profile is the NACA001944 and the vertical one is the NACA16025. Once these profiles are chosen and the hydrodynamics analysis is completed, the hull can be meld by linking the two NACA profiles. The figure 2 shows the two profiles enclosing the pilot.

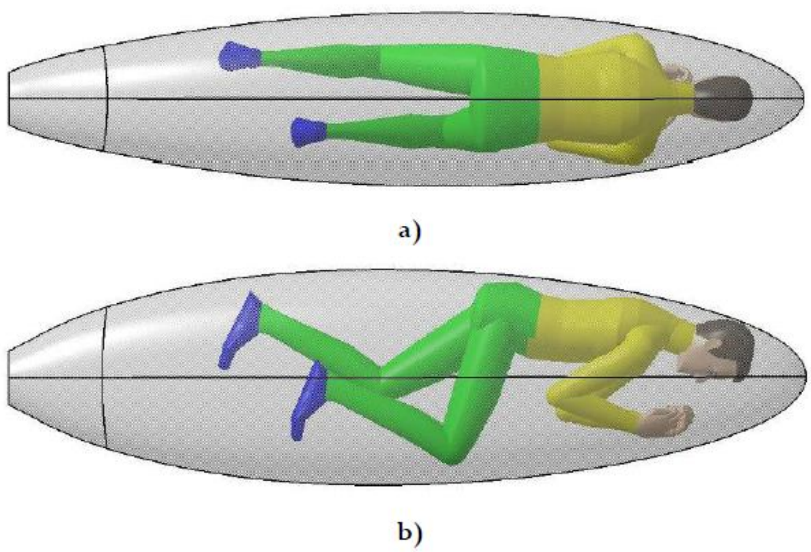

Figure 2 - a) Profile NACA001944 ; b) Profile NACA16025

1.3. Security and technicality related to the hull

Another essential point is to ensure the pilot's security, which is done by different systems as required by the competition's rulebook. The most important one is the evacuation of the pilot. A door is positioned on the top of the submarine. This door can be opened by the pilot and by the teammates in the water. With this mechanism, the pilot can be rescued in an emergency at anytime. Another door is disposed at the back of the submarine to let the team work easily on the propulsion system. At the front of the submarine, a porthole allows the pilot to see clearly under and in front of him while pedaling. This porthole is also a security item because the teammates are able to see the face of the pilot at anytime during the tests or the competition.

Moreover, some supports have been disposed at different places inside the hull to be able to attach the float, the gas cylinder and the stroboscope. These systems are shown in the figure 3.

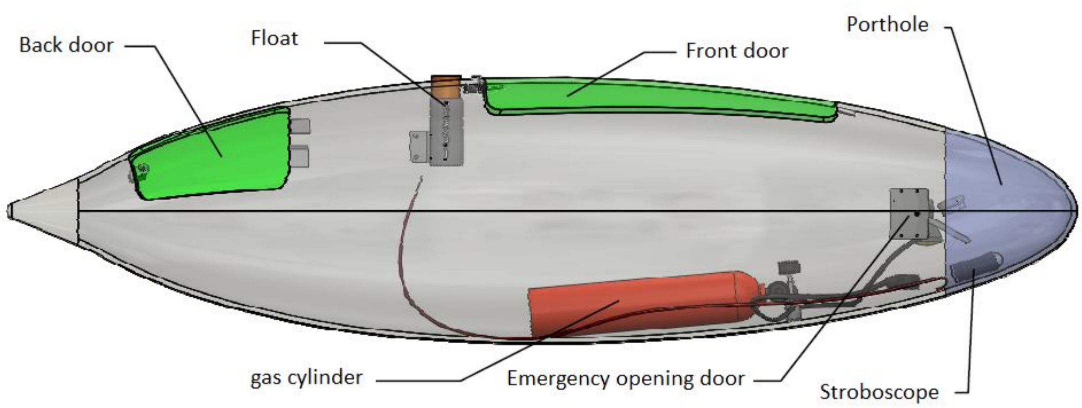

Figure 3 - Overview of the hull and cockpit

2. Propulsion system

The propulsion assembly is composed of three general systems that are shown in figure 4. More precisely, they are the cranks, the energy transfer and the propeller systems. The main function of this mechanism is to transfer the power of the pilot into the rotary movement of the propeller. The propeller will produce thrust in order to move the submarine forward. The efficiency of the propulsion system is one of the most important challenges in achieving our goal of breaking the world record for speed.

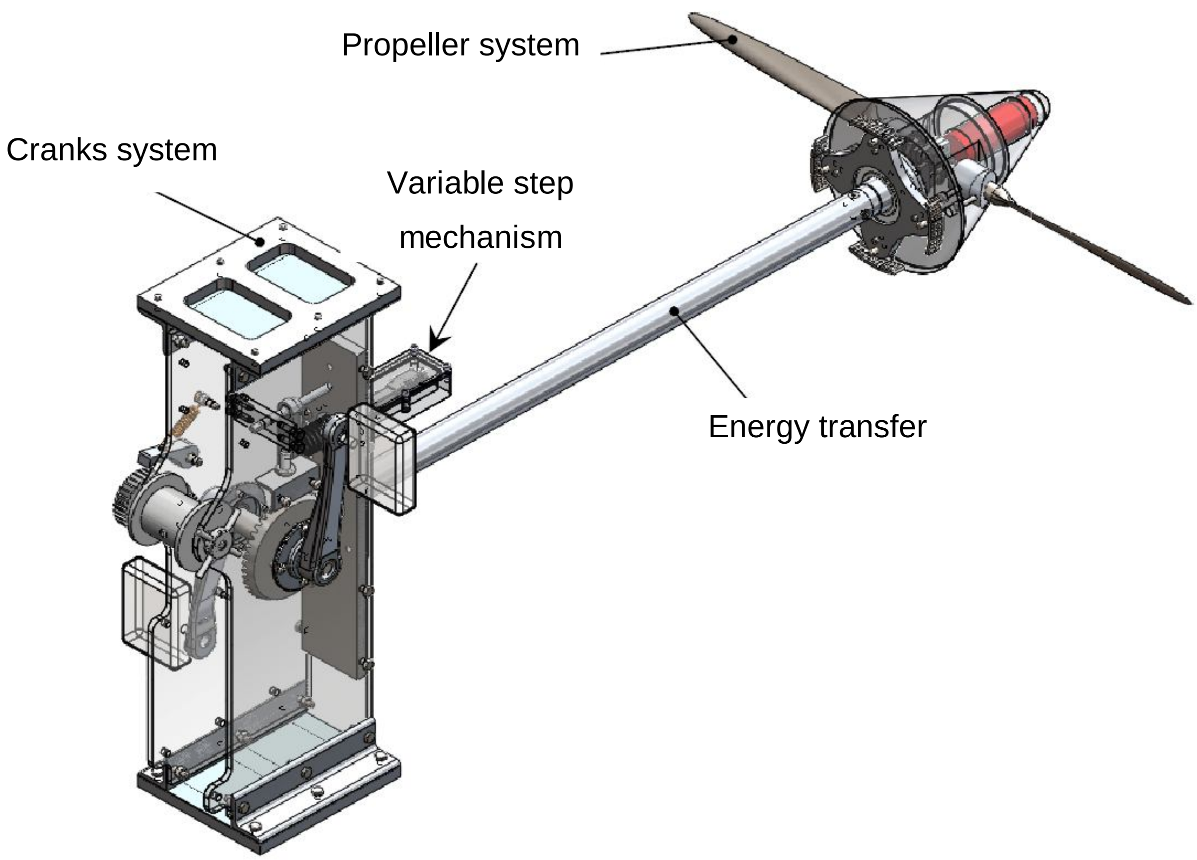

Figure 4 - Propulsion system assembly

2.1. Crank system

The first step in the submarine propulsion is the crank system. Its function is to take the energy produced by the force of the pilot and transform it into rotational energy. This system also gives the rigidity of all the propulsion setup. The system is shown in the figure 5 below.

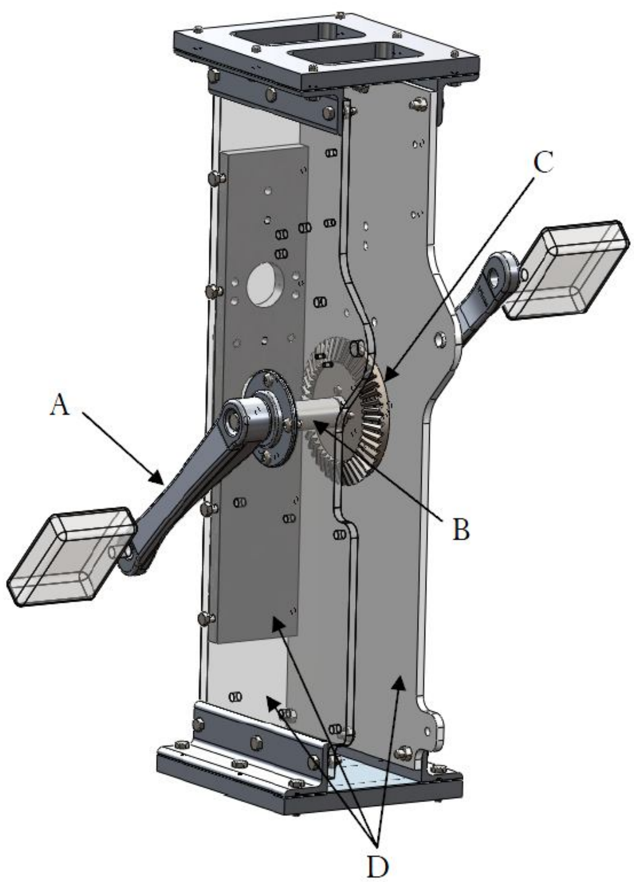

Figure 5 - Cranks assembly

The crank system works in the following way. First, the pilot pushes onto the cranks (A). These are fixed to a shaft (B), which is supported by two bearings. On the end of the shaft, there is a conical gear (C), which is linked to rest of the propulsion system. We can also notice the crank system supports (D). This system is designed to support a worst case scenario, were the pilot gives a full load to the cranks equivalent to 667N per crank.

2.2. Energy transfer system

The purpose of this system is to bring the energy from to pilot to the rear of the submarine. The setup of the gears gives a ratio of 2.5:1. This means that if the pilot pedals at 100 RPM in the water, the expected rotational speed of the propeller is 250 RPM.

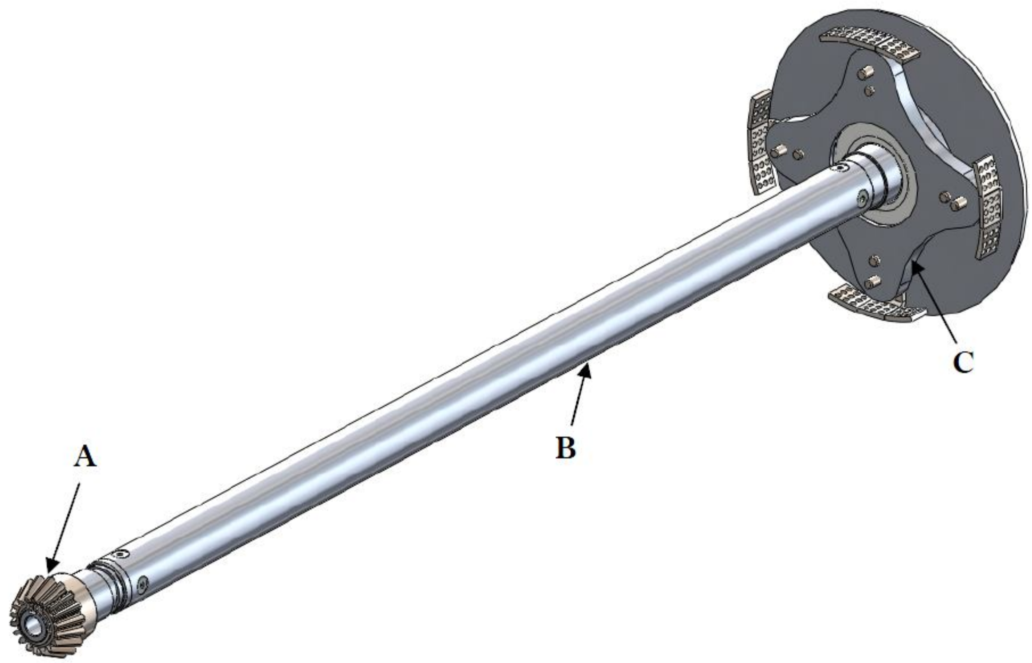

Figure 6 - Energy transfer system assembly

The energy transfer system starts with the conical gear (A) which is linked to the gear in the crank assembly. The shaft's (B) function is to transfer power to the rear of the submarine and to give a passage to the variable pitch control system. Finally, there is the rear support (C). The maximal torque of the transfer system is 110 N.m. The efficiency of the system is about 98%.

2.3. Propeller system and variable step mechanism

The optimisation of the thrust is the principal function of the variable step mechanism of the propeller. In resume, this system changes the angle of the blade from the propeller. The angle of the blade is set with the speed of the submarine and the rotational speed of the propeller. This, of course, gives the ability to always maximise the thrust, and in so doing, the acceleration of the submarine.

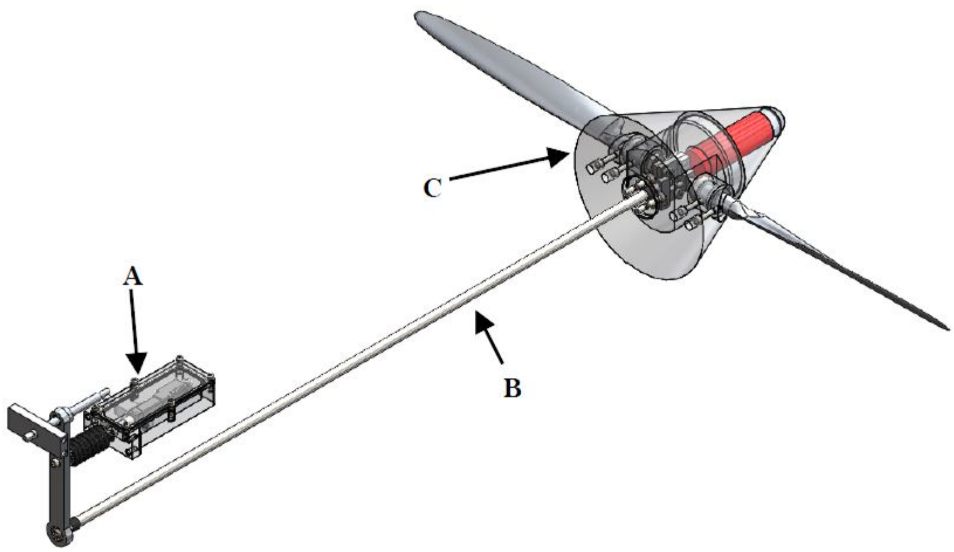

Figure 7 - Variable step mechanism of the propeller

The figure 7 shows how the variable step mechanism works: An actuator (A) transfers a linear movement to the central link (B) and to the rotary mechanism (C). The end rotary mechanism is shown in more detail in figure 8.

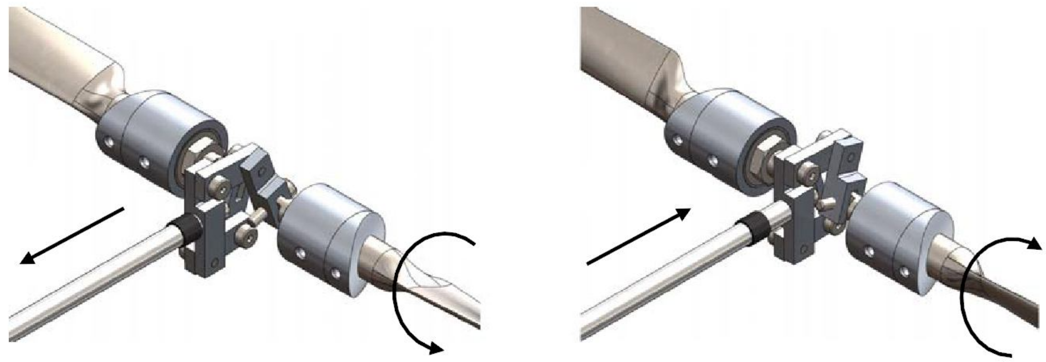

Figure 8 - End rotary mechanism

3. Maneuverability

The dynamic stability of the submarine is ensured by electronically controlled fins, situated at of the rear of the vehicle. The maneuverability system is entirely computer-assisted and servomotors control movements of the fins. However, in case of the malfunctioning of one of the electronic parts, the pilot can take control of the submarine with an entirely mechanical device composed of push-pull cables. Two different sets of flaps are available for both systems, as seen in figure 9.

In order to reduce the drag, an innovative aileron retraction system was conceived. When the pilot feels the computer-assisted system is doing its job correctly, he can retract the ailerons in order to reduce drag. By retracting the fins at the half of the run, the drag can be reduced up to 4%. The mechanism by which this is achieved is shown in figure 9.

As a security measure, the pilot is able to detract the fins at any time in order to retrieve manual maneuverability of the submarine. The activator is fixed to the central chariot, which can move the ailerons' assembly mounted on four independent rails. To control the vehicle in both yaw and pitch, there are four ailerons placed in a cross form (+). The ailerons have a NACA-0015 shape and the dimensions have been optimized to minimize the drag.

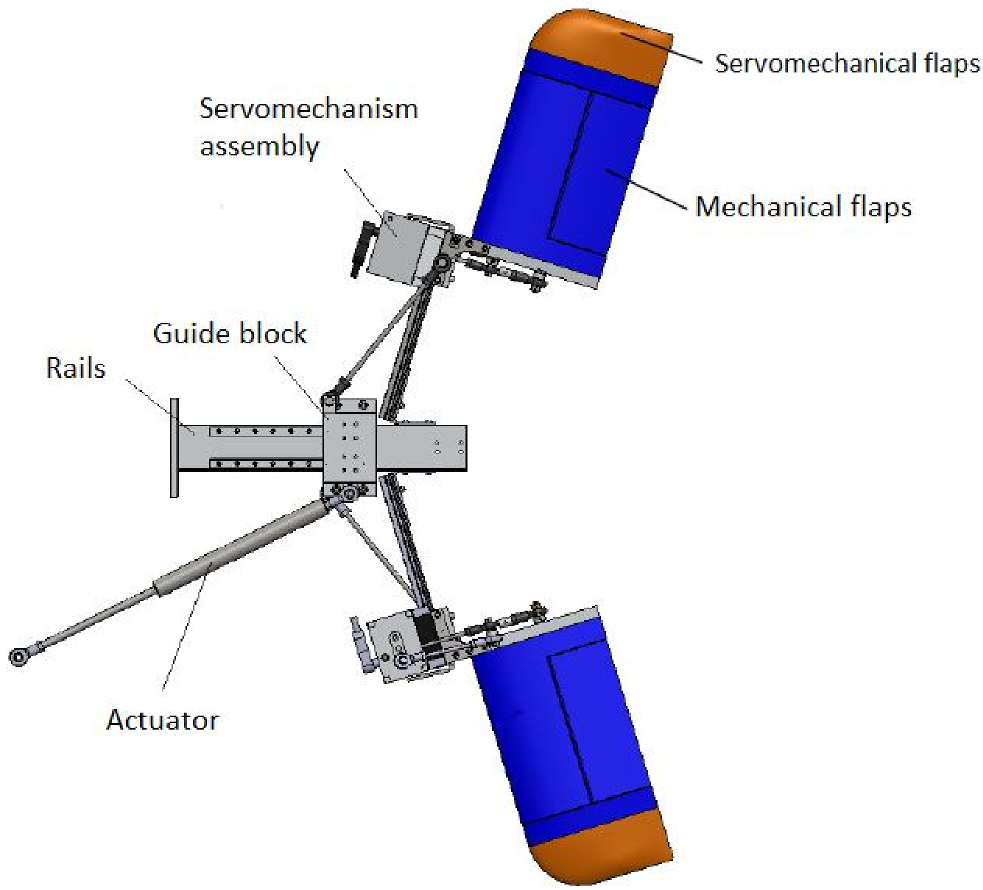

Figure 9 - Smash's maneuverability system

4. Electrical Controls

In order to optimize the mechanical aspect of the submarine, two electro-mechanical systems are included. The first system is the variable pitch on the propeller to obtain the best efficiency during the acceleration. The second system is the computer-assisted stabilization. Both systems will be described in the following section. Another section will describe the electrical components.

4.1. Closed loop control of propeller pitch

The main function of the variable pitch is to ensure that the propeller is used to its full effectiveness for the whole speed range of the submarine, and the speed of rotation of the propeller. The advantage of using a variable pitch propeller is that the human pilot can pedal at a constant speed and the enslavement of the propeller thrust ensures the best propulsion. The pilot does not need to adjust its pedaling speed, which enables him to develop the maximum power his muscles can provide. The purpose of the variable pitch is to position the propeller to provide the best compromise between the power generated by the pilot and the propeller efficiency.

4.2. Important parameters

The pitch has little influence on the maximum speed of the propeller; the most important parameter is the acceleration of the submarine. Indeed, since competition has a relatively low distance for acceleration at 55 meters, the submarine must be able to reach the highest speed possible over this distance to establish a new record.

4.3. Dynamics model

Modeling the dynamics of the propeller begins by first determining the thrust force developed and the drag torque applied and, depending on the speed of the submarine, the speed of rotation of the propeller and the angle of attack.

In the case of a fixed-pitch propeller, the map of the propeller is actually a curve and would look like Figure 10. It is possible to notice that at constant speed, efficiency is optimal at one point. This means that to achieve a higher speed while keeping the same efficiency, the speed of rotation of the propeller must increase. In cases where the available power is large, it has little influence. However, when the power is limited and available only at a specified speed, it becomes important to change the shape of this curve.

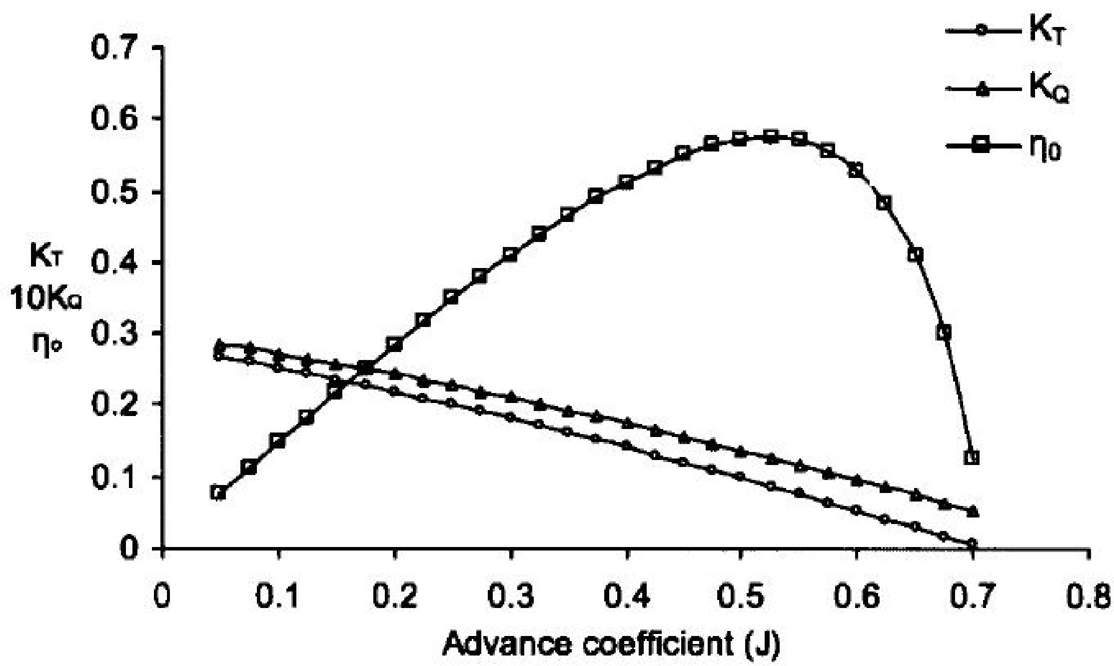

Figure 10 - Typical curve of a fixed-pitch propeller

4.4. Strategy for control

As mentioned above, the purpose of pitch is to ensure that the propeller is always used to its maximum efficiently. To do this, the optimum blade angle θ, at which the propeller must be positioned, is calculated using the Matlab model of the helix as a function of advanced ratio J. This value is the instruction that leads to the position of the actuator controlling the pitch. Figure 10 shows the results obtained in terms of speed, the thrust force, the required power and efficiency. For now, no controller is integrated into the model. A proportional-derivative (PD) controller enslaving the linear actuator will be scheduled once all the electronic components are received. The shape of the curves may nevertheless be very similar because the rate of change of the angle of the pitch is relatively slow, changing by about 1°/s. These results are obtained by setting the speed of rotation of the impeller constant at 250 RPM.

5. Security

In order to conform to the competition's security measures, a float has to be released from the submarine in case of any problem coming from the pilot. This emergency system is fixed in front of the crank-gear and in the superior part of the submarine. During the race, the pilot has to pull down a dead-man system located on one of the controls maintaining the float, with a rope that is wounded around the handle. This previous system is illustrated in the figure 11.

The submarine has a strobe light installed near its front end and on its tail to ensure its visibility under water. The submarine respects the color pattern of the competition. The handles and releases are indicated by a bright color and arrows indicate the procedure to open them.

If the pilot needs to break, he can back-pedal. This will spin the propeller in reverse and slow down the submarine.

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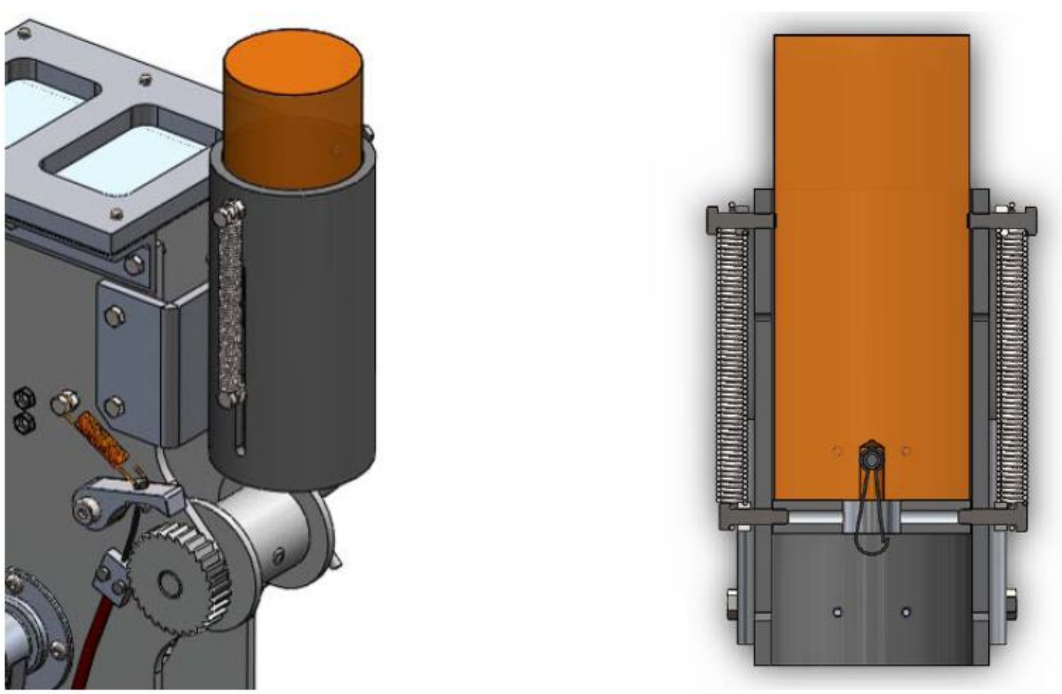

Figure 11 - Smash's security system

The complete technical report

of the

Université de Sherbrooke

KrUSer53

is available in French

upon request to

Claube Brancart

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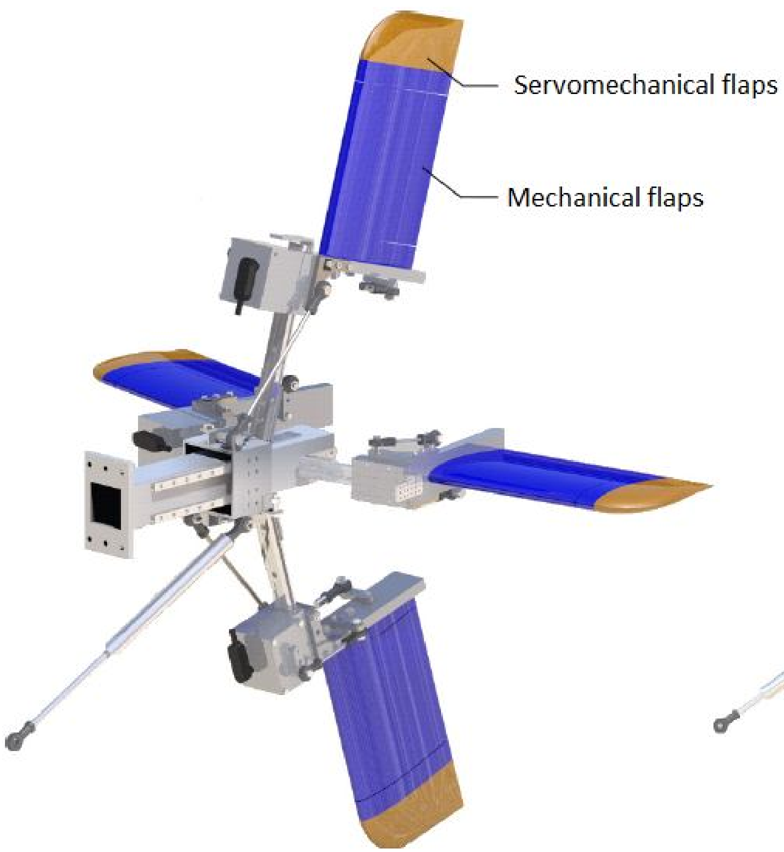
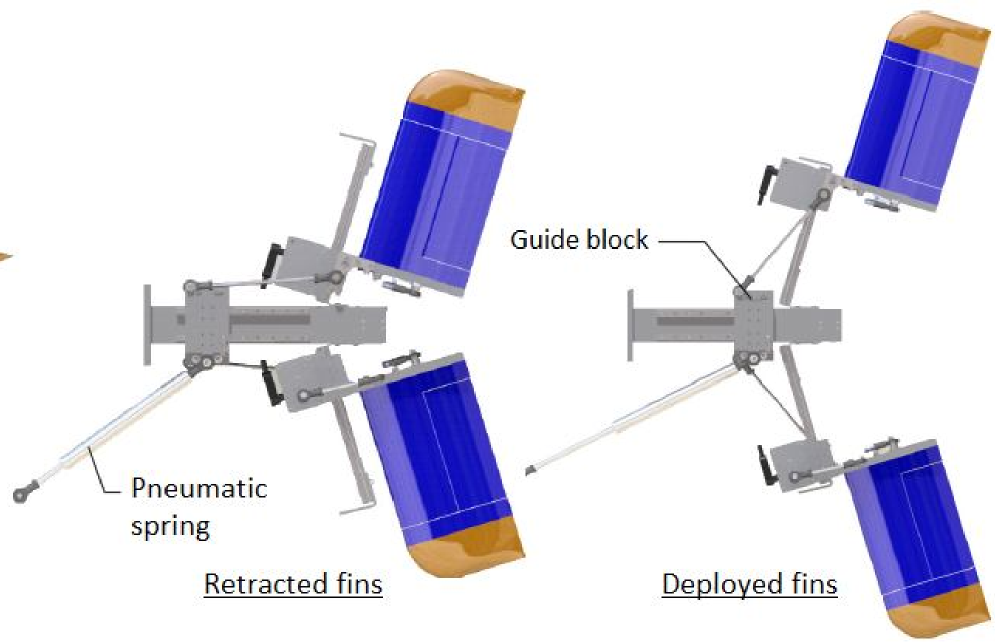
Technical Worksheet – Retractable fins

Specification	Value
System weight	10 kg
Fin length	28 cm
Servomechanism flap length	8,5 cm
Manual flap length	17 cm
Retraction pitch	9,2 cm
Guide block path length	11 cm





Specification	Value
Hull shape (Side view)	NACA 16025
Hull shape (top view)	NACA001944
Hull's material	Fiberglass and corcellTM
Wet area	4.55 m²
Front area	0.35 m²
Submarine's length	2,9 m
Theoretical maximum speed	3,7 m/s
Total drag at 3,7 m/s with deployed fins	146,0 N
Total drag at 3,7 m/s with retracted fins	142,0 N
Coefficient drag of the hull's shape	0,0133
Reynolds @ 3,7 m/s	2,6 X 10^6
Submarine's weight	70 kg
Added weight	21 kg
Gear ratio	2,5 : 1
Propeller's rotation speed	250 RPM
Propeller's shape	FX63137

Technical Worksheet – Smash

SMASH