



uOttawa

CAD/CAM Group Sub 1B:

Capstone Report

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Presented by: Group Sub 1B

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MCG4322 A, Computer-Aided Design

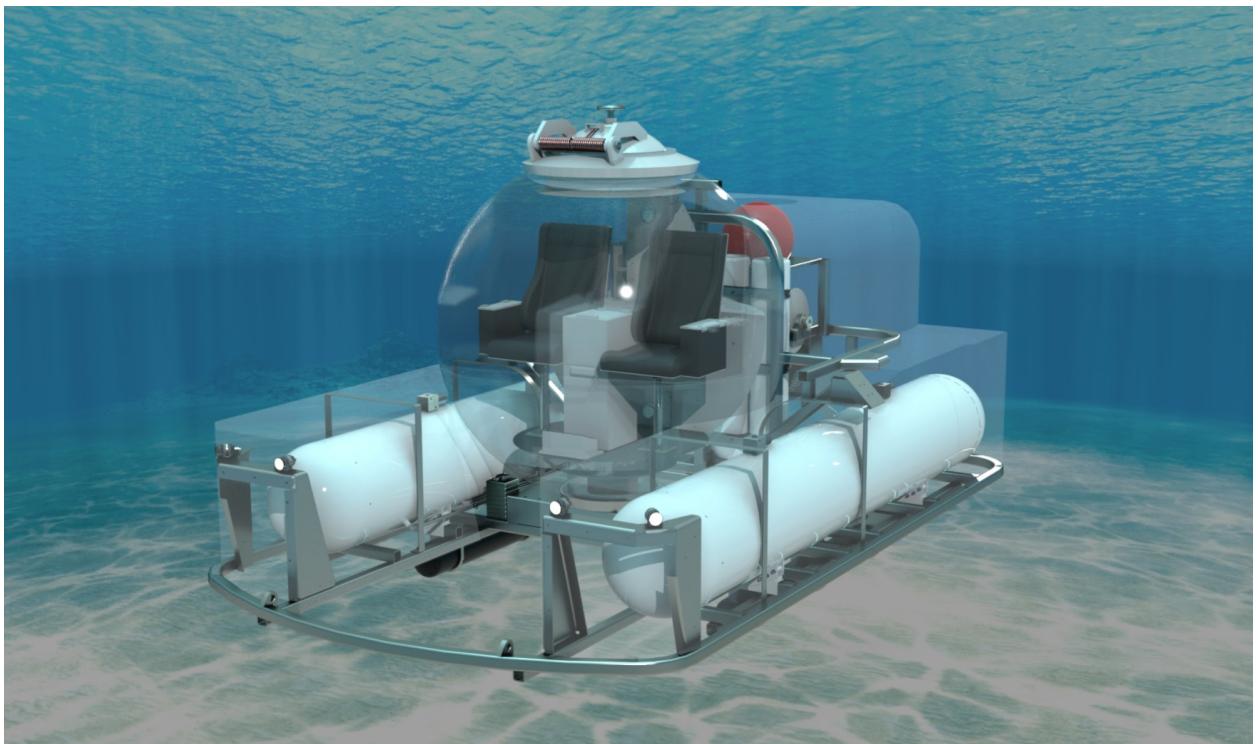
Fall 2020

Prof. Mihaita Matei

Abstract

The design presented in this report consists of ballast systems and emergency drop weights for a manned submersible capable of diving to depths up to 1000m. The MBTs are used for surfacing and allow up to 0.9m of freeboard. The front and rear VBTs permit depth control for ascent and descent with speeds up to 0.5 m/s and 1.79° of trim control to level the submarine horizontally. The release of the drop weights is a fail-free procedure allowing the submarine to surface when solenoid actuators supporting the weights open upon power outage in the event of an emergency. The design is also equipped with enough air bottles to blow the main ballast tanks at any depth up to 1000m, and is used as a second emergency procedure that requires electricity. The maximum payload is assumed to be 250kg. Passengers are weighted before boarding, and Lead weight is added to the submarine's drop weights to meet the set maximum payload. The ballast system is designed in a way to permit easy access for both external and internal maintenance and an affordable manufacturing of spare parts. Most of the components of the design are made of 2507 Stainless Steel, which has a PREN number higher than 40 and makes it a very good corrosion resistant metal for seawater applications. The pump, the motor, the valves and the piping as well as other external features exposed to sea pressures are all capable of accommodating pressures up to 1000m. The design solution is shown on figure bellow:

[H]



Isometric View of The Design

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Nomenclature

Acronyms and Abbreviations

VBT	Variable Ballast Tank
MBT	Main Ballast Tank
DW	Drop Weight
WHVBS	Water Hydraulic Variable Ballast System
GUI	Graphical User Interface
SUB1B	Submarine team #1 group B
SUB1A	Submarine team #1 group A
PREN	Pitting Resistance Equivalent Number

1 Project Charter

1.1 Mandate

Aquatica Submarines is a Canadian company that provides small submersibles for commercial, scientific, and personal use at lower costs with no compromise to functionality or safety. Currently, the submersibles are unable to sustain depths greater than 330m. The new proposed design of the ballast system and emergency drop weights should allow the submersible to operate at depths up to 1000m. The design should allow an easy parametrization to change mass and buoyancy properties of the submersible to satisfy multiple market demands.

1.2 Requirements

The submarine should be equipped with a soft ballast tank as the principle component providing buoyancy. The variable ballast tanks must be powered electrically. The submersible must be equipped with an emergency drop weight that allows the submarine to rapidly surface. The drop weight mechanism should be fail-free. Additionally, all the components exposed to sea pressures must be designed to resist pressures up to 1000 MSW of depth. The hydraulic system should be protected from exposure to unallowed pressures by using a closed circuit safety valve that directs water to the sea when the pressure indicated is too high. When blowing the air into the ballast tanks, an arrangement should be present to protect these tanks from over pressurization. The compressed air supply used should be sufficient for the intended mission, without any refill during the trip. When the hatch is open to access the entry of passengers and equipment, the submarine should be able to remain floating under normal environment and payload conditions. While ascending and descending, the submersible should be able to maintain an acceptable stability and trim.

1.3 Constraints and criteria

To increase the submersible's freeboard, the soft ballast tanks should be able to provide up to 2200 Kg of buoyancy. The variable ballast tanks should provide up to 50 Kg of controlled depth and trim, operate at depths between 330 and 1000 MSW and provide variable buoyancy between 0 and 50kg. The design criteria of the submersible is to have variable ballast tanks sized as small as possible.

1.4 Design optimization

The GUI is allowing the user to enter 5 different inputs. The first two inputs are a range of temperatures of the surface of sea water a selection of seas or oceans where the submersible will operate. They both determine the critical density of seawater. The third input is the maximum depth at which the submarine is operating, ranging from depths of 330m to 1000m. The fourth input is the normal ascent and descent speed desired ranging from 0.4 m/s to 0.5 m/s. The final input is the minimum desired freeboard. The outputs are displayed on Solidworks through changing the radius and the thickness of the MBTs, the thickness and water capacity of the VBTs, the length and number of solenoid actuators on the drop weights, and finally the number of compressed air bottles used to purge the MBTs.

2 Proposed Design

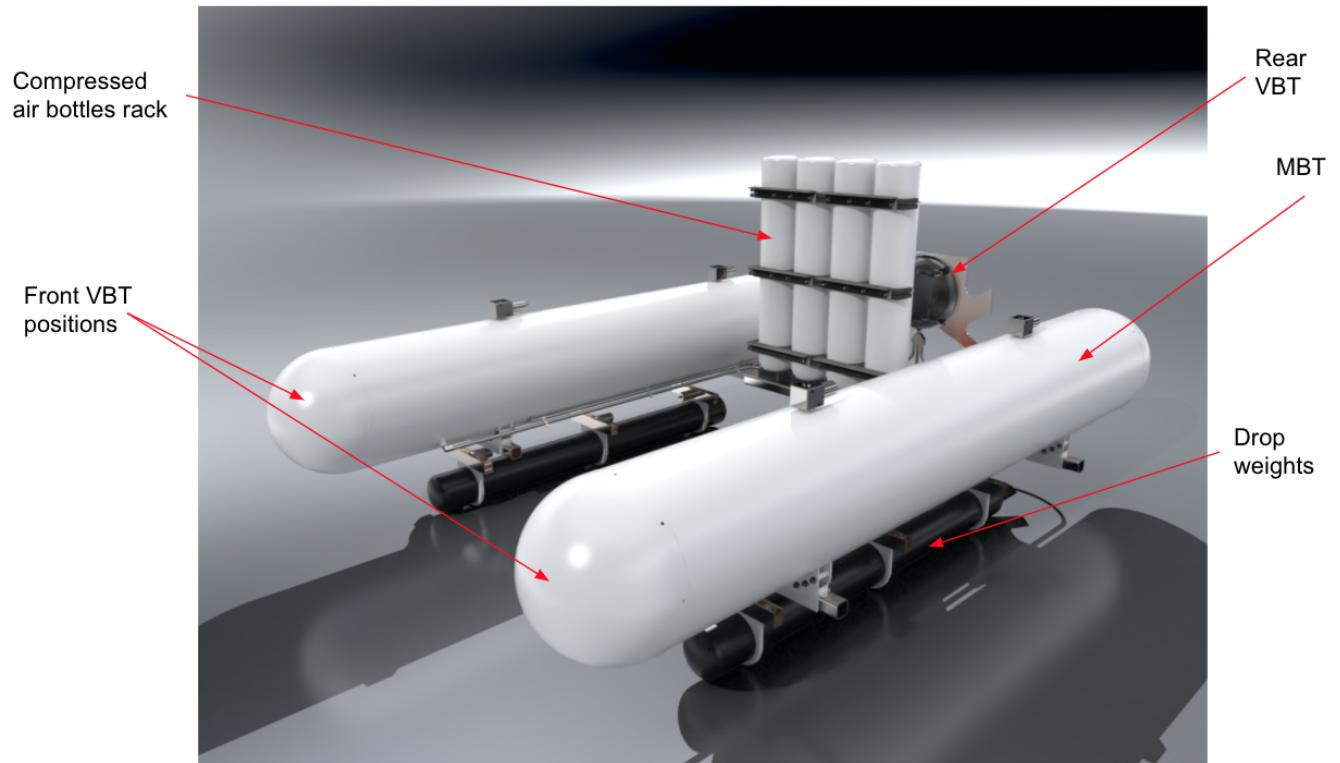


Figure 2-1: Isometric view of the proposed design

2.1 Main Ballast System

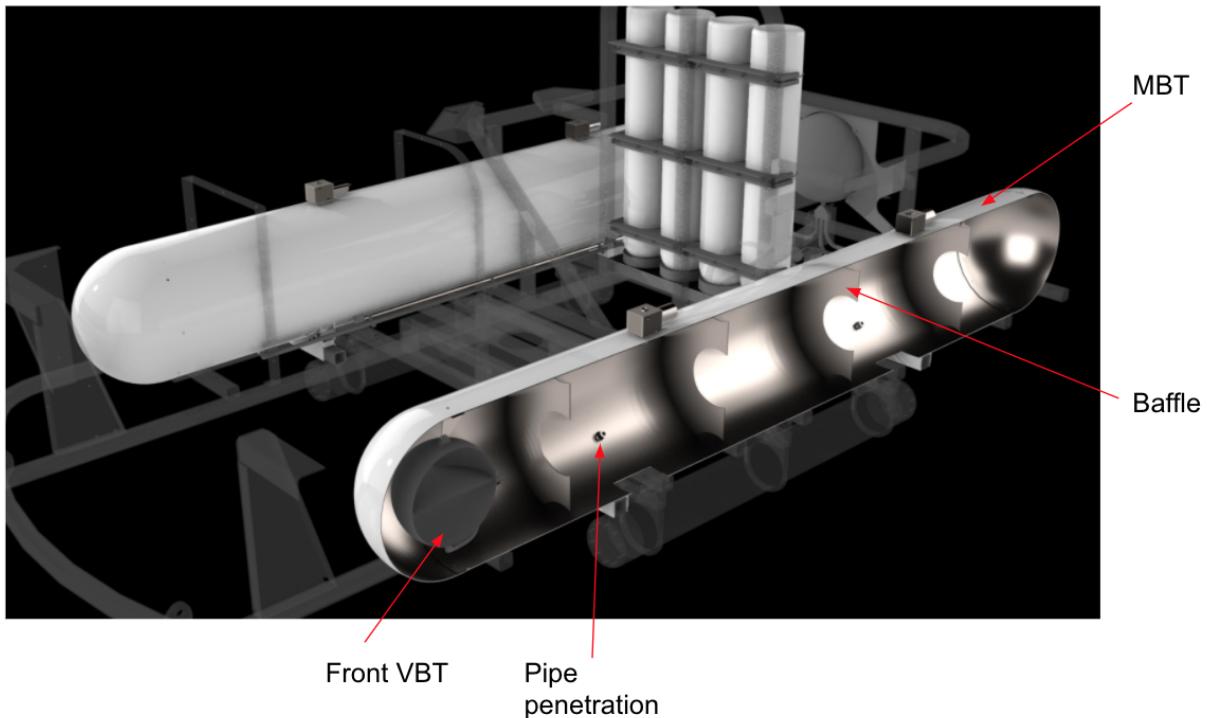


Figure 2-2: Isometric cross section of the MBT

As seen in Figure 2-2, The main ballast tank is divided into 5 sections via 4 equally spaced baffles to prevent sloshing of water during different processes like MBTs purging and submarine pitching. Two solenoid air vents are placed on the top face of the tanks to allow air to vent out at the surface and bring the submarine to neutral buoyancy. Two flood holes are implemented to facilitate MBT flooding.

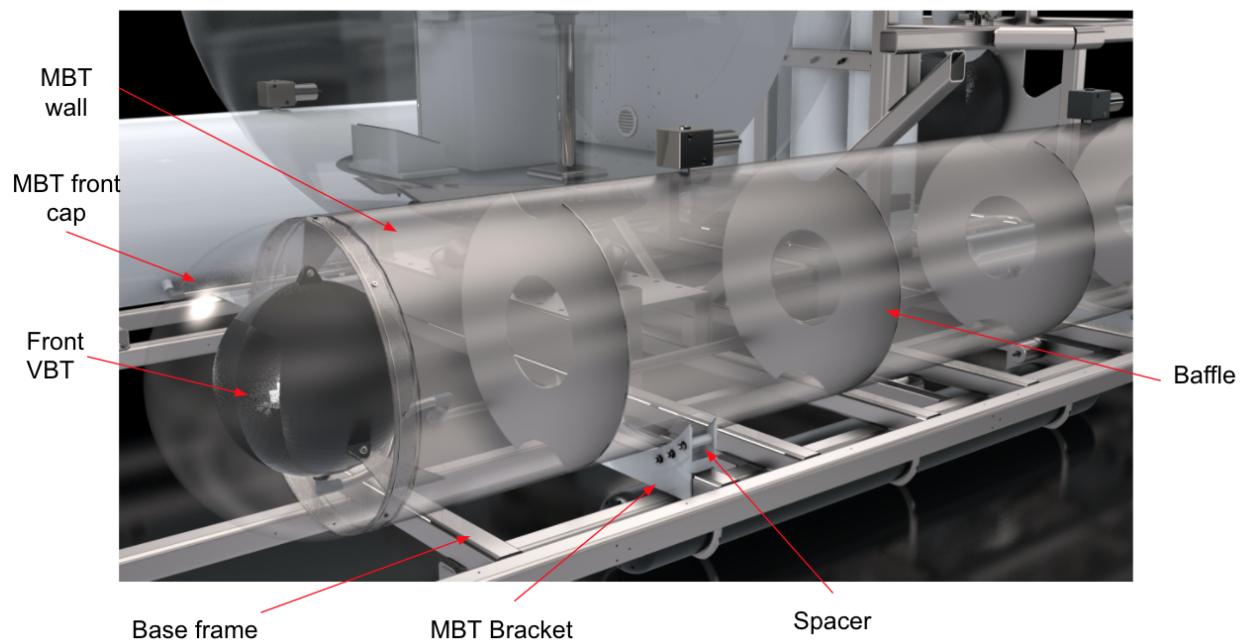


Figure 2-3: MBT Frame Brackets

The MBTs are attached to the main frame using two brackets shown in Figure 2-3. Each bracket is welded to the frame and contains 6 bolts that hold the MBT firmly to the bracket. Solenoid air vents are fitted on top of the MBTs using press fittings.

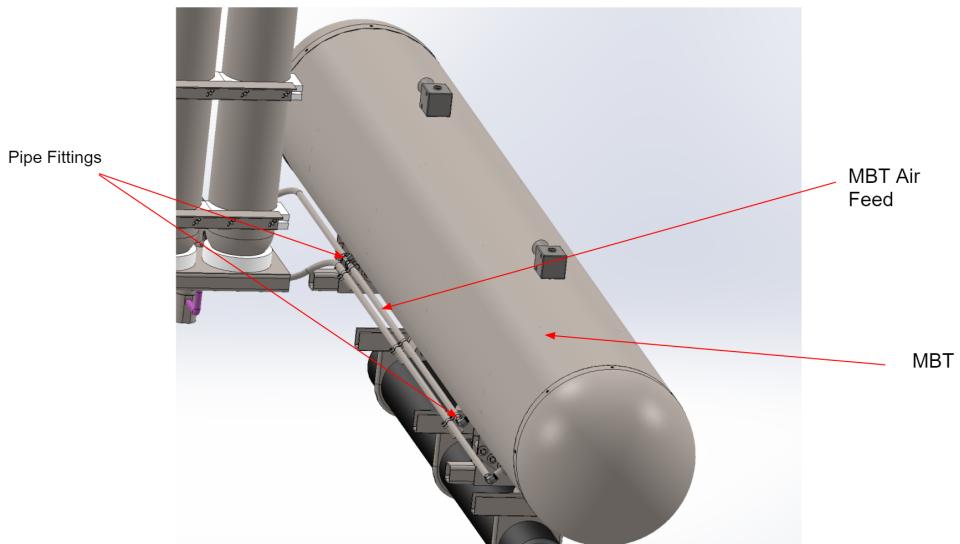


Figure 2-4: Main Ballast Tank Air Feed Pipes

Air feed pipes run along the MBTs lenght connecting the air bottles to the air inlets. Pipes are assembled with the MBT using pipe fittings as shown in Figure 2-4.

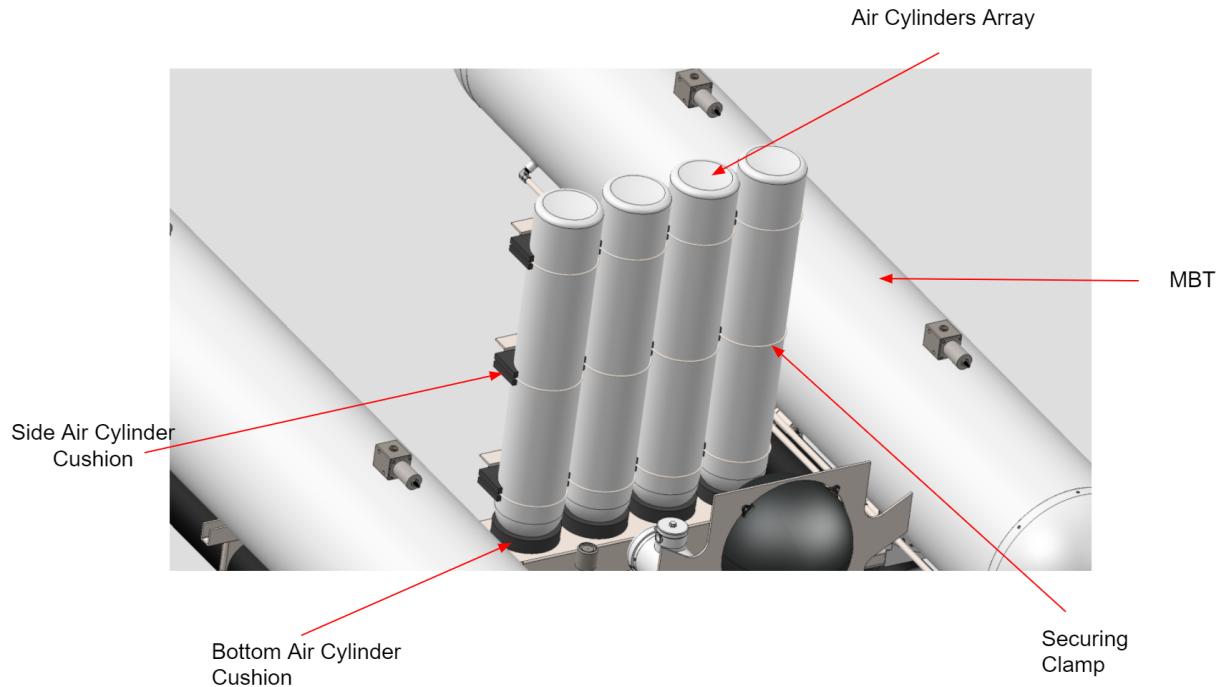


Figure 2-5: MBTs Air Cylinder Array

Compressed air is stored in one to four compressed air cylinders shown in Figure 2-5. This air is used for surfacing and emergency ascent purposes. The air cylinders are secured to the frame through securing clamps and a combination of side and bottom cushions as seen in Figure 2-6

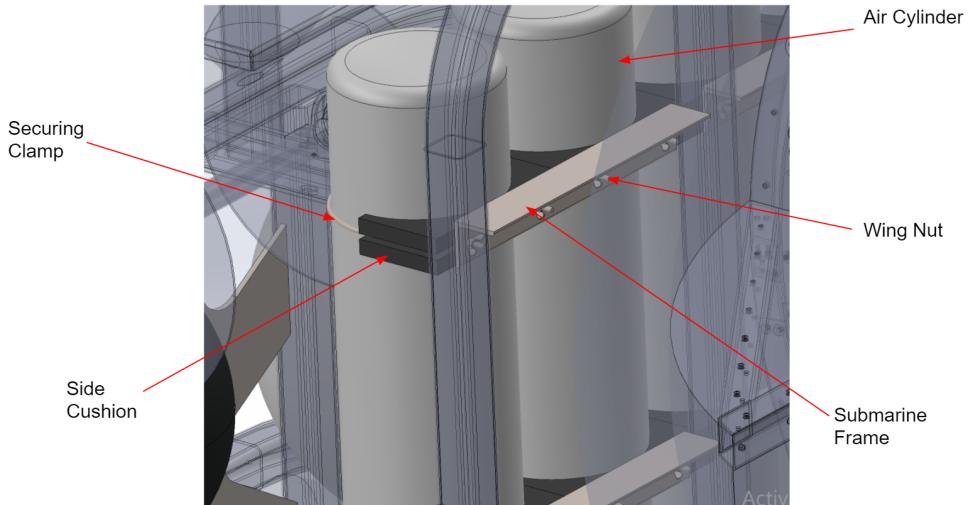


Figure 2-6: MBTs Air Cylinders Frame Attachment

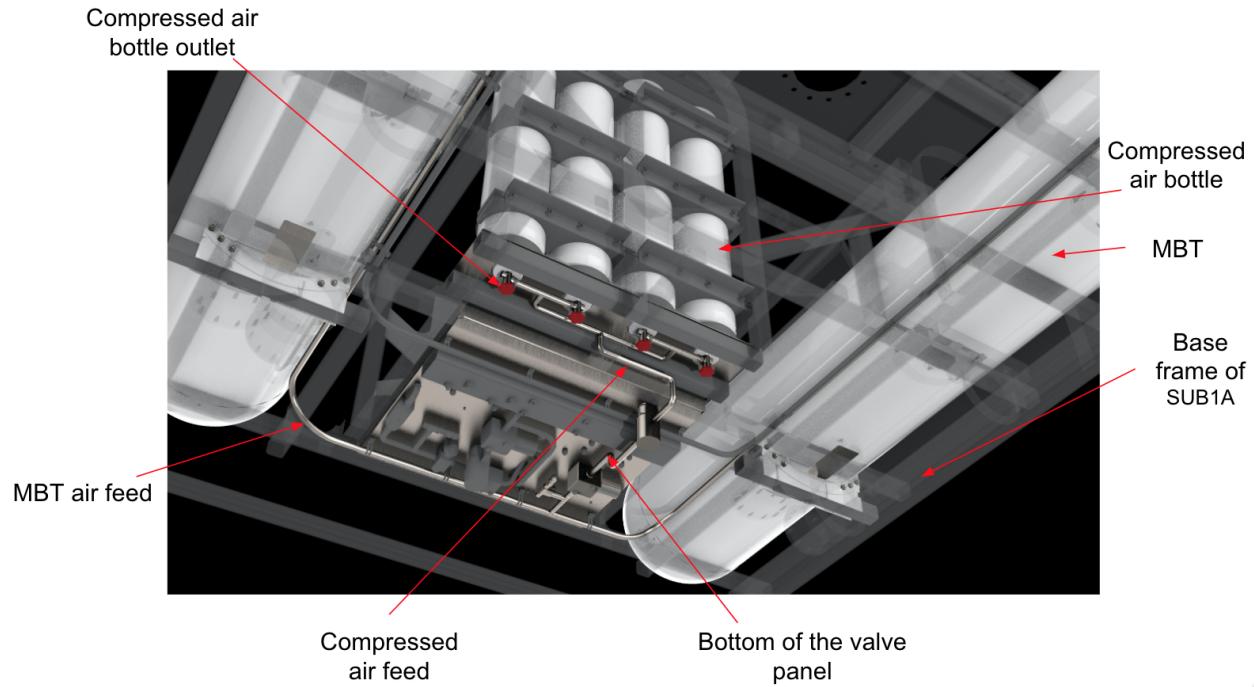


Figure 2-7: Bottom view of the compressed air bottles rack

Figure 2-7 shows the valve circuit of the compressed air. Air is first regulated to $200kPa$ above ambient sea water pressure through the pressure regulator, and then purges the MBT through a pneumatic solenoid

valve.

2.2 Variable Ballast System

2.2.1 Rear VBT

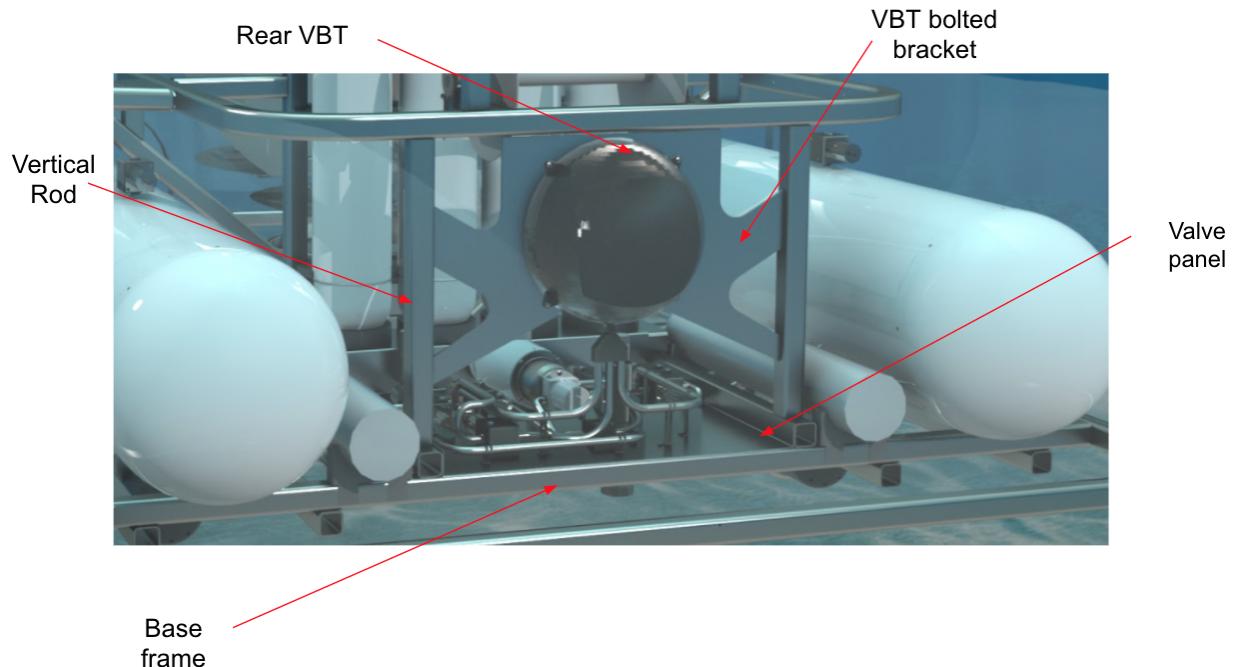


Figure 2-8: Rear variable ballast tank and supports

The figure 2-8 shows the rear VBT, which assures the depth control and trimming. It has a buoyancy of 25 kg (minimum thickness of 2mm). This spherical tank with four brackets and one support, is connected to the depth and pitch panel through hydraulic pipes. The tank is welded at the middle, with a specific welded steam, which supports any over stress due to torsion.

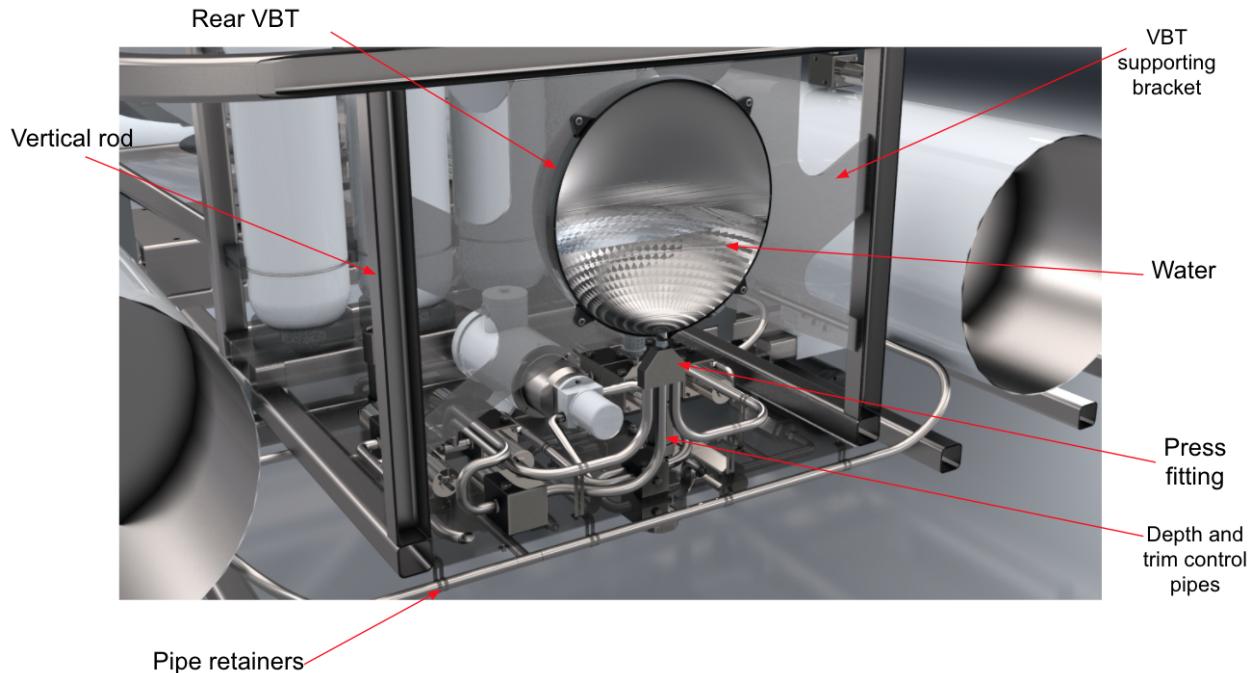


Figure 2-9: Water Level of rear VBT

The figure 2-9 is a cross section that shows the water lever in the VBT. In this situation, the VBT is half filled. The height of water at neutral buoyancy is fixed, and varies to control the ascent and descent speed of the submarine.

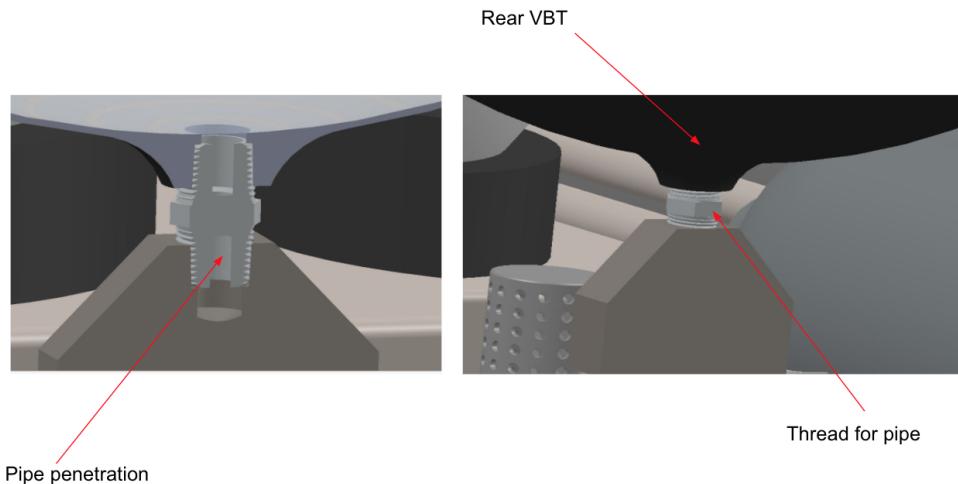


Figure 2-10: Rear VBT pipe penetration and threads

The figure 2-10 shows the connectivity of the pipes in the rear VBT. The pipe is threaded (male threads),

to be connected to the pipe penetration which is as well threaded (female thread) to ensure the best connectivity, at a high safety factor. Pipe sealants are added in the threaded joints, to prevent fluid from leaking out.

2.2.2 Front VBT

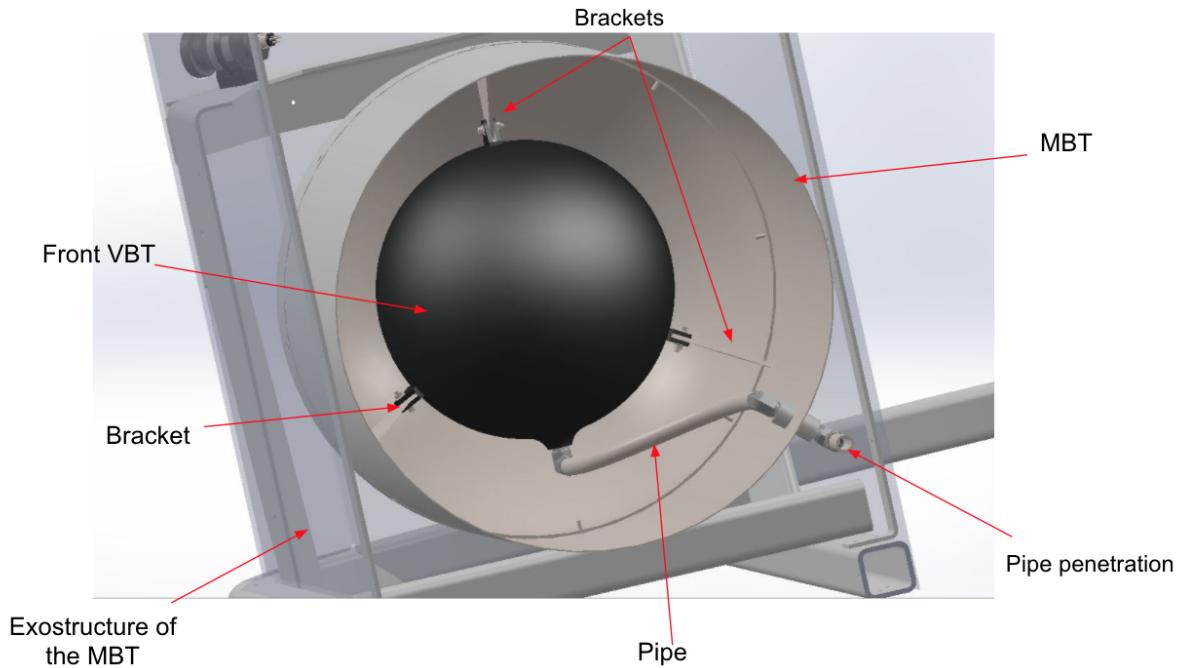


Figure 2-11: Front VBT with supports and brackets

The figure 2-11 shows the front VBT, which along with the rear VBT provides the trimming and depth control systems. Both front VBTs contribute with 25kg of buoyancy. That gives to the total variable system a buoyancy of 50kg. The two front VBTs are in the main ballast tanks. They are stabilized with brackets and supports, which ensures a high safety factor at any internal pressure of the main ballast tanks. The tank is welded at the middle, with a specific welded steam, which is going to support any over stress due to torsion.

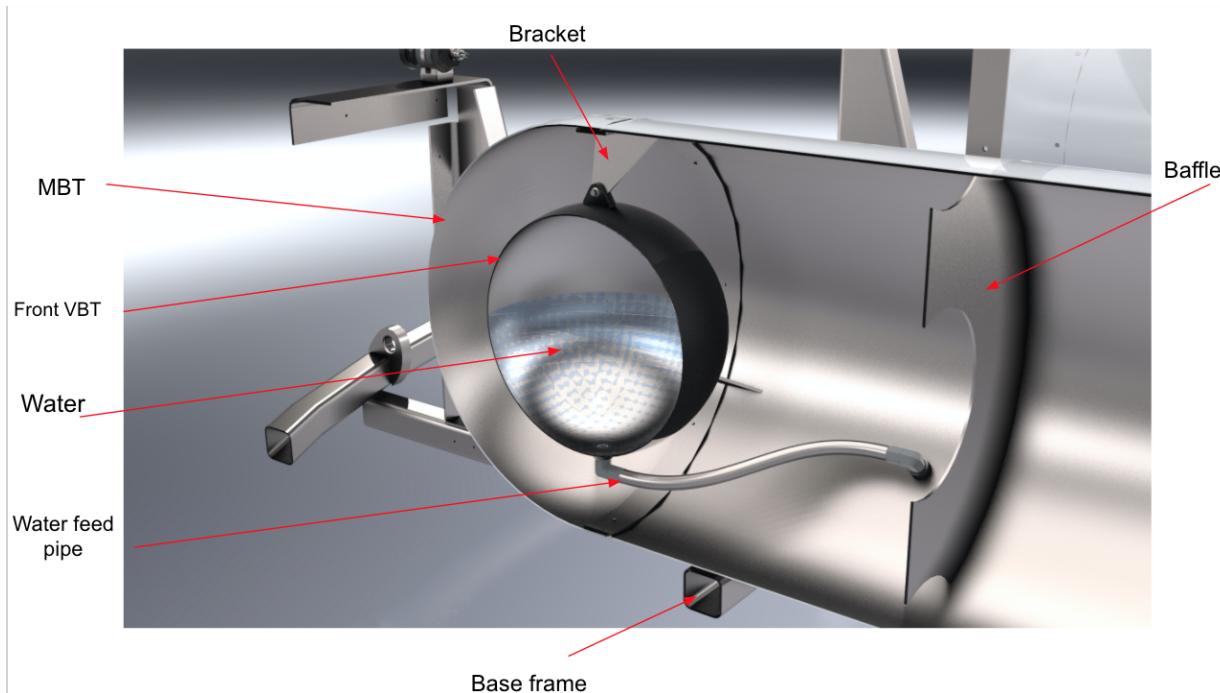


Figure 2-12: Water Level of Front VBT

As shown in the figure 2-12, the front VBTs provide neutral buoyancy. To achieve a maximum pitch, the hydraulic circuit is closed from sea water to allow moving water from one VBT to the other through the closed circuit.

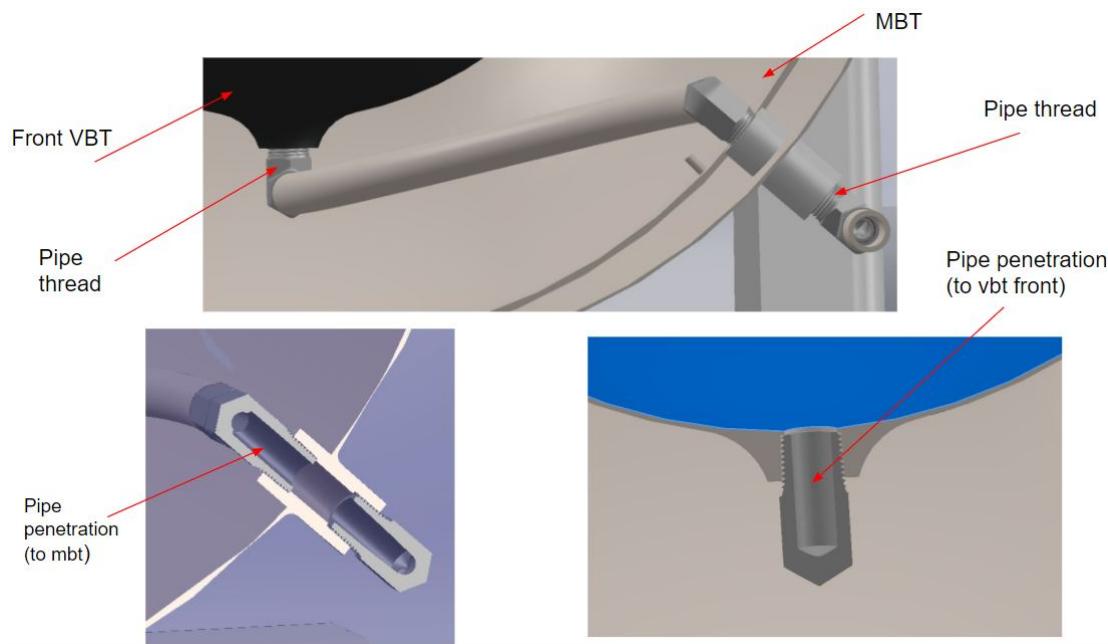


Figure 2-13: Front VBT pipe penetrations and threads

The figure 2-13 above shows the pipe entrances of the Front VBT and their fittings: the first entrance is from depth or pitch panel to the MBT, and the second entrance is to the VBT. For the fitting of the pipe, the pipe is threaded at the two entrances. Like the rear VBT, pipe sealants are used, on the threaded penetrations, to prevent fluids from leaking out.

2.3 Valve panel, pipes pump and motor

2.3.1 Valve panel

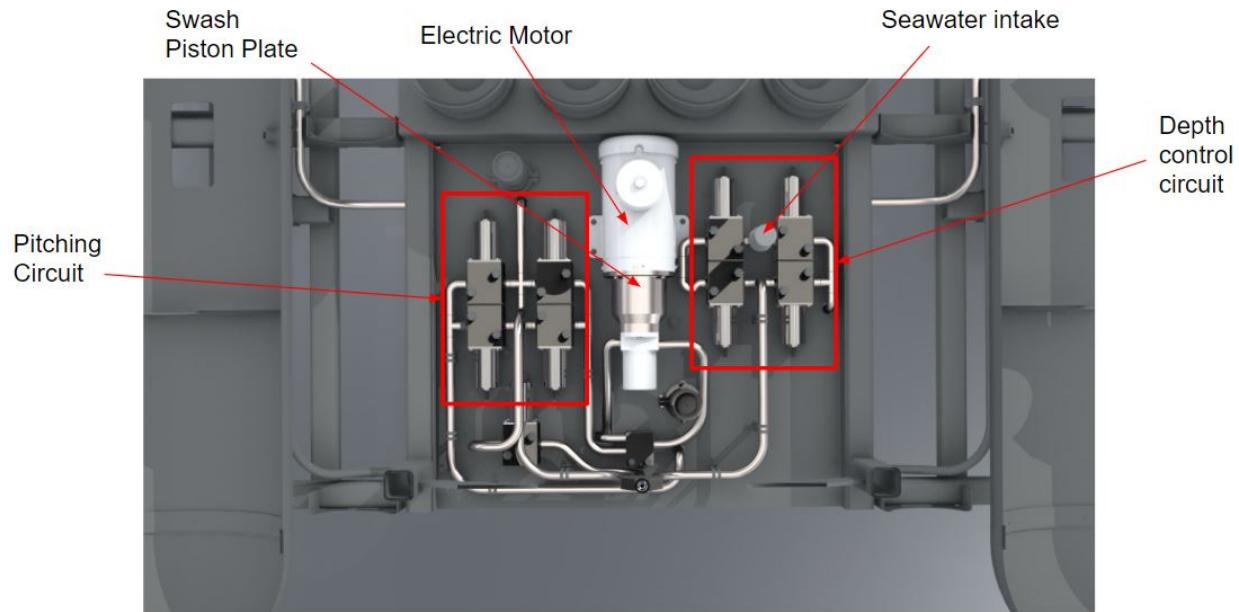


Figure 2-14: Top view of the valves panel with depth control and pitching circuit

The figure 2-14 shows the valve panel, with the two circuits: the depth control circuit, and the pitching circuit. Both circuits are related to the front and rear vbt. The depth control circuit controls the height of the water inside of the vbt, depending on the depth where the submarine is operating. the pitching circuit moves water from fronts VBTs to rear VBT, or the inverse. The maximum pitching angle obtained is 1.5° , since the buoyancy given by the VBTs is very small (50kg).

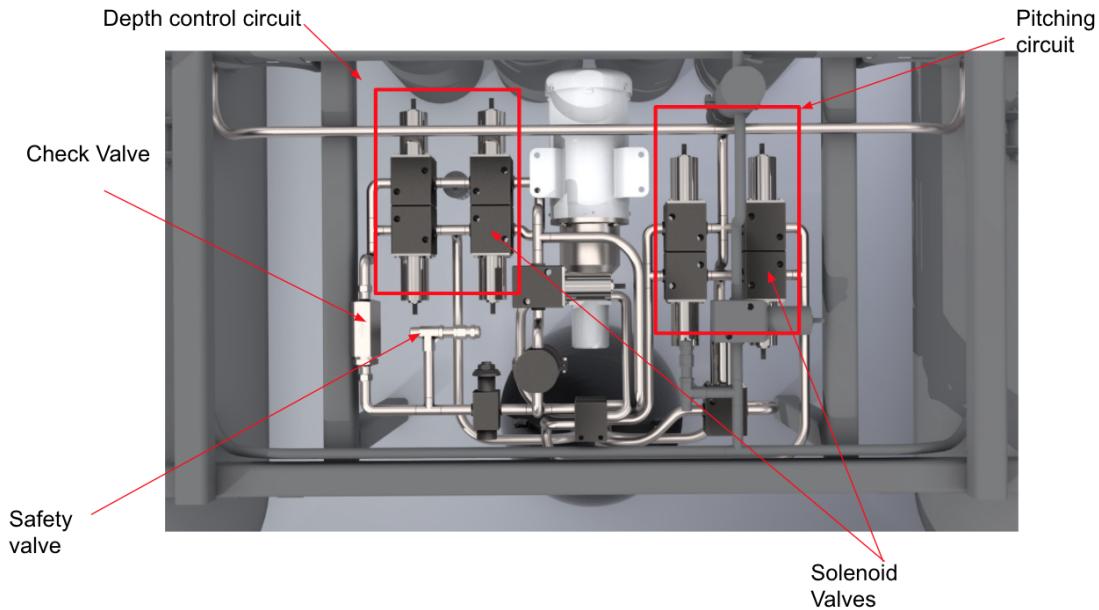


Figure 2-15: Bottom view of the valves panel with depth control and pitching circuit

As we can see on this figure 2-15, for both the depth control and the pitching control circuits, pipes are connected to solenoid valves, controlled automatically by the pilot, with the control panel in the pressure hull. The check valve provides back pressure surge protection to the pressure balance valve. The safety valve prevents over pressure of the seawater pump [7].

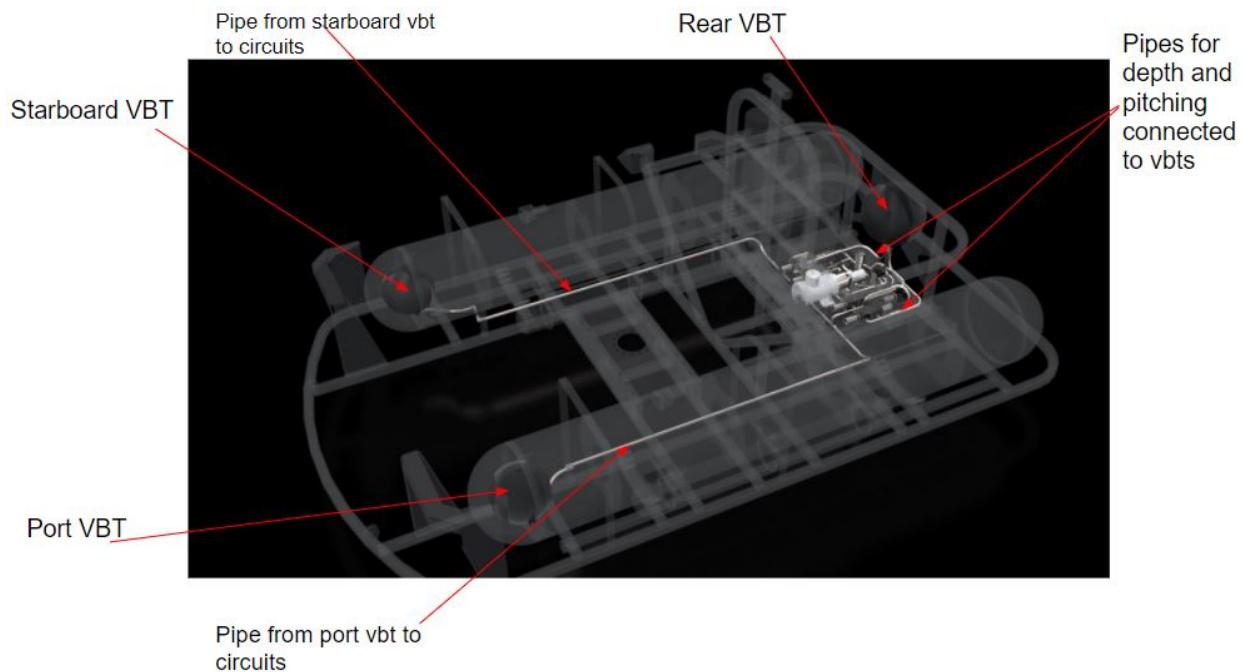


Figure 2-16: Pipes connections from VBTs to circuit

The figure 2-16 shows how the pipe is connected from the rear VBTs and Front VBTs to the circuits. The functionality of the circuit is on the appendix E.1.

2.3.2 Pump and Motor

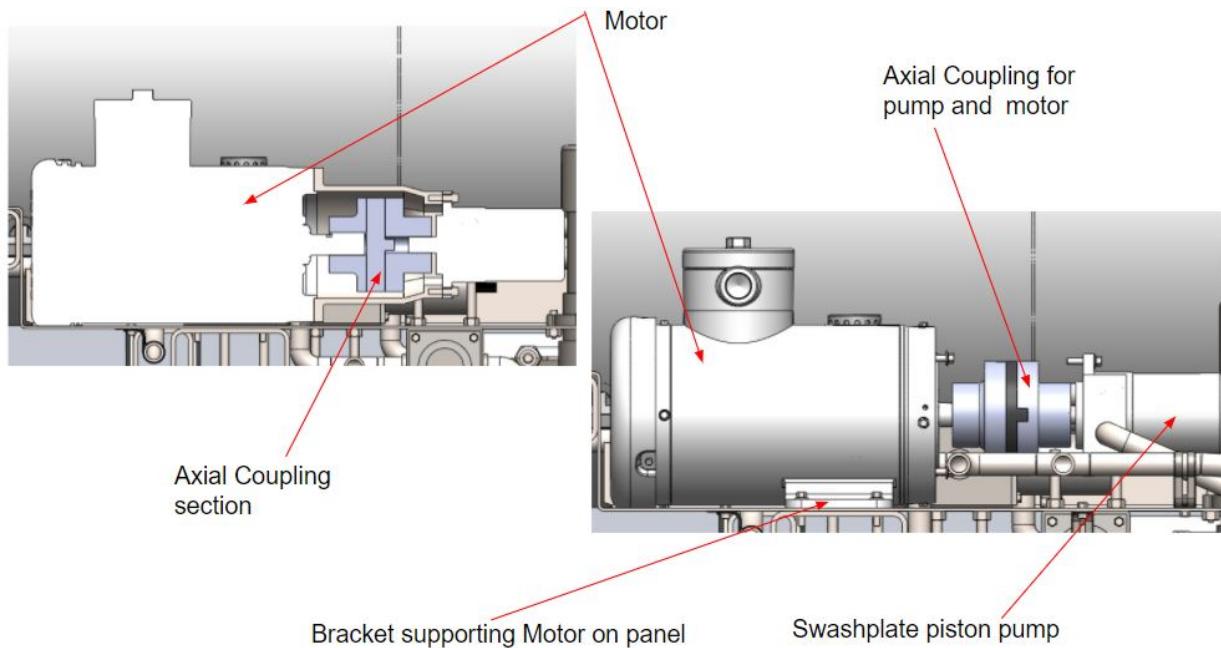


Figure 2-17: Pump and motor, with axial coupling

The figure 2-17 shows the pump and the motor from Danfoss (Appendix E). They ensure depth and pitching control. This pump is chosen by considering to satisfy maximum and minimum outlet and inlet pressures respectively. They work at any depth between 330m and 1000m. The axial coupling ensures a good connectivity and transmission between the pump and motor.

2.4 Drop Weights

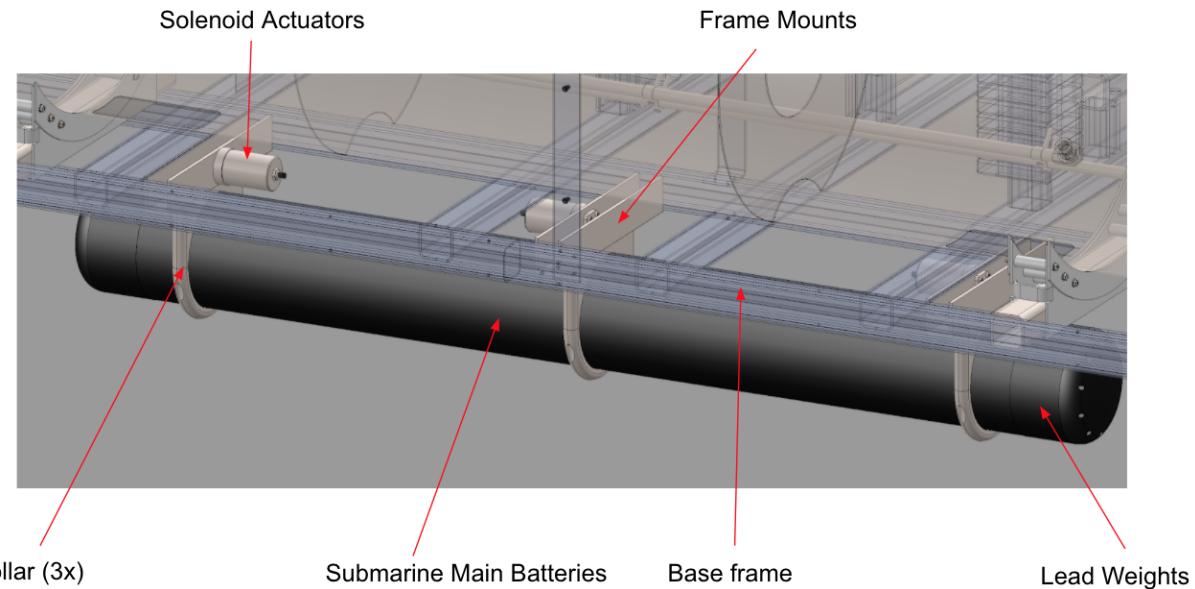


Figure 2-18: Drop Weights Assembly

Drop Weights are the primary safety feature of the design. Upon release, the sub is guaranteed to jettison to the surface. Figure 2-18 shows the Drop weights assembly. The middle of the weights is reserved for the main submarine batteries, if the design determines that more weight is needed then solid lead is added on both ends as needed. The weights are supported by three collars that are held in place with the frame mounts via solenoids actuators.

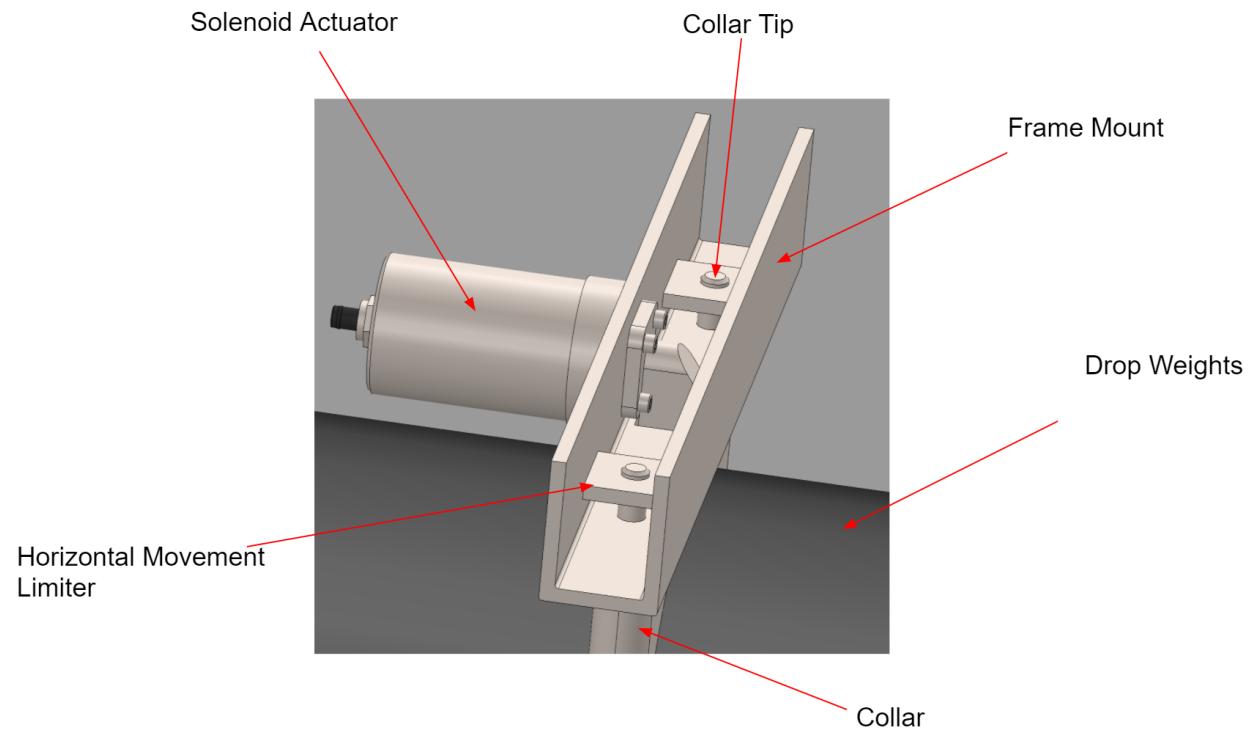


Figure 2-19: Drop Weights Mounts

The frame mounts has two horizontal movement limiter to restrict the movement drop wieghts in the horizontal plane. This can be seen in Figure 2-19.

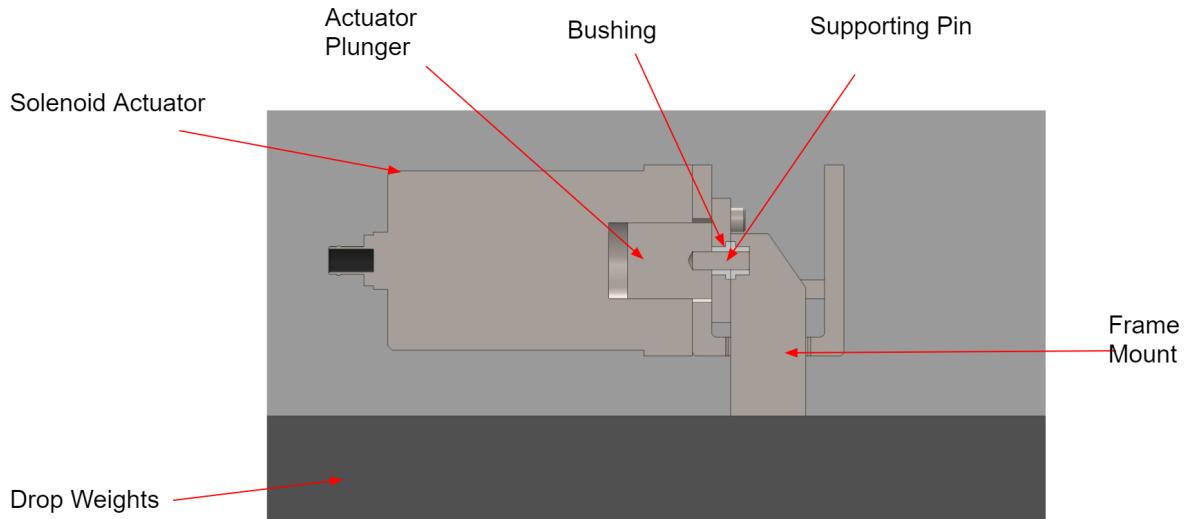


Figure 2-20: Drop Weights Actuator Cross Section

Figure 2-20 shows how the solenoid actuators are used to release the drop weights. Upon emergency, the plunger is pulled back sliding the pin out of the bushes and releasing the drop weights.

2.5 Interconnectivity

- Design

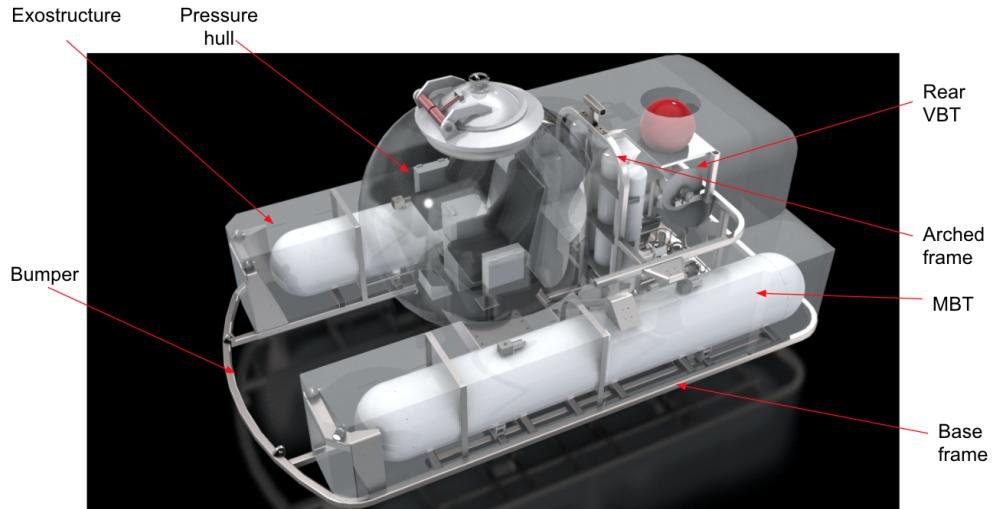


Figure 2-21: Interconnectivity of SUB1A and SUB1B designs

Team SUB1A is responsible for building the exostructure the hull, frame, hatch, seals and access mechanisms, as well as other other internal features. The MBTs have two brackets as seen on Figure 2-3, each one welded to a support beam. The support beams are welded to SUB1A's front base structure. The compressed air bottles rack is supported by three horizontal rear beams, which are welded to the arched structure of SUB1A behind the pressure hull in Figure 2-7. Three solenoid actuators mounts supporting the length of the drop weights. These mounts are welded to the base frame of SUB1A's design. The radial bracket of the VBT is welded the stern frame and the valve panel is also welded to the stern base frame as seen in Figure 2-8.

- Functionality

Initially, the overall design of the submarine with the exostructure and the ballast system combined, was not horizontally leveled. The center of gravity and buoyancy were not vertically aligned, which was causing the submarine to have a default pitch that can not be canceled by trim control alone. After bringing up the issue to SUB1A's team, it was agreed that the MBT's center of mass needs to be vertically aligned with the center of mass of the submarine. Additionally, a volume of at least $2.2m^3$ of foam placed at the rear of the submarine is needed to drag the center of mass of the submarine horizontally and align it with the center of buoyancy. The second issue brought up related to the overall mass of the submarine that was too high relative to its buoyancy. Consequently, both SUB1A and SUB1B had to shed as much weight as possible to make the submarine positively buoyant upon releasing the drop weights. Finally, Sub 1A team needed to store 250 kg of batteries on board. Consequently, It was agreed to store the batteries in the drop weights to avoid unnecessarily increasing the weight of the submarine.

3 Parameterization

3.1 Outline

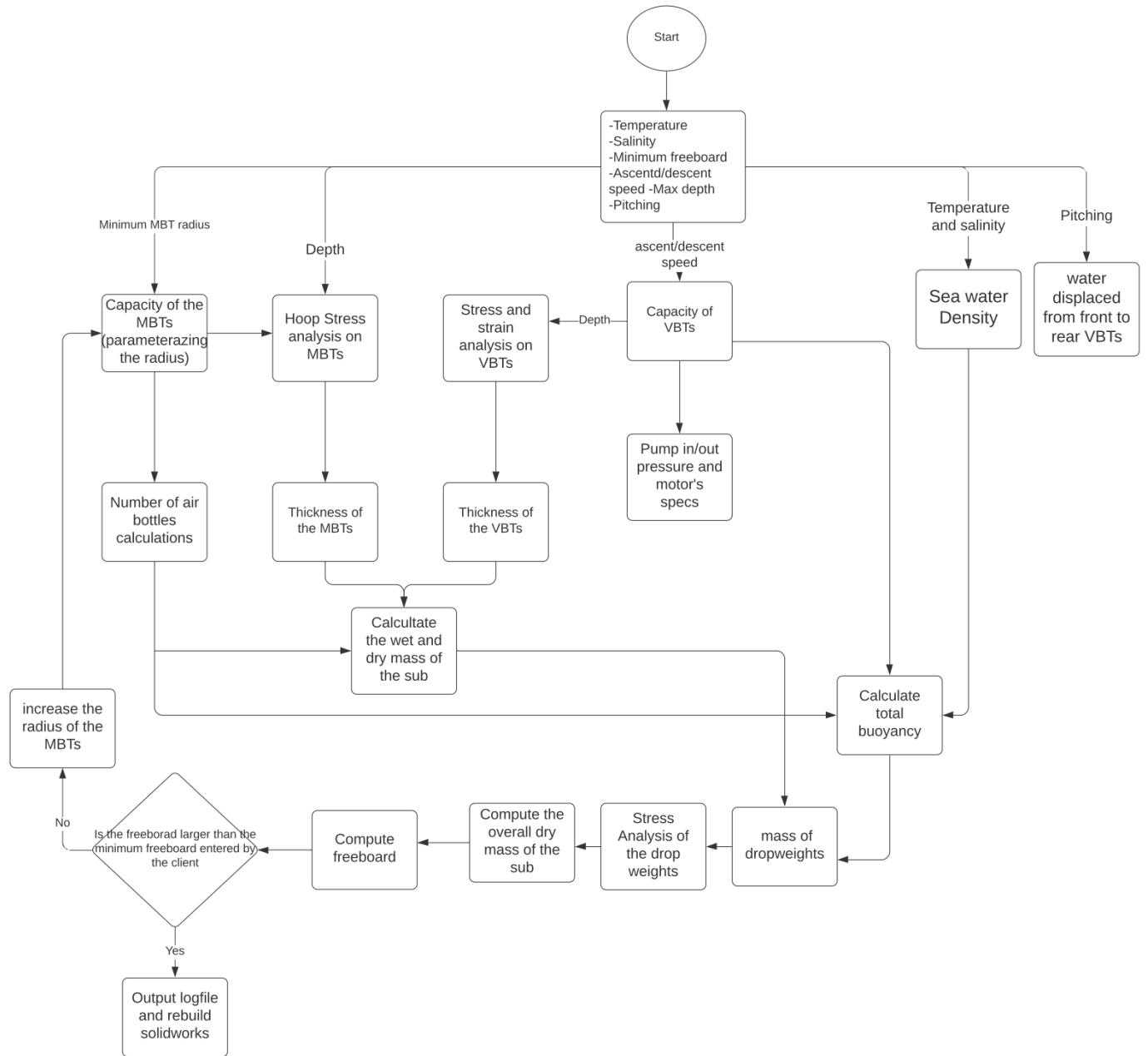


Figure 3-1: Parameterization outline

3.2 Component optimization and discussion on results

Table 3-1: Structural optimizations of the MBTs, VBTs and drop weights

Assembly	Components	Optimization
MBTs	Radius	$0.24 \text{ m} < R_{mbt} < 0.3 \text{ m}$
	Thickness	$1.4 \text{ mm} < t_{mbt} < 1.7 \text{ mm}$
	Number of air bottles	$1 < N_{air.b} < 4$
Fronts VBTs	Capacity	$6.25 < M_{water.f} < 12.5 \text{ kg}$
	Thickness	$2.001 \text{ mm} < t_{vbt.f} < 3.428 \text{ mm}$
Rear VBT	Capacity	$12.5 < m_{water.vbt} < 25 \text{ kg}$
	Thickness	$2.001 < t_{vbt.r} < 4.241$
Drop weights	length	$1.659 \text{ m} < L_{dw} < 2.371$
	Number of solenoid actuators	$1 < N_{airbottles} < 4$

The parameterization of the components above on table 3-1 allows to determine an optimized range of values depending on the desired inputs by the user. The range range of depths from 330m to 1000m effects primarily the thickness of the the MBTs and the VBTs. The shallower the maximum depth is, the lower the thicknesses needed to overcome Hoop stresses and the lower the number of air bottles needed for emergency surfacing on air. The submarine therefore becomes lighter. Consequently, this increases the mass of the drop weights, hence their length and the number of solenoid actuators needed for their release. On the other hand, decreasing the radius of the MBTs decreases the freeboard of the submarine, but also decrease the number of air bottles needed to blow the MBTs. The density of water is a key factor in determining the buoyancy of the submarine. If the user inputs the lowest temperature and the highest salinity, this will allow the highest buoyancy and therefore a higher value for the mass of drop weights needed to keep the submarine neutrally buoyant. Additionally, the fastest emergency ascent is achieved when the drop weights are the heaviest. At neutral buoyancy, the MBTs are completely submerged with water and the front and rear VBTs are half filled with water. For ascent and descent control, 25kg of buoyancy is added or subtracted from the VBTs and 500N of upward/downward force of the thrusters to a reasonably good ascent and descent time. The figure bellow shows two extreme of cases parameterization

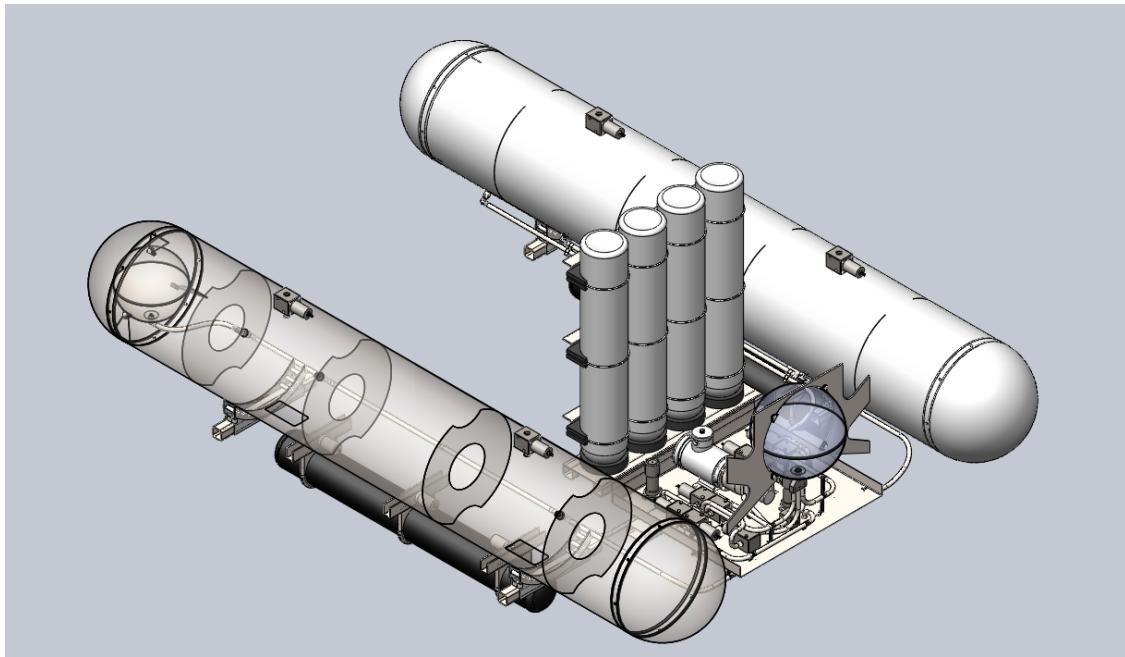


Figure 3-2: Assembly showing Maximum MBTs Size, VBT Capacity and Number of Air Bottles

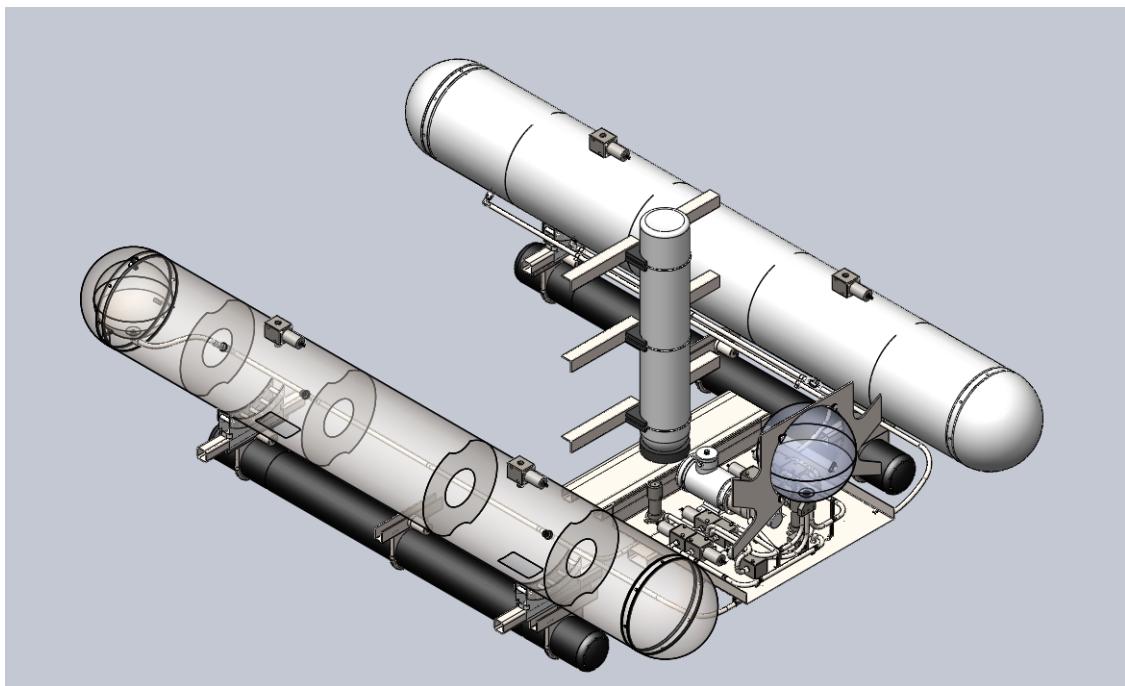


Figure 3-3: Assembly showing Minimum MBTs Size, VBT Capacity and Number of Air Bottles

The first case shown on Figure 3-2 is under conditions of highest maximum depth (1000m), lowest buoyancy (highest temperature and lowest salinity), and highest freeboard (highest MBT radius and number of compressed air bottles). This results in having the smallest length for the drop weights due to the heavy mass of the submarine. The second case, Figure 3-3 presents opposite conditions that showcase the smallest depth depth at 330m, highest buoyancy and lowest freeboard (smallest MBT radius and number of air bottles). This results in having the largest and heaviest drop weights.

4 Discussion and critical review of the solution

The ballast systems and drop weights of this design are capable of satisfying the required functionalities of the submarine. The MBTs are capable of contributing 2200 kg of buoyancy for surfacing purposes and achieving enough free board to allow passengers to enter the hatch. The saddle design of the MBTs also contributes to stabilizing the submarine on the surface during passengers and equipment's entry. The MBTs are completely vented and filled with water to initiate the descent. At neutral buoyancy, the MBTs remain flooded and the VBTs are at 50% of their capacity. Flooding the MBTs solves a major issue of the compressibility of air inside the MBTs. If the MBTs were not completely vented, the air will compress more the deeper the submarine dives. Air bubbles will start forming trapped inside the MBT's water and will be difficult to vent for ascent. Using VBTs and thrusters only for depth control makes this design simple, cost efficient and adjustable to different applications that can suit different market demands.

Parameterization allowed evaluating the design's performance under different conditions, under the constraints of a 1000m maximum depth, 2200kg and 50kg maximum buoyancy from the MBTs and VBTs respectively. The VBTs design is capable of affording speeds up to. The MBTs parameterization allows a minimum freeboard ranging from 0.5m to 0.95m. The VBTs allow an ascent and descent up to 0.5m/s while only using a 6th of the thrusters maximum power, which saves on energy consumption and cost. In any case of outage of power, the submarine is capable of surfacing at 12.6mins from a maximum depth upon releasing the drop weights. the submarine is also equipped with enough compressed air bottles to afford a second emergency procedure that consists of blowing the air in the MBTs at any maximum depth if there is no outage of power. This procedure permits costs less than releasing drop weights which are storing batteries, is fast enough to accommodate an emergency event (13 mins from maximum depth).

The front and rear VBTs are connected to a closed loop circuit that allows trim control at neutral buoyancy. However, the constraint of 50kg of buoyancy from the VBTs restricted the range of trim control to 1.37° to 1.79°. To accommodate this constraint on the capacity of the VBTs, a parameterization of the position of the rear VBTs was initially tested to attempt optimizing the maximum pitch. However, only a maximum pitch of 2° was obtained upon translating the rear VBT further away from the front VBTs by 0.8m. After further calculations, the results demonstrated that ideal trim angle ranges of 5° to 10° can only be achieved with VBTs with capacities of at least 100kg. This design would have been able to afford the ideal trim range for no additional cost if the mandate allowed 100kg buoyancy from the VBTs.

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A Instructions for installing and running the GUI

To run the GUI, open the main.m file available in SUB1B directory and click on Run as shown below

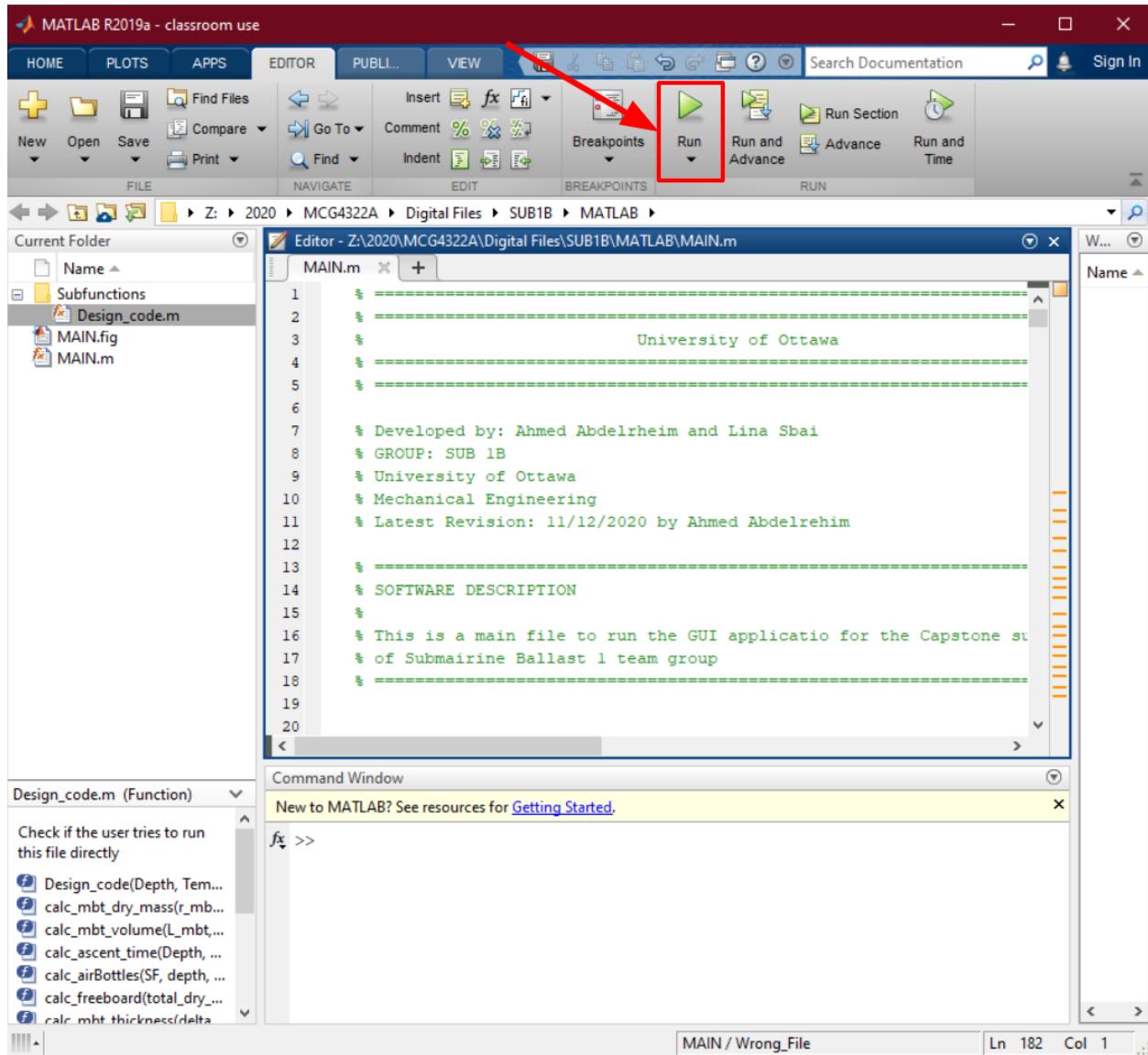


Figure A-1: Clicking Run to start the GUI application

Once you click on Run, the following GUI should pop up.

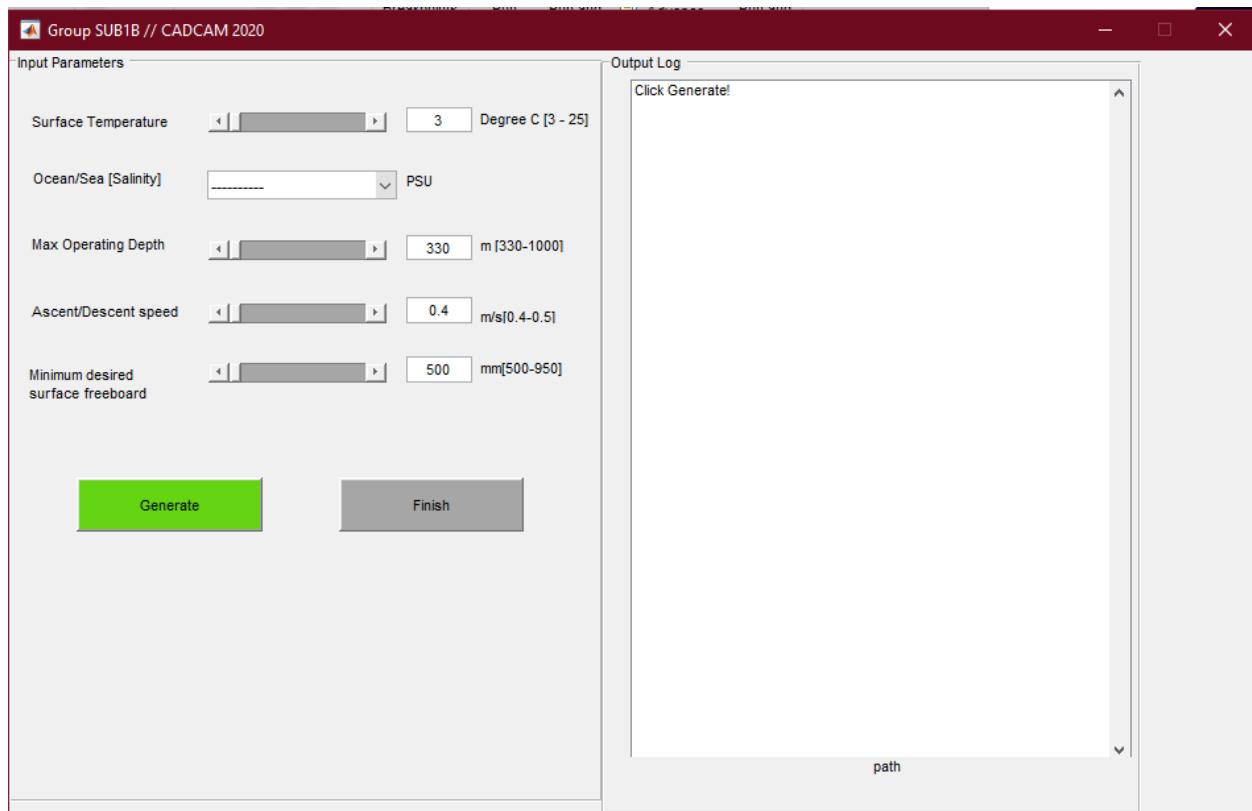


Figure A-2: The Parameterisation GUI Upon Startup

You can now set the input parameters that fit your requirements. Once the inputs are in, click on the green button Generate to see the result of the right panel on the GUI as seen below

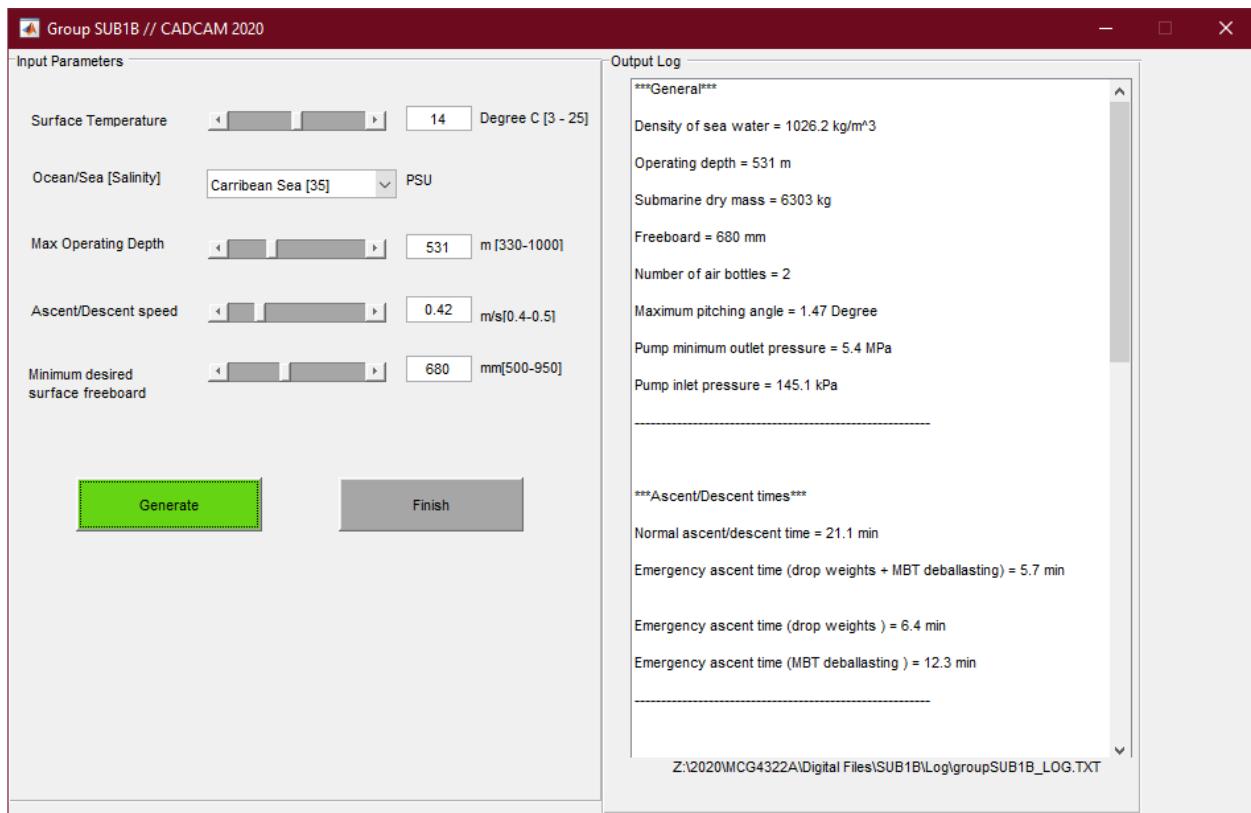


Figure A-3: The Results of Parameterisation After Clicking Generate

B Component parameterization flowcharts

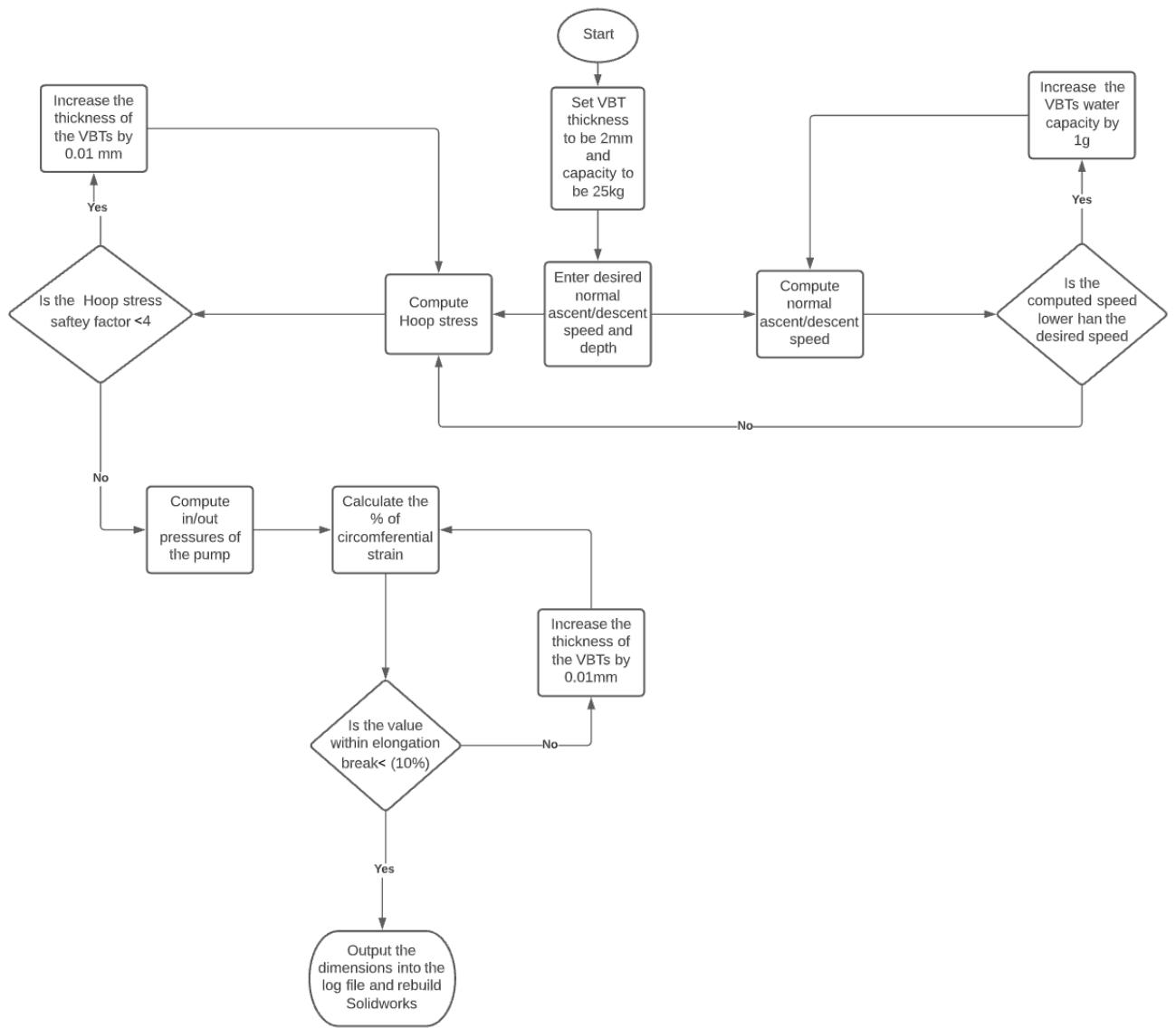


Figure B-1: VBT Parameterization outline

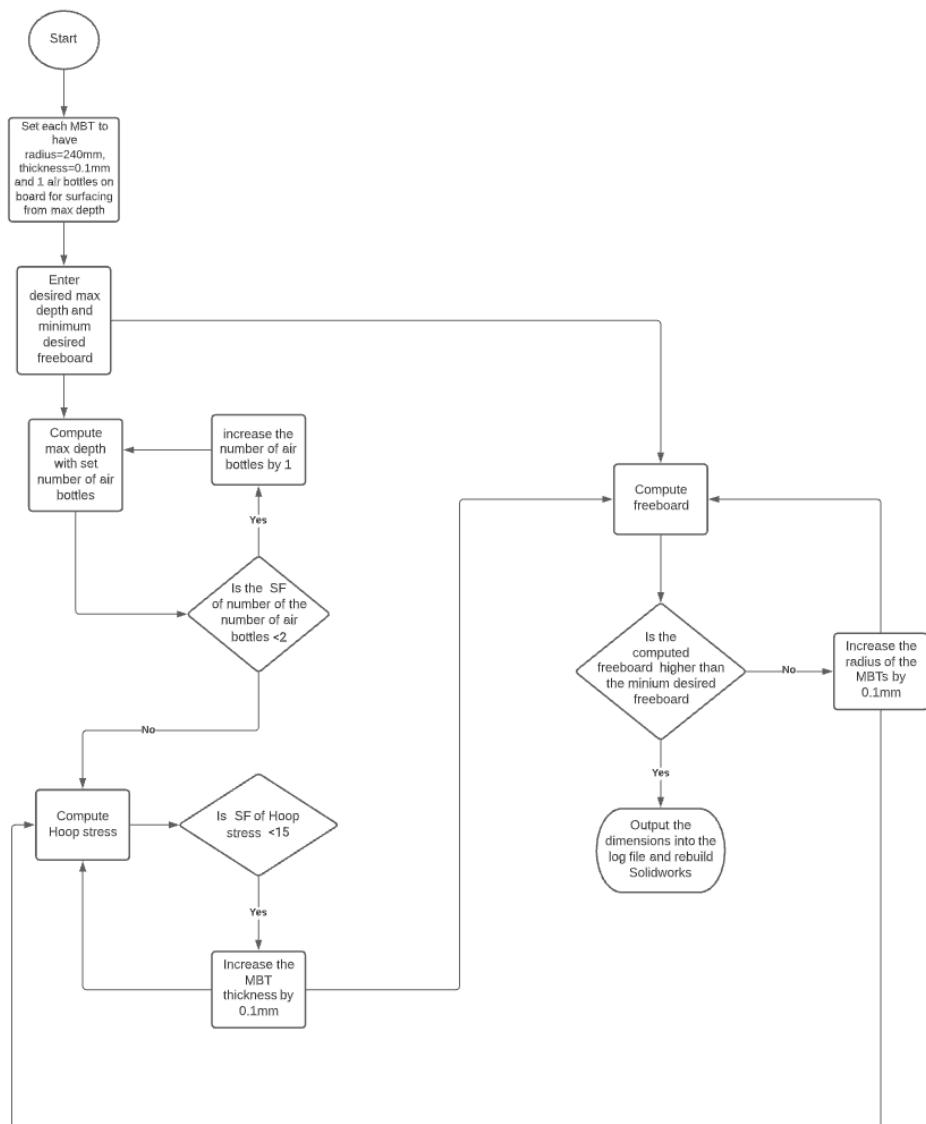


Figure B-2: MBT Parameterization outline

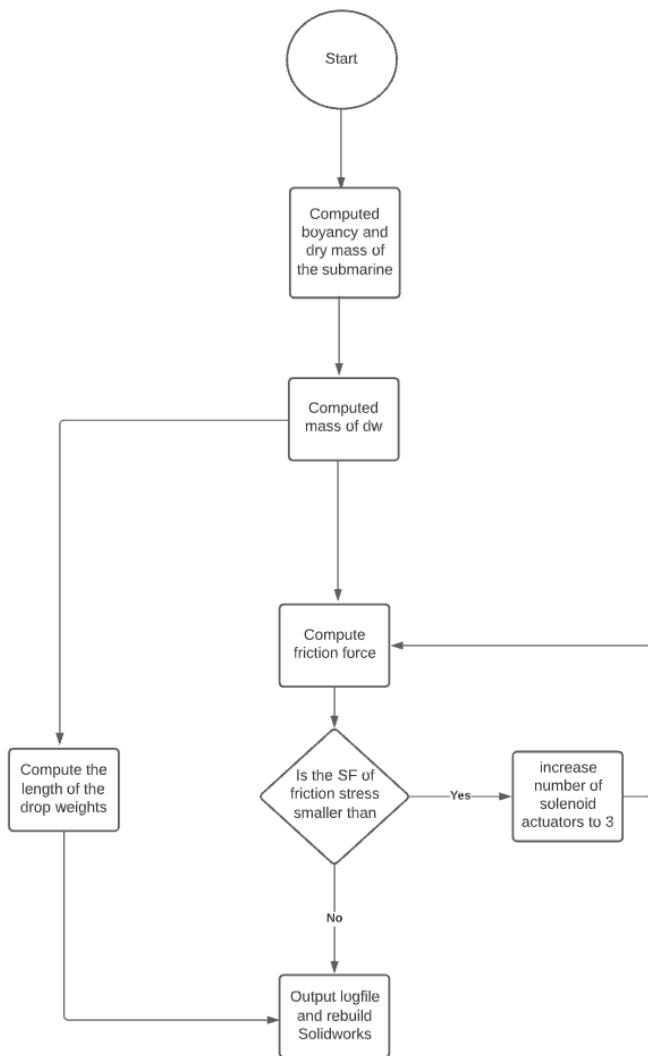


Figure B-3: Drop Weights Parameterization outline

C Design code

```

1
2 function Design_code(Depth, Temperature, Freeboard, ADspeed, Salinity)
3 %Check if the user tries to run this file directly
4 if ~exist('Depth', 'var')
5     cd H:\groupSUB1B\MATLAB\
6     run H:\groupSUB1B\MATLAB\Main.m; %Run Main.m instead
7     return
8 end
9
10 log_file = 'Z:\2020\MCG4322A\Digital Files\SUB1B\Log\groupSUB1B.LOG.
11             TXT';
12 fid = fopen(log_file, 'w+t');
13
14
15 %% constants to be used
16 rho=calc_density_seawater(Temperature, Salinity); %Units (kg/m^3), density
17 of the sea water at a given temperature and salinity
18 g=9.81; %(N/Kg) gravitational acceleration constant
19 P_atm=101325; %Units (Pa), atmospheric pressure
20 mbt_delta_pressure = 200E3; %(Pa) Pa), regulators of the MBTs insure that
21 the pressure difference between the inside and outside of the MBTs is
22 always 200kPa
23
24 %%%
25 %%VBT Calculations%%
26 %%%
27
28 %safety factors
29 vbt_Hs_SF=4; % Hoop stress
30
31 %The following is a list of constants and calculations of masses, volumes
32 and dimensions of the front and back VBTs
33
34 V_vbt_r=0.048; %Units (m^3), Volume of the rear VBT
35 V_vbt_f=0.024; %Units (m^3), Volume of front VBTs
36 R_vbt_r=0.226; %Units (m), outer radius of the rear VBT

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34 R_vbt_f=0.179; %Units (m), outer radius of front VBTs
35 vbt_cap_neutBuoy=25; %(kg) amount of water in VBT to get sub to neutral
36 bouyancy
37
38 %The following are function calls to calculate the new water capacity of
39 %the VBTs
40 vbt_capacity=calc_VBT_capacity(rho,ADspeed, vbt_cap_neutBuoy);
41
42
43 %The following are calculations of pressures inside the VBTs due to the
44 %the mass of water inside
45
46 P_rear=(P_atm*V_vbt_r)/(V_vbt_r-((0.5*vbt_capacity)/rho)); %Units (Pa),
47 %pressure of the air inside the rear VBT when compressed by water
48 P_front=(P_atm*V_vbt_f)/(V_vbt_f-((0.25*vbt_capacity)/rho));%Units (Pa),
49 %pressure of the air inside the front VBT when compressed by water
50 P_sea=P_atm+rho*g*Depth; %Units (Pa), sea water pressure at a chosen depth
51 %entered by the client
52 P_out_front=P_sea+mbt_delta_pressure;
53
54 %The following are function calls to calculate the new optimized thickness
55 %of the rear and front VBTs at a given depth with a safety factor of 2
56 vbt_r_thickness=calc_VBT_thickness(R_vbt_r, P_sea, P_rear, vbt_Hs_SF);%
57 %Units (m),new thickness of the rear VBT
58 vbt_f_thickness=calc_VBT_thickness(R_vbt_f, P_out_front, P_front,
59 %vbt_Hs_SF);%Units (m),new thickness of the front VBT
60 %Displaying the new values of the thickness of the rear and front VBTs
61
62 f_vbt_water_height = calc_VBT_water_height(rho,0.25*vbt_capacity,(R_vbt_f-
63 vbt_f_thickness));
64 r_vbt_water_height = calc_VBT_water_height(rho,0.5*vbt_capacity,(R_vbt_r-
65 vbt_r_thickness));
66
67
68
69
70
71 %The required inlet and outlet pump specifications for pitching and depth
72 %control purposes

```

```

62 P_out_pump=P_sea ;
63 P_in_pump=P_rear ;
64
65 %Displaying pump and motor specs
66
67 %fprintf(fid , sprintf( 'The motor specifications are:\n' ,) ;
68
69 %The following are function calls to calculate the new optimized masses of
70 %the rear and front VBTs at a given depth with a safety factor of 2
71 m_dry_vbt_r=calc_mass_material(R_vbt_r,vbt_r_thickness); %Units (kg) , new
72 % dry mass of the rear VBT
73 m_dry_vbt_f=calc_mass_material(R_vbt_f,vbt_f_thickness); %Units (kg) , new
74 % dry mass of the front VBTs
75
76 %%%%%%
77 %MBT Calculations%%
78 %%%%%%
79
80 mbt_length = 3.44;% $(m^3)$ 
81 mbt_min_radius=0.24; %(m)minimum radius of mbt due to the front vbt
82 sub_area_projected = 7.543; %( $m^3$ )
83
84
85 %%foam%%
86 V_foam=2.21; %( $m^3$ )
87 rho_foam=385; %( $kg/m^3$ )
88 m_foam = V_foam*rho_foam; %(kg)
89
90
91 %submarine constant masses
92 m_sub1A=3755;%(kg) given to us by sub 1A team
93 m_payload = 250;%(kg) payload is kept constant at 250 by adding tungsten
94 % weights , taken care of by sub 1A
95 m_valve_panel = 212.37;%(kg)
96 m_air_bottle = 137.44;%(kg)
97 m_vbt_total = 2*m_dry_vbt_f+m_dry_vbt_r; %(kg) we have 2 front and 1 rear

```

```

vbt
98 V_pressureHull=(4/3)*pi*0.97^3; %(m^3) volume of the pressure hull
99 V_air_bottle = 0.043; %(m^3) volume of one air bottle
100
101
102 %safety Factors
103 air_bottles_SF=2;
104 mbt_thickness_SF=15;
105
106
107
108 %%now we optimise everything until we get a suitable freeboard
109 flag=false;
110 computed_freeboard=0;
111 mbt_diameter = 2*mbt_min_radius; %(m) minimum starting diameter due to the
112 presence of front VBT
113 while(computed_freeboard<Freeboard/1000)
114     %skip increasing the diameter in the first loop
115     %to see if the starting diameter will
116     %work for freeboard
117     if(flag)
118         mbt_diameter=mbt_diameter+0.0001;% (m)
119     end
120
121     %maximum MBT capacity of 2200kg as entitled in the project mandate
122     if(mbt_diameter>0.6)
123         fprintf(fid,sprintf('Maximum allowable freeboard with this
124             combination is %.0f mm. Please try different inputs\n\n',
125             computed_freeboard*1000));
126         break;
127     end
128     flag=true;
129
130     %find MBT volume
131     mbt_volume = calc_mbt_volume(mbt_length, mbt_diameter/2); %(m^3)
132
133     %optimise number of air bottles based on current MBT diameter and
134     %desired depth
135     Num_air_bottles=calc_airBottles( air_bottles_SF ,Depth ,mbt_volume ,279 ,
136     rho);

```

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133
134 %optimise mbt thickness based on MBT diameter and desired depth
135 mbt_thickness=calc_mbt_thickness( mbt_delta_pressure , mbt_diameter/2 ,
136 mbt_thickness_SF );%(m)
137
138 mbt_dry_mass=calc_mbt_dry_mass( mbt_diameter/2,mbt_length,mbt_thickness
139 ); %(kg)
140
141 %find current total submarine masses (dry and wet)
142 sub_dry_mass = m_sub1A+m_payload+m_valve_panel+m_air_bottle*
143 Num_air_bottles+m_foam+m_vbt_total+2*mbt_dry_mass; %(kg)
144
145 %note that the wet mass is with VBT partially filled with water to get
146 %neutral
147 %buoyancy
148 sub_wet_mass = sub_dry_mass+(2*rho*mbt_volume)+vbt_cap_neutBuoy; %(kg)
149
150 % main volume contributing to the buoyancy of the sub
151 buoyant_volume = V_foam+(2*mbt_volume)+V_vbt_r+V_pressureHull+
152 Num_air_bottles*V_air_bottle); %(m^3)
153
154 %force calculations
155 F_gravity = sub_wet_mass*g;%(N) % weight of the sub without the drop
156 weights
157
158 F_bouyancy = buoyant_volume*rho*g; %(N) % maximum buoyancy of the
159 submarine
160
161 F_net = F_bouyancy-F_gravity; %(N) delta force
162
163
164 %find drop weights to get the sub to neutral buoyancy at partially
165 %filled VBTs as discussed
166 m_drop_weights=F_net/g; %(kg)
167
168 % total mass with drop weights
169 sub_dry_mass_total = sub_dry_mass+m_drop_weights; %(kg)
170
171
172 %compute freeboard based on new total mass. If less than desired,

```



```

199 fprintf(fid , sprintf('***General***\n'));

200

201 fprintf(fid , sprintf('Density of sea water = %0.1f kg/m^3\n', rho));
202 fprintf(fid , sprintf('Operating depth = %0.0f m\n', Depth));
203 fprintf(fid , sprintf('Submarine dry mass = %0.0f kg\n', sub_dry_mass_total));
204 ;
205 fprintf(fid , sprintf('Freeboard = %0.0f mm\n', computed_freeboard*1000));
206 fprintf(fid , sprintf('Number of air bottles = %0.0f\n', Num_air_bottles));
207 fprintf(fid , sprintf('Maximum pitching angle = %0.2f Degree \n',
208 Pitching_angle));
209 fprintf(fid , sprintf('Pump minimum outlet pressure = %0.1f MPa\n',
210 P_out_pump/1000000));
211 fprintf(fid , sprintf('Pump inlet pressure = %0.1f kPa\n', P_in_pump/1000));
212 fprintf(fid , sprintf('
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228
229     fprintf(fid , sprintf( '***VBT***\n')) ;
230     fprintf(fid , sprintf( 'VBTs capacity = %0.1f kg\n' , vbt_capacity)) ;
231     fprintf(fid , sprintf( 'Thickness of rear VBT is=%0.2f mm\n' , vbt_r_thickness
232             *1000));
233     fprintf(fid , sprintf( 'Thickness of front VBT  is=%0.2f mm\n' ,
234             vbt_f_thickness*1000));
235     fprintf(fid , sprintf( '
236             \n')) ;
236
237     fprintf(fid , sprintf( '***Drop Weights***\n')) ;
238     fprintf(fid , sprintf( 'drop weights mass = %0.1f kg\n' ,m_drop_weights)) ;
239     fprintf(fid , sprintf( 'drop weights length = %0.1f mm\n' ,(dw_length*1000)
240             +1655));
241     fprintf(fid , sprintf( 'The number of solenoid actuators = %i\n' ,num_sol));
242     fprintf(fid , sprintf( '
243             \n')) ;
243
244     fprintf(fid , sprintf( '***Net forces at differnt states***\n')) ;
245     fprintf(fid , sprintf( 'Buoyancy Force = %0.1f N\n' ,F_bouyancy)) ;
246     fprintf(fid , sprintf( 'Gravitational Force(without dropweights) = %0.1f N\n'
247             ,-F_gravity));
248     fprintf(fid , sprintf( 'Net Force (without dropweights)= %0.1f N\n' ,
249             F_bouyancy-F_gravity));
250     fprintf(fid , sprintf( 'Gravitational Force (with dropweights) = %0.1f N\n' ,-
251             F_gravity-m_drop_weights*g));
252     fprintf(fid , sprintf( 'Net Force (with dropweights i.e neutral buoyancy)=
253             %0.1f N\n' ,F_bouyancy-F_gravity-m_drop_weights*g));
254     fclose(fid);
255
256
257     %Declaring text files to be modified
258     %Files
259
260
261     equations_file = 'Z:\2020\MCG4322A\Digital Files\SUB1B\Solidworks\
262                     equations.txt';
263
264
265
266
267     %Write the equations file(s) (FILE(s) LINKED TO SOLIDWORKS).

```

```

258 %You can make a different file for each section of your project (ie
259     one for steering , another for brakes , etc...)
260 %or one single large file that includes all the equations. Its up to
261     you!
262
263 fid = fopen(equations_file , 'w+t');
264 fprintf(fid , strcat( ''r_o''= , num2str(( mbt_diameter+mbt_thickness)*1000/2) , '
265     '\n'));
266 fprintf(fid , strcat( ''t''= , num2str(mbt_thickness*1000) , '\n'));
267 fprintf(fid , strcat( ''t_vbt''= , num2str(vbt_f_thickness*1000) , '\n'));
268 fprintf(fid , strcat( ''vbt_water_height''= , num2str(f_vbt_water_height*1000) ,
269     '\n'));
270 fprintf(fid , strcat( ''t_vbt_rear''= , num2str(vbt_r_thickness*1000) , '\n'));
271 fprintf(fid , strcat( ''vbt_water_height_rear''= , num2str(r_vbt_water_height
272     *1000) , '\n'));
273
274 fclose (fid);
275
276
277 end
278
279 %function to calculate the dry mass of the MBT
280 function mbt_dry_mass = calc_mbt_dry_mass(r_mbt,L_mbt,t_mbt)
281
282 %Eq.(1)
283
284 %mbt are made from stainless steel
285 rho_ss=7800; %(kg/m^3)
286
287 m_mbt_peripherals=98.6; %air vents , baffles , mounting brackets
288
289 mbt_material_volume=pi*(L_mbt*(r_mbt+t_mbt)^2+(4/3)*(r_mbt+t_mbt)^3-L_mbt*
290     r_mbt^2-(4/3)*r_mbt^3);%(m^3)
291 mbt_dry_mass=(mbt_material_volume*rho_ss)+m_mbt_peripherals;%(kg)
292
293 end
294
295 %function to calculate the volume of the MBT
296 function mbt_volume = calc_mbt_volume(L_mbt , r_mbt)

```

```

292 %Eq.(2)
293 mbt_volume = pi*r_mbt^2*L_mbt + (4/3)*pi*r_mbt^3;
294 end
295
296 %function to calculate the ascent time by equating vertical forces
297 function ascent_time = calc_ascent_time(Depth, area_proj, rho, mbt_radius,
298 drop_weight_mass)
299 %Eq.(3)
300 mbt_length=3.44;%m constant length to enable max pitching
301 C_d = 0.8;%found by looping over reynolds number
302
303 mbt_volume = calc_mbt_volume(mbt_length, mbt_radius);%(m^3)
304
305 %the net force is only coming from MBTS, assuming the average displaced
306 %volume to be 20%, because the 10% purge will keep expanding as the
307 %submarine move up, this is combined with the upward force from
308 %dropping the drop weights
309 Net_upward_force=0.2*mbt_volume*rho*9.81+ drop_weight_mass*9.81;%N
310
311 %ascent speed can now be calculated by equating the upward force to
312 %drag force
313
314 ascent_speed = sqrt((2*Net_upward_force)/(area_proj*C_d*rho));%(m/s)
315
316 %finding time
317 ascent_time = Depth/(ascent_speed*60); %(min)
318
319
320 %function to find number of air bottles based on depth and MBT volume
321 function new_num_airbottles = calc_airBottles(SF, depth, mbt_volume, Temp, rho)
322
323 %Eq. (4)
324
325 P_atm = 101325; %(Pa)
326 R_air = 287;% (J/(kg*K)) air ideal gas constant
327 P_bottle = 41.4e+6 ;%(Pa) air pressure in bottle
328 V_bottle = 0.043; %(m^3) volume of air
329 %calculte pressure at max depth
330

```

```

331 P_max = P_atm+ rho*9.81*depth;
332
333 %calculate the mass of air needed to fill 10% of the mbt volume at
334 %max depth
335 mass_air_mbt = (2*P_max*mbt_volume*0.1)/(R_air*Temp);%(kg)
336
337 %air is going to get out of the bottle until the inside pressure is
338 %equal to ambient pressure P_max
339
340 %so the mass of air to get out of one bottle is
341 mass_air_bottle_out = ((P_bottle - P_max)*V_bottle) / (R_air*Temp);%(kg)
342
343 %optimise number of air bottles
344 num_bottles = 0;
345 n=0;
346 while(n<SF)
347
348     num_bottles = num_bottles+1;
349     %new safety factor
350     n = (num_bottles*mass_air_bottle_out)/mass_air_mbt;
351
352 end
353
354 new_num_airbottles = num_bottles;
355 end
356
357 %Finding freeboard based on net weight and surface buoyancy
358 function new_freeboard = calc_freeboard(total_dry_mass , rho , r_mbt)
359
360 %Eq. (5)
361 %solidworks dimensions
362 %foam
363 L_foam=2.6; %(m)
364 W_foam=0.83; % (m)
365 H_foam= 1.16; % (m)
366
367 %pressure hull
368 r_pressureHull = 0.97; %(m)
369
370 L_mbt=3.44; %(m) mbt length

```

```

371 %equating submarine weight to bouyancy at surface , then solving for
372 %displaced volume gives
373
374
375
376 V_displaced = total_dry_mass/rho; %(m^3)
377
378
379 %submarine submerged volume at surface needs to be found using the
380 %following geometry equations
381 V_total_submerged=0;
382 h_submerged = 0;
383
384 %find water height at sea surface
385 while(V_total_submerged<V_displaced)
386
387 %fprintf('here\n');
388 h_submerged = h_submerged + 0.00005; %(m)
389
390 %if the mbt is partially submerged
391 if(h_submerged<(2*r_mbt))
392     %finding volume of partially filled cylinder with spherical
393     %caps , (m^3)
394     V_mbt_submerged = 2*((r_mbt^2*acos((r_mbt-h_submerged)/r_mbt)-
395         r_mbt-h_submerged)*(sqrt(2*r_mbt*h_submerged-h_submerged^2)))*
396         L_mbt+((pi/3)*h_submerged^2*(3*r_mbt-h_submerged));
397
398 else
399     %mbt fully submerged
400     V_mbt_submerged = 2*(pi*r_mbt^2*L_mbt); %(m^3)
401
402 end
403
404 %if foam is partially submerged
405 if(h_submerged<H_foam)
406     V_foam_submerged = L_foam*W_foam*h_submerged;%(m^3)
407 else %foam is fully submerged
408     V_foam_submerged = L_foam*W_foam*H_foam;%(m^3)
409 end

```

```

409
410 if ( h_submerged < 0.354 )
411     %water level is below pressure hull
412     V_pressureHull_submerged = 0;%(m^3)
413 elseif ( h_submerged < 2.294 )
414     %water level is within the pressure hull
415     V_pressureHull_submerged = ( pi / 3 ) * ( h_submerged - 0.354 ) ^ 2 * ( 3 *
416         r_pressureHull - ( h_submerged - 0.354 ) );%(m^3)
417 else
418     %pressure hull is fully submerged
419     V_pressureHull_submerged = ( 4 / 3 ) * pi * r_pressureHull ^ 3;%(m^3)
420 end
421
422 V_total_submerged = V_mbt_submerged + V_foam_submerged +
423     V_pressureHull_submerged ;%(m^3)
424 end
425
426 %submarine height
427 H_sub = 2 * r_pressureHull + 2 * r_mbt - 0.354;%(m)
428
429 %freeboard height is simply then the total height minus the water
430 %height
431 new_freeboard = H_sub - h_submerged ;%(m)
432 end
433
434 %function to find MBT thickness MBT geomtry and pressure difference
435 function new_mbt_thickness=calc_mbt_thickness( delta_P , mbt_radius , SF)
436 %Eq. (6)
437 Sigma_y = 551E6; %(Pa) of 2507 stainless steel
438 thickness = 0;
439 n=0;
440 %optimise thickness based on hoop stress
441 while (n<SF)
442     thickness = thickness+0.0001;
443     Hoop_Stress = ( mbt_radius * delta_P ) / thickness ; %(Pa)
444     n=Sigma_y / Hoop_Stress ;
445 end
446 new_mbt_thickness=thickness ;%(m)

```

```

447 end

448 %%%%%%
449 %%VBT%%%%%
450 %%VBT%%%%%
451 %%VBT%%%%%

452

453 %Find the VBT capacity to get to the desired vertical speed
454 function new_vbt_capacity=calc_VBT_capacity(density , desired_speed ,
    vbt_cap_neutBouy)
455 %Eq. (7)
456 capacity=0;% Units (kg) , the mass of water that the VBT can contain
457 A_cc=7.543; %Units (m^2) , The longitudinal cross section area of the
    submarine
458 C_d=0.8; %Drag coefficient
459 F_thrust=500; %Units (N); The force generated by the vertical thrusters
460 v=0;
461 %At neutral buoyancy , the VBT are half filled
462 while (v<desired_speed) && (capacity<=25)
463     capacity=capacity+0.0001;
464     F_net=F_thrust+capacity*9.81;%Units (N) , the net force applied on the
        submarine during ascent and descent
465     v=sqrt ((2*F_net)/(A_cc*C_d*density));%Units (m/s) ; ascent and descent
        speed
466 end
467 new_vbt_capacity=vbt_cap_neutBouy+capacity;% Units (kg) , the mass of water
    that the VBT can contain
468 end

469

470 %function to find the water height at VBT
471 function VBT_water_height=calc_VBT_water_height(rho , capacity , radius)
472 %Eq. (8)
473 water_level=0;
474 mass_cap=0;
475 while (mass_cap<capacity)
476     water_level=water_level+0.0001;
477     mass_cap=rho*((4/3)*pi*radius^3)-(pi*((2*radius- water_level)^2)*(3*
        radius-(2*radius- water_level))/3);
478 end
479 VBT_water_height=water_level;% Units (m) , the height of water that the VBT
    can contain

```

```

480
481 end
482
483 %function to find VBT thickness given VBT geomtry and pressure difference
484 function new_vbt_thickness=calc_VBT_thickness(radius ,P_out ,P_in ,SF)
485 %Eq. (9&10)
486 n=0;%setting the safety factor to a value of 0
487 thickness=0.002;%setting the thickness to a value of 0.001m
488 strain=0;%setting the circumferential strrain to a value of 0
489 sigma_yield_Tit=1100E6; %Units (Pa), yield strength of Titanium
490 Young_Tit=114E9; %Units (Pa), Young modulus of Titanium
491 %Increasing the thickness of the VBTs until n==SF
492 while (n<SF)
493     thickness=thickness+0.00001; %Incrementing the thickness by 0.000001 m
494     Hoop_stress_VBT=((radius ^2)*P_in-((radius+thickness) ^2)*P_out)/((2*
495         radius+thickness)*thickness);%Units (Pa), Hoop stress on the walls
496         of the VBTs
497     n=sigma_yield_Tit/abs(Hoop_stress_VBT); %Safety factor of Hoop stress
498     strain=(100*(-Hoop_stress_VBT+0.33*Hoop_stress_VBT))/Young_Tit;% Units
499         (%), Cicumferential strain
500 end
501 stress_thickness = thickness;
502 new_strain=strain;%Units (%); Strain applied of the walls of the VBT due to
503     Hoop stress
504 %Evaluating if the thickness computed in the first loop accomodates a
505     strain lower than 10%
506 while (new_strain>10)
507     stress_thickness=stress_thickness+0.00001;
508     Hoop_stress_VBT=((radius ^2)*P_in-((radius+stress_thickness) ^2)*P_out)
509         /((2*radius+stress_thickness)*stress_thickness);%Units (Pa)
510     new_strain=(100*(-Hoop_stress_VBT+0.33*Hoop_stress_VBT))/Young_Tit;
511 end
512 new_vbt_thickness=stress_thickness;%Units (m)
513
514 %The following are the functions called for calculations of the volume and
515 mass
516
517 function mass_hollow_sphere=calc_mass_material(radius ,thickness )

```

```

513 %Eq. (11)
514 rho_Tit=4430; %Units (kg/m^3), density of Titanium
515 volume=(4/3)*pi*((radius+thickness)^3-(radius^3));%Units (Kg/m^3), Volume
      of the material of the VBTs
516 mass_hollow_sphere= rho_Tit*volume;%Units (kg), mass of a hollow Titanium
      sphere
517 end
518
519 %function to find density of sea water based on salinity and water
520 %temperature
521 function rho_sea_water= calc_density_seawater(Temperature, Salinity)
522 %Eq. (12)
523 T=Temperature;
524 S=Salinity;
525 C=999.83;%Units(kg/m^3), density of pure water
526 Beta=0.808; %Units(kg.m^-3.psu^-1), saline contraction
527 alpha=0.0708*(1+(0.068*T)); %Units(m^3.C^-1), coefficient of thermal
      expansion
528 gamma=0.003*(1-0.012*T); %Units(kg.m^-3.C^-1.psu^-1), compressibility
      coefficient
529 rho_sea_water=C+Beta*S-alpha*T-gamma*(35-S)*T;%Units (kg/m^3), density of
      sea water at the surface of seawater at a given temperature and
      salinity
530 end
531
532 %function to calculate the pitching angle given the total mass and buoyancy
533 %of the submarine
534 function angle=calc_trim_angle(m_drop_weights,mbt_volume,Num_air_bottles,rho,
      mbt_dry_mass,m_dry_vbt_r,m_dry_vbt_f,sub_wet_mass,R_vbt_r)
535 %The maximum pitch angle is calculated by assuming that 12.5 kg is
      %displaced from the front VBTs to the rear VBT at neutral buoyancy
536 rho_lead=11340;%Units (kg/m^3), density of Lead
537 volume_dw=m_drop_weights/rho_lead;%Units (m^3), Volume of drop weights
538 rho_foam=385;%Units (kg/m^3), density of foam
539 V_foam=2.21;%Units (m^3), volume of foam
540 m_foam=rho_foam*V_foam;%Units (kg), mass of the foam
541
542
543 y_B=((2.21*0.735-0.40185*volume_dw)+(2*0.14515*mbt_volume)
      -(0.41373*0.048)+(1.018*3.82)+(Num_air_bottles*0.6665*0.043))/(2.21+
      volume_dw+2*mbt_volume+0.048+0.048+3.82+Num_air_bottles*0.043);%

```

```

    Units (m) , y coordinate of center of buoyancy
544 z_B=(( -0.735*0.735-0.5*volume_dw)-(2*0.500*mbt_volume)-(0.41373*0.048)+(
      Num_air_bottles*-1.1661*0.043))/(2.21+volume_dw+2*mbt_volume
      +0.048+0.048+3.82+Num_air_bottles*0.043);%Units (m) , z coordinate of
      center of buoyancy

545
546 m_water_r=25;%Units (kg/m^3) , the final mass of water at the rear VBT
      after maximum pitching
547 h_r_new=R_vbt_r;%Units (m) , height of water inside the rear VBTs
548
549 y_Gr_water=(3*(2*R_vbt_r-h_r_new)^2)/(4*(3*R_vbt_r-h_r_new));%Units (m) ,
      center of mass of the displaced water
550 y_G=((m_foam*0.735)+(-0.40185*m_drop_weights)+(0.70104*4390.14)
      +(2*0.14515*(mbt_dry_mass+rho*mbt_volume))+(0.41373*m_dry_vbt_r)
      +(2*0.11218*m_dry_vbt_f)+((y_Gr_water+0.18773)*m_water_r)+(
      Num_air_bottles*0.6665*137))/(sub_wet_mass+m_drop_weights);%Units (m)
      , y coordinate of the new center of gravity

551
552 z_G=(( -2.220*m_foam)+(-0.500*m_drop_weights)-(2*0.500*(mbt_dry_mass+rho*
      mbt_volume))-(2.047*4390.14)-(2.04774*(m_dry_vbt_r+m_water_r))+(-
      Num_air_bottles*1.1661*137))/(sub_wet_mass+m_drop_weights);%Units (m)
      , z coordinate of the new center of gravity
553 angle=(180/pi)*atan((12.5*3.9)/((sub_wet_mass+m_drop_weights)*abs(y_G-
      y_B)));%Units (degrees) ,maximum pitch angle

554
555 end
556
557
558 %%DWs function calls%%
559 %%DWs function calls%%
560 %%DWs function calls%%

561
562 %function to find the number of solenoids supporting the drop weights
563 function new_num_sol=calc_num_sol(SF, m_drop_weights)
564 %Eq. (13)
565 mu=0.1; %Friction factor of PTFE-Steel
566 F_sol=177.93; %Units (N) ,linear force generated by the solenoid actuotor
567 num_sol=1;
568 n=0;
569 while (n<SF) && (num_sol<3)

```

```
570 num_sol=num_sol+1;
571 F_N=(1/num_sol)*m_drop_weights*9.81; %Units (N), normal force applied
      on each pin
572 F_f=mu*F_N;%Units (N), friction force applied on the pin
573 n=F_sol/F_f;
574 end
575 new_num_sol=num_sol;
576 end
577
578 %function to find the length of drop weights given its mass
579 function length_dw=calc_length_dw(mass_dw)
580 %Eq. (14)
581 lead_mass = abs(mass_dw-125); %(kg) taking away the mass of batteries
      located inside the drop weights
582 r_dw=0.1;%Units(m); radius of one drop weight(dw)
583 rho_lead=11340;%Units (kg/m^3), density of Lead
584 length_dw=(lead_mass/rho_lead)/(pi*r_dw^2);%Units (m), length of one dw
585 end
```

D All minutes (team/partner and group)

Group Minutes					
Attendees: Jeromy, Osman, Lina, Ahmed, Fanta		Absent: None	Date & Time: Meeting 1: 09/14/20 4:30pm Meeting 2: 09/16/20 8:30am	Venue: Discord/MS Teams	
Minute taker: Who is filling out this form? Lina		Chairperson: Who is organising the meeting? Jeromy			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Literature Review: Broad Research	<ul style="list-style-type: none"> - Understanding of the literature review and its required contents - Each member is to carry out broad and individual investigations and research about the SUB B task 	Entire Team	2 Days (48 Hours)	Yes
2	Literature Review: Division of Tasks	<ul style="list-style-type: none"> - Share collected research for the literature review - Divide literature review tasks among team members with deadlines - Discuss task requirements with the professor and TA 	Entire Team	3 Days (72 Hours)	No
3					
4					
5					
Next meeting Chairperson: Osman	Minute taker: Lina	Date & Time: 09/19/20	Venue: Discord/MS Teams		

Minutes	
09/14/20 During the meeting: 1. Discuss work accomplished since the last meeting (No work assigned) 2. Discuss tasks not-completed since the last meeting (No work assigned) 3. Review action items and tasks to be completed after the meeting - Understanding of the literature review and its required contents - Each member is to carry out broad and individual investigations and research about the SUB B task	
Meeting minutes content: 1. Summarize completed work (Each member successfully completed a broad research of the entire lit review) 2. List previous tasks that have not been completed in the prescribed timeline (No previous work assigned) 3. Specify task reassessments (No reassigned tasks) 4. List additional tasks completed but not listed in previous minutes (None to be listed) 5. Specify additional out-of-class meeting attendance (Discussions via group text chat on messenger)	
09/16/20 During the meeting: 1. Discuss work accomplished since the last meeting (Each member successfully completed a broad research of the entire lit review) 2. Discuss tasks not-completed since the last meeting (Proper review of ballast and hull integration) 3. Review action items and tasks to be completed after the meeting - Each member now has an assigned portion of the literature review to be completed in depth -Osman/Jeromy = VBT -Ahmed/Lina/Fanta = Soft Ballast/Drop Weight - Keep literature review design oriented - Use a higher ratio of academic journals rather than general google links	
Meeting minutes content: 1. Summarize completed work (Discussion with prof/TA - designation of tasks for final lit review - discussion of proper hull/ballast integration) 2. List previous tasks that have not been completed in the prescribed timeline (None) 3. Specify task reassessments (No reassigned tasks) 4. List additional tasks completed but not listed in previous minutes (None to be listed) 5. Specify additional out-of-class meeting attendance (Discussions via group text chat on messenger)	
Previous Friday lab attendance	Previous lecture attendance
All group members attended	All group members attended

Figure D-1: Week1st minutes

Group Minutes				
Attendees: Jeromy, Lina, Ahmed, Fanta	Absent: N/A	Date & Time: 22/09/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Lina		Chairperson: Who is organising the meeting?		
Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1 Discuss the concept report requirements	Meeting through MS teams	All	1 day	yes
2 Sketching solutions	Drawing rough sketches then clean ones	All	2 days	in progress
3 Distributing report sections among team members	Meeting through MS teams	All	1 hour	yes
4 Finalize drawings	using drawing software	Jeromy	3 days	no
5 Finalize the report	Meeting through MS teams	Ahmed, Lina, Fanta	3 days	no
Next meeting Chairperson: Jeromy	Minute taker: Lina	Date & Time: 24/09/2020	Venue: MS Teams	

Minutes	
<p>Minutes</p> <p>During the meeting:</p> <ol style="list-style-type: none"> 1. Discuss work accomplished since the last meeting. - Rough sketches finalized 2. Discuss tasks not-completed since the last meeting. - Clean drawings in process 3. Review action items and tasks to be completed after the meeting - Editing of final drawings. - Working on cost assessment and decision matrix. - Working on discussion. <p>Meeting minutes content:</p> <ol style="list-style-type: none"> 1. Summarize completed work. - Each member completed rough sketches. - Distribution work load between member. 2. List previous tasks that have not been completed in the prescribed timeline - None 3. Specify task reassignments - Lina and Fanta will work on main ballast sketches + drop weight sketches - Ahmed and Jeromy will work on variable ballast sketches. 4. List additional tasks completed but not listed in previous minutes - None 5. Specify additional out-of-class meeting attendance - Meeting at SITE to discuss tasks distribution 	
Previous Friday lab attendance Lina, Ahmed, Jeromy, Fanta	
Previous lecture attendance	Lina, Ahmed, Jeromy, Fanta

Figure D-2: Week2nd minutes

Group Minutes					
Attendees:		Absent:	Date & Time:	Venue:	
Jeromy, Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot		N/A	30/09/2020	MS Teams	
Minute taker: Ahmed Who is filling out this form?			Chairperson: Who is organising the meeting?		
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Requiring feedback from professor and TA about the concept report	Meeting through MS teams	All	15 min	yes
2	Editing concept report	Drawing rough sketches then clean ones	All	2 days	in progress
3	Importing document into Laitex	Meeting through MS teams	Ahmed/Jeromy	1.5 hour	no
4	Finalize report	using drawing software	All	1 hour	no
5					
Next meeting Chairperson:	Minute taker:	Date & Time:	Venue:		
Jeromy	Ahmed	30/09/2020	MS Teams		

Minutes	
<p>-Feedback was given to us about the concept report.</p> <p>-Ahmed showed the drawings in the report and asked if we need a sketch that involves all the subsystems together.</p> <p>-The professor inquired about the software used to developed the drawings</p> <p>-Nathaniel mentioned that our drawings are not what is required in this report, pointing that they are more of a schematic than mechanical drawings.</p> <p>-Nathaniel suggested that we should not worry about this at this point in time but rather focus on submitting it in the best way possible and implement the changes in the modeling report.</p> <p>-The Professor asked to meet on us on Friday to give us critical feedback on the concept report so we can implement the changes in the modeling report</p>	
Previous Friday lab attendance	Previous lecture attendance
Lina, Ahmed, Jeromy, Fanta	Lina, Ahmed, Jeromy, Fanta

Figure D-3: Week3rd minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot		Absent: Jeromy	Date & Time: 7/10/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Ahmed		Chairperson: Who is organising the meeting? Ahmed			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Requiring feedback from professor and TA about the Modelling report	Meeting through MS teams	All	15 min	yes
2	Editing modelling report	Drawing rough sketches then clean ones	All	2 days	yes
3	Importing document into overleaf	Meeting through MS teams	All	1.5 hour	yes
4	Finalize report	using overleaf	All	1 hour	yes
5					
Next meeting Chairperson: Jeromy	Minute taker: Ahmed	Date & Time: 7/10/2020	Venue: MS Teams		

Minutes	
<p>-Ahmed started by sharing the report and asking for feedback from the professor and the TA</p> <p>-Professor pointed out that the shape of the MBT might need some modifications to withstand high pressure</p> <p>- Professor liked that we have error percentage for our calculations</p> <p>-Ahmed asked the professor for feedback about the buoyancy convention.</p> <p>- Professor answered accordingly</p> <p>-Modelling report feedback meeting was scheduled on Tuesday at 8:50 am.</p>	
Previous Friday lab attendance Lina, Ahmed, Fanta	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-4: Week4th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Jeromy, Mihaita Matei, Nathaniel Mailhot		Absent:		Date & Time: 13/10/2020 14/10/2020	Venue: MS Teams
Minute taker: Lina Who is filling out this form?			Chairperson: Ahmed Who is organising the meeting?		
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Requiring feedback from professor and TA about the Modelling report	Meeting through MS teams	All	15 min	yes
2	Discussing possible solutions for the VBTs	Meeting through MS teams	All	1h	yes
3	Discussing how to divide tasks regarding drawings of the design dossier	Meetig through MS teams	All	1h	yes
4					
5					
Next meeting Chairperson: Jeromy	Minute taker: Lina		Date & Time: 14/10/2020	Venue: MS Teams	

Minutes	
<p>-The professor and TA gave us an elaborate feedback of our modelling report</p> <p>-Professor pointed out that the shape of the MBT might need some modifications to withstand high pressure</p> <p>-There are some mistakes in calculations that need to be corrected</p> <p>-All group members discussed the number of VBTs and their locations with regards to the pressure hull.</p>	
Previous Friday lab attendance Lina, Ahmed, Fanta, Jeromy	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-5: Week5th minutes

Group Minutes				
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot, Jeromy	Absent:	Date & Time: 19/10/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Ahmed	Chairperson: Who is organising the meeting? Ahmed			
Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1 Requiring feedback from professor and TA about the Design Dossier	Meeting through MS teams	All	15 min	yes
2				
3				
4				
5				
Next meeting Chairperson: Jeromy	Minute taker: Ahmed	Date & Time: 19/10/2020	Venue: MS Teams	

Minutes	
<p>-Professor mentioned that it is really important to consider where the submarine subcomponents are mounted on the main structure. That includes MBTs, air tanks, valve panels and pipes.</p> <p>- Professor expressed some concerns about the back plate of the MBTs. Preferring to give them a spherical shape to withstand hydrostatic pressure.</p> <p>- Nathaniel mentioned a question about the safety valve, recommending to use it as an active safety mechanism rather than passive one.</p> <p>- Nathaniel mentioned the importance of figuring out the force used at the air-water interface as this would be the main element of stress on the MBT structure.</p> <p>- Nathaniel emphasized on the fact that the team need to analysis the shafts of the pumps and motors, to be able to produce the required flow rate at the maximum given pressure.</p> <p>- Lina asked if we can use the ideal gas law, Professor approved using it with the MBTs.</p> <p>-Nathaniel expressed some improvments on how to mount the front VBTs. recommending that we take into consideration easy installation and accessibility</p>	
Previous Friday lab attendance Lina, Ahmed, Fanta, Jeromy	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-6: Week6th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot, Jeromy		Absent:		Date & Time: 06/11/2020	Venue: MS Teams
Minute taker: Who is filling out this form? Fanta			Chairperson: Who is organising the meeting? Fanta		
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Feedback from professor and TA about the Analysis Dossier	Meeting through MS teams	All	25 min	yes
2					
3					
4					
5					
Next meeting Chairperson: Jeromy	Minute taker: Fanta		Date & Time: 06/11/2020	Venue: MS Teams	

Minutes	
<ul style="list-style-type: none"> - Professor mentionned that we were supposed to write everything on world. - He mentionned that we should complete more the analysis - Professor mentioned that we only have to o calcuation that make sens - He said that we had to check again ascending, pitching, descending and rolling situation - The professor said that we don't need to consider forces with a small intensity - He advices us the start doing programmation, and to finish by manufacturing - Nathaniel said that we have to make very clean FBD - Nathaniel said that we have to focus first on pump an motor - He said as well hat we shoul be able to determine how deep the submarine ca go 	
Previous Friday lab attendance Lina, Ahmed, Fanta, Jeromy	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-7: Week7th minutes

Group Minutes					
Attendees: Lina, Ahmed, Mihaita Matei, Nathaniel Mailhot		Absent: Fanta, Jeromy	Date & Time: 11/11/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Ahmed		Chairperson: Who is organising the meeting? Ahmed			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Getting feedback about the progress of the Analysis report	Meeting through MS teams	All	15 min	yes
2					
3					
4					
5					
Next meeting Chairperson: Jeromy	Minute taker: Ahmed	Date & Time: 11/11/2020	Venue: MS Teams		

Minutes					
<ul style="list-style-type: none"> - Lina mentioned that we are adding foam to increase buoyancy to help determine the drop weights mass - Lina mentioned that foam will also be used to induce more pitching angles caused by the VBTs - Professor Mihaita liked the idea that several aspects are being taken into consideration regarding foam, and that is an optimisation problem - Nathaniel asked about the reason behind the absence of the two team members 					
Previous Friday lab attendance			Previous lecture attendance		
Lina, Ahmed, Fanta, Jeromy			Lina, Ahmed, Jeromy, Fanta		

Figure D-8: Week8th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot		Absent: Jeromy	Date & Time: 18/11/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Ahmed		Chairperson: Who is organising the meeting? Ahmed			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Discussing the issue of centering the center of mass and buoyancy	Meeting through MS teams	All	15 min	yes
2	Discussing the specification of the pump used for trim and depth control	Meeting through MS teams	All	15 min	yes
3					
4					
5					
Next meeting Chairperson: Fanta		Minute taker: Ahmed	Date & Time: 25/11/2020	Venue: MS Teams	

Minutes	
<p>-Lina mentioned that we are adding foam to increase buoyancy to help determine the drop weights mass</p> <p>-Ahmed explained the method used to calculate the drop weight's mass.</p> <p>-Lina mentioned that foam will also be used to induce more pitching angles caused by the VBTs.</p> <p>-Fanta asked about the lack of online resources to find a sea water pump.</p> <p>-Nathaniel suggested to increase the volume of the VBTs to increase the buoyancy.</p>	
Previous Friday lab attendance Lina, Ahmed	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-9: Week9th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot		Absent: Jeromy	Date & Time: 18/11/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Ahmed		Chairperson: Who is organising the meeting? Ahmed			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Discussing the issue of centering the center of mass and buoyancy	Meeting through MS teams	All	15 min	yes
2	Discussing the specification of the pump used for trim and depth control	Meeting through MS teams	All	15 min	yes
3					
4					
5					
Next meeting Chairperson: Fanta	Minute taker: Ahmed	Date & Time: 25/11/2020	Venue: MS Teams		

Minutes	
<p>-Lina mentioned that we are adding foam to increase buoyancy to help determine the drop weights mass</p> <p>-Ahmed explained the method used to calculate the drop weight's mass.</p> <p>-Lina mentioned that foam will also be used to induce more pitching angles caused by the VBTs.</p> <p>-Fanta asked about the lack of online resources to find a sea water pump.</p> <p>-Nathaniel suggested to increase the volume of the VBTs to increase the buoyancy.</p>	
Previous Friday lab attendance Lina, Ahmed	Previous lecture attendance Lina, Ahmed, Jeromy, Fanta

Figure D-10: Week10th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Mihaita Matei, Nathaniel Mailhot		Absent: Ahmed	Date & Time: 25/11/2020	Venue: MS Teams	
Minute taker: Who is filling out this form? Fanta		Chairperson: Who is organising the meeting? Fanta			
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Discussing quickly about the capsone	Meeting through MS teams	All	15 min	yes
2					
3					
4					
5					
Next meeting Chairperson: Jeromy	Minute taker: Fanta		Date & Time: 25/11/2020	Venue: MS Teams	

Minutes					
<p>-The prof give us some advices about the capstone</p> <p>- The prof recommand us to do a Video for our presentaion, in case we loose our connexion</p> <p>-Lina asked if we have to combine our solidworks with SUB1A's solidworks to do our parametrization</p> <p>- Jeromy asked how we can do the piping connexion</p> <p>- The prof explain us how they are going to correct the Analysis Report, and said that he will give us a feedback, even without marks.</p>					
Previous Friday lab attendance Fanta, Jeromy, Lina, Ahmed	Previous lecture attendance Fanta, Lina, Jeromy, Ahmed				

Figure D-11: Week11th minutes

Group Minutes					
Attendees: Lina, Ahmed, Fanta, Jeromy, Mihaita Matei, Nathaniel Mailhot		Absent:		Date & Time: 02/12/2020	Venue: MS Teams
Minute taker: Who is filling out this form? Fanta			Chairperson: Who is organising the meeting? Ahmed		
	Task What has to be done?	Action What action is required to get it done?	Who Who is responsible?	Duration How long will it take to complete?	Status Has the task been completed?
1	Discussing about the capstone report	Meeting through MS teams	All	15 min	yes
2					
3					
4					
5					
Next meeting Chairperson: Jeromy	Minute taker: Fanta		Date & Time: 02/12/2020	Venue: MS Teams	

Minutes	
<ul style="list-style-type: none"> - Jeromy asked if we have to consider the fitting of all the piping - And Matei said that we shouldnt consider the fitting of the pipes - Ahmed asked if we can invite people to assist the presentation, like the president of Aquatica - Ahmed asked if we have to redo the analysis report, or if we have only to upload what we had, and the prof said that we have only to upload the past reports on the file, and to only focus on the capstone report - Fanta asked if we have to do the parametrization of the depth - Nathaniel suggests us to choose a range of depth, and to do the parametrization for that range 	
Previous Friday lab attendance Fanta, Ahmed, Lina, Jeromy	Previous lecture attendance Fanta, Ahmed, Lina, Jeromy

Figure D-12: Week12th minutes

E Additional material

E.1 VBT Hydraulic Circuit PID

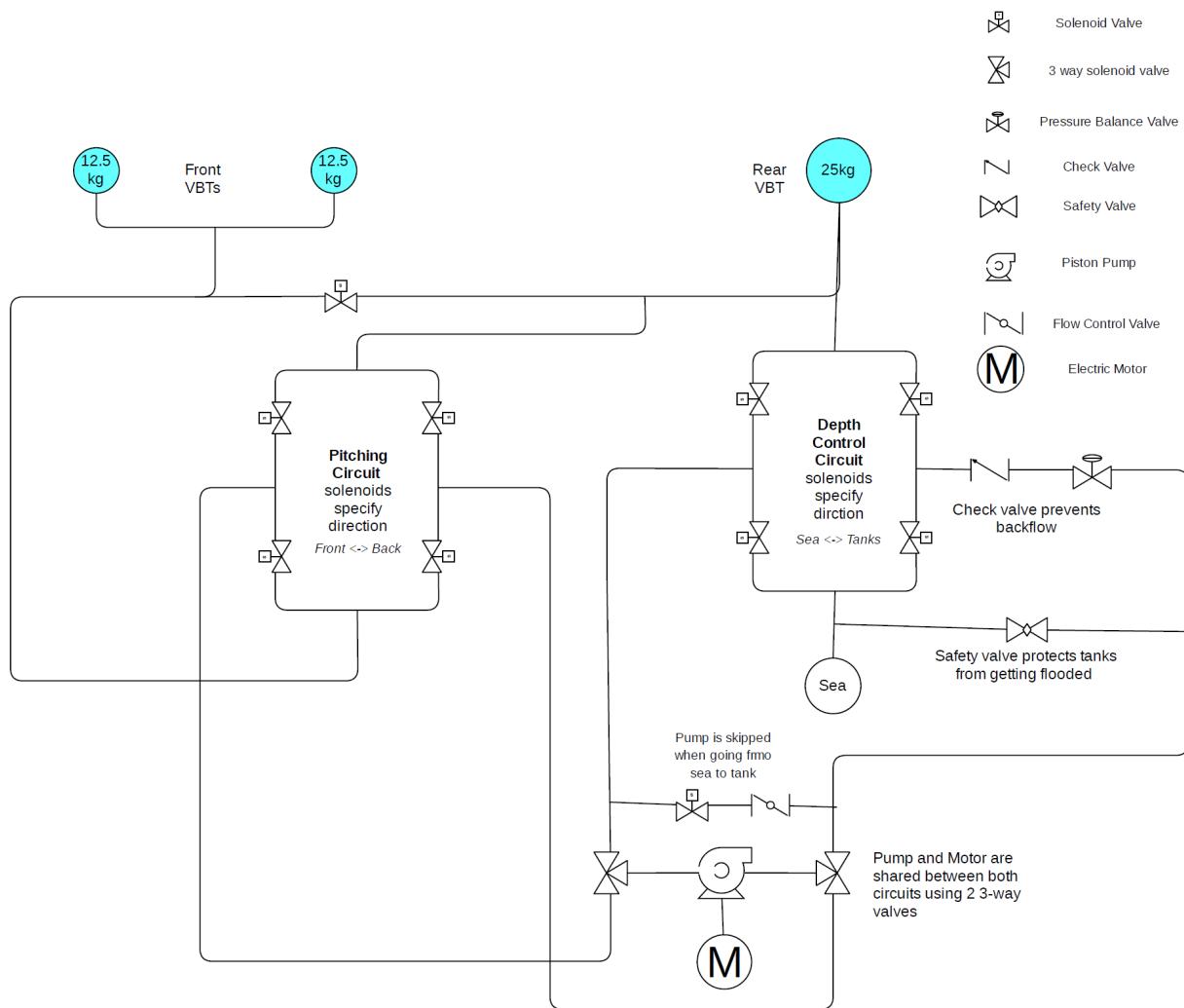


Figure E-1: VBT circuit including pitching and depth control

E.2 Data sheets

Data sheet		PAH 2/4/6.3, PAH 10/12.5, PAH 20/25/32 and PAH 50/63/70/80/100 pumps				
4. Technical data		4.1 PAH 2-12.5				
Pump size		2	4	6.3	10	12.5
Code number		180B0024	180B0022	180B0023	180B0008	180B0007
Code number ATEX²⁾		180B6124	180B6122	180B6123	180B6108	180B6107
Housing material		AISI 304	AISI 304	AISI 304	AISI 304	AISI 304
Geometric displacement	cm ³ /rev	2	4	6.3	10	12.5
	in ³ /rev	0.12	0.24	0.38	0.60	0.75
Pressure						
Min. outlet pressure	barg	30	30	30	30	30
	psig	435	435	435	435	435
Max. outlet pressure	barg	140	140	140	160	160
	psig	2030	2030	2030	2320	2320
Inlet pressure, continuous	barg	0-4	0-4	0-4	0-4	0-4
	psig	0-58	0-58	0-58	0-58	0-58
Speed						
Min. speed, continuous	rpm	700	700	700	700	700
Max. speed	rpm	1800	1800	1800	1800	1800
Typical flow - Flow curves available in section 5						
1000 rpm at max. pressure	l/min	1.0	3.2	5.6	8.4	11.0
1500 rpm at max. pressure	l/min	2.0	5.2	8.7	13.4	17.2
1200 rpm at max. pressure	gpm	0.4	1.0	1.8	2.7	3.5
1800 rpm at max. pressure	gpm	0.7	1.7	2.8	4.3	5.5
Typical motor size						
1500 rpm at max. pressure	kW	0.9	1.7	2.6	4.5	5.6
1800 rpm at max. pressure	hp	1.5	2.7	4.2	7.3	9.0
Torque at max. spec.	Nm	5.9	10.9	16.7	29.0	35.8
	lbf-ft	4.4	8.0	12.3	21.4	26.4
Media temperature	°C	2-50	2-50	2-50	2-50	2-50
	°F	36-122	36-122	36-122	36-122	36-122
Ambient temperature	°C	0-50	0-50	0-50	0-50	0-50
	°F	32-122	32-122	32-122	32-122	32-122
Sound pressure level¹⁾	dB(A)	76	76	76	75	75
Weight	kg	4.4	4.4	4.4	7.7	7.7
	lbs	9.7	9.7	9.7	17.0	17.0

Figure E-2: Danfoss Pump

SUBSEA SOLENOID VALVE

Oil Spill Containment System

Features:

- FULL FLOW - 1/2" NPT
- DIRECT SOLENOID OPERATED
- BUBBLE-TIGHT CLOSURE
- CONTAMINATION TOLERANT
- SEAWATER SUBMERSIBLE
- UNDERWATER CONNECTOR
- HERMETICALLY SEALED SOLENOID
- SHOCK RESISTANT
- LONG CYCLE LIFE
- LOW POWER CONSUMPTION
- **NO ADJUSTMENTS NEEDED**

Specification:

1. 2-way, 2-position, normally closed
2. Ocean Submersible
3. Fluid Pressure: 3,000 psid Operating
4. Ocean Ambient to 4,500 psi
5. Fluids: hydraulic or pneumatic
6. Ports: 1/2" NPTF
7. Zero Leakage
8. Electrical: 1.85 amps @ 24vdc
9. Corrosion Resistant Stainless Steels
10. Weight: <15 lbs.
11. Size: 3.25" sq x 8"+ subsea connector

**MODEL NO.
1723-100**



Submersible solenoids meet IPX8 of IEC 529 for protection against the effects of continuous water submersion.

Figure E-3: Hydracon solenoid valve

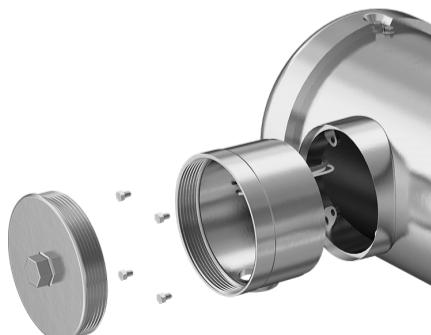
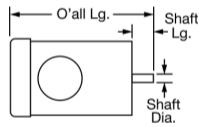
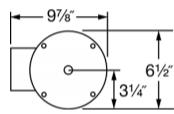
11/23/2020

Sanitary Washdown Face-Mount AC Motor, 230/460V AC, 3-Phase, NEMA 145TC, Totally Enclosed Fan-Cooled, 2 hp, 1800 rpm | McMaster-Carr



Sanitary Washdown Face-Mount AC Motor
230/460V AC, 3-Phase, NEMA 145TC, Totally Enclosed Fan-Cooled, 2 hp, 1800 rpm

\$1,632.27 Each
3540N26



Rotatable Conduit Box

Power Source	Electric
Mounting	Face
Style	
Voltage	230V AC/460V AC
Electrical	
Phase	Three
Motor Frame	NEMA 145TC
Size	
Power	2 hp
Maximum Speed	1,800 rpm
Full Load Current	5.6/2.8 A
Frequency	60 Hz
Electrical Connection	Hardwire
Type	
Wire	
Connection	Wire Leads
Type	
Inverter Rated	Yes
Duty Cycle	Continuous
Service Factor	1.15
Efficiency	86.5%
Motor Enclosure Type	Totally Enclosed Fan Cooled (TEFC)
Enclosure Material	304 Stainless Steel
Overall Length	14"
Width	9 7/8"
Height	6 1/2"
Mounting Orientation	Any Angle, Horizontal, Vertical
Bearing Type	Ball
Shaft Diameter	7/8"
Length	2 1/8"
Center to Base (A)	3 1/4"

<https://www.mcmaster.com/3540N26/>

1/4

Figure E-4: Sanitary Washdown Face-Mount AC motor