MECH 2400
ASSIGNMENT C
GROUP 5
OCTOBER 28, 2022

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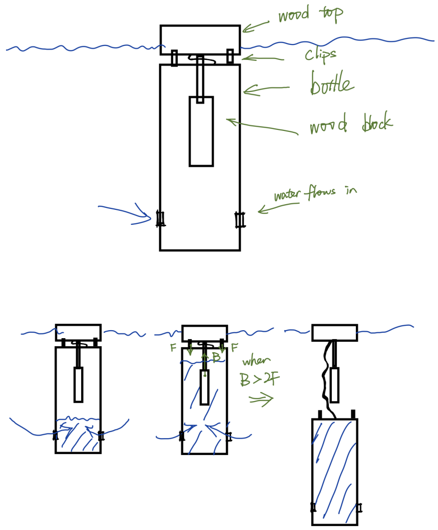
Contents:

1.0: Detailed Design and Report

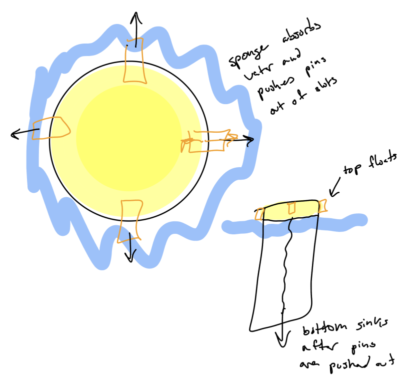
1.1: Brainstorming

We came together for our brainstorming session once we had all read and understood the assignment details. In this session, we each presented some initial design concepts that we had come up with while critiquing each other's and slightly modifying them. We then decided on 5 main ideas that we thought were going to be simple and executable. These ideas are listed below with their respective initial sketches.

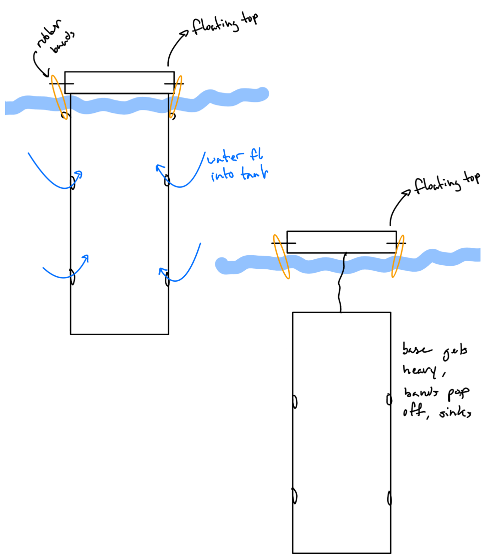
- **Idea 1:** piston and clips



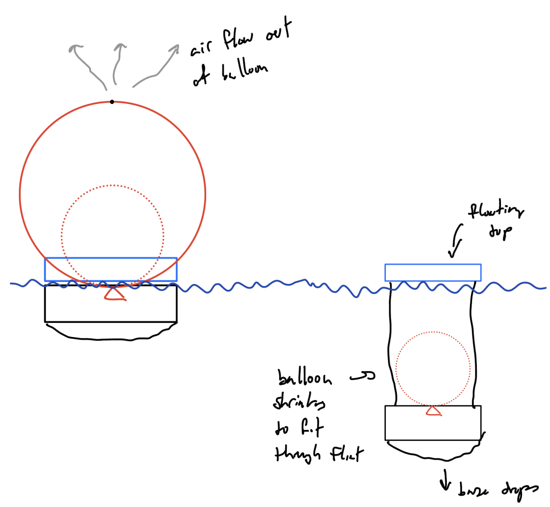
- **Idea 2:** sponge



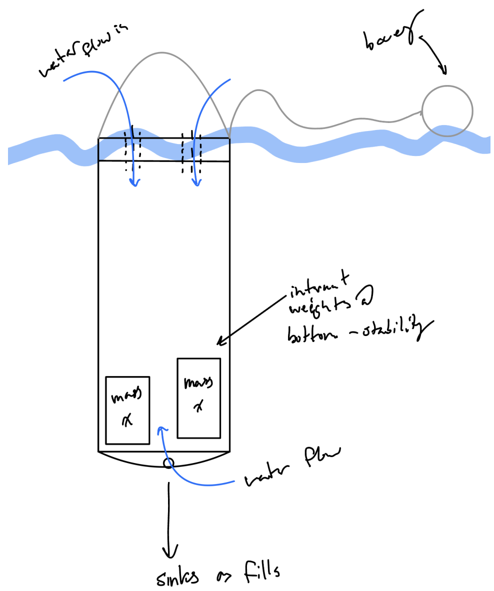
- **Idea 3:** rubber band



- **Idea 4:** balloon



- **idea 5:** weighted cylinder



1.2: Trade-off Table

The trade-off table contains our determined Vales, Scores, and the combination of Value * Score as well as the final totals which determined the final prototypes design basis. All of the values assigned and calculated were done in collaboration with all group members.

Design Considerations		Assigned Value /10
1	Cost (wanted to keep a low budget)	8
2	Durability (needed to withstand multiple tests)	9
3	Manufacturability (ability to re-assemble/test)	9
4	Size (how close to height limit)	5
5	Weight (how close to weight min)	6
6	Stability in water/buoyancy (how well it floated)	7

Table 1.2.1: Design Consideration Values

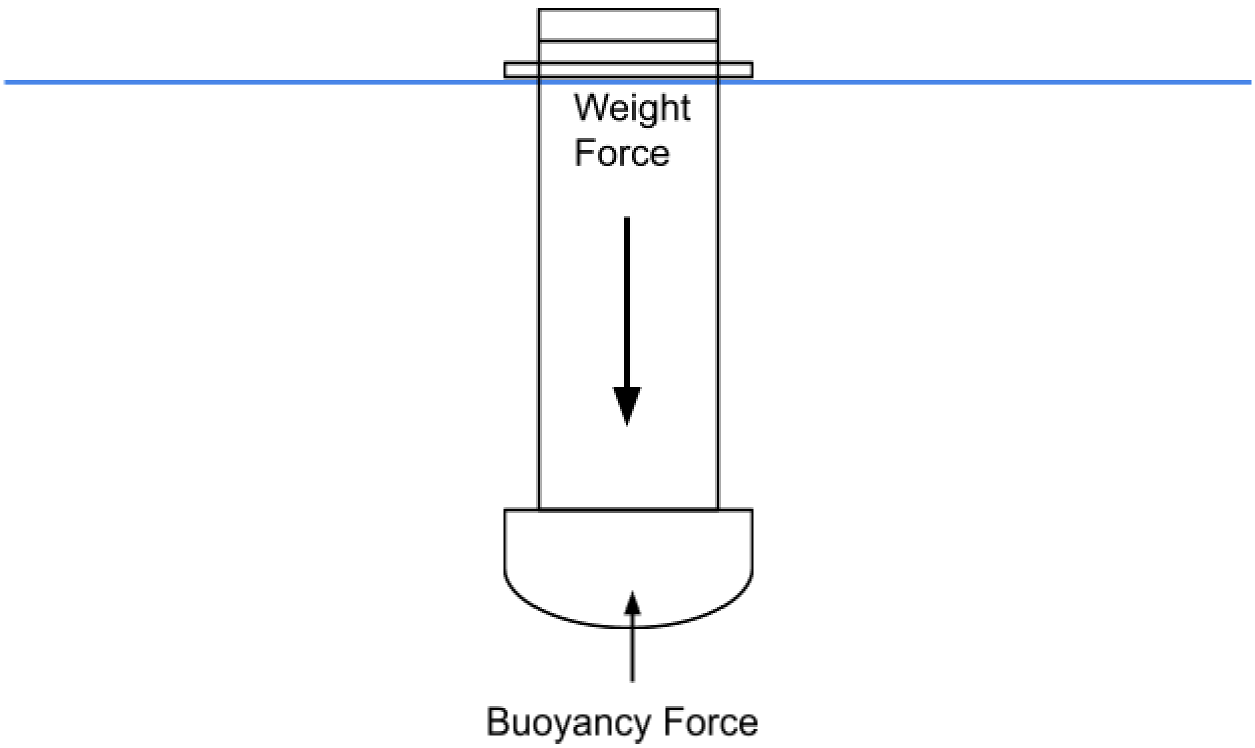
Design Consideration	Design 1			Design 2		Design 3		Design 4		Design 5	
	Value	Score	V*S	Score	V*S	Score	V*S	Score	V*S	Score	V*S
Cost	8	7	56	6	48	8	64	8	64	8	56
Durability	9	8	72	8	72	5	45	5	45	8	72
Manufacturability	9	9	81	6	54	7	63	7	63	9	81
Size	5	3	15	6	30	4	20	4	20	7	35
Weight	6	5	30	5	30	7	42	8	48	9	54
Stability in water/buoyancy	7	5	35	7	49	7	49	9	63	6	42
Total			289		283		283		303		**340**

Table 1.2.2: Final Trade-Off Table

The trade-off table yielded very close scores for the majority of our designs, but there was a clear winner, Design 5 had a total of 340 points which was over 50 points higher than the next closest design total. Choosing Design 5 also aligned with our intentions of making the prototype as simple and as functional as possible.

1.3: Static and Dynamic Force Analysis

Static Force Analysis on the device at water surface:



Using,

- $Density\ of\ air$: $\rho_{air} = 1.225\ kg/m^3$
- $Acceleration\ of\ gravity$: $g = 9.81\ m/s^2$

Volume submerged is needed to be found in order to solve for buoyancy. Hence,

$$V_{submerged} = \pi r^2 h$$

$$V_{submerged} = \pi(0.0253)^2(0.171) = 0.00034659\ m^3$$

$$F_B = -\rho_{air} gV_{submerged} = 1.225 * 9.81 * 0.00034659 = 0.0041651N$$

$$F_{weight} = mg = 0.2711 * 9.81 = 2.6595N$$

To find when device will begin to sink, $F_{weight} > F_{Buoyancy}$

$\rho_{water} g V_{sink} = F_{weight}$

$997 * 9.81 * V_{sink} = 2.6595N$

$V_{sink} = \frac{F_{buoyancy}}{\rho_{water} * g}$

$V_{sink} = \frac{2.6595N}{997*9.81}$

$V_{sink} = 0.00027192\, m^3$

Hence, for the device to sink, it must be filled until the volume is greater than V_{sink}

With this information, the volume metric flow rate can be found. Using:

$Q = \frac{V}{t}$, *where Q is the volumetric flow rate*

- $V = V_{sink} = 0.00027192$
- $t = 29s$ (*Obtained from the official testing of the device*)

Hence,

$Q = \frac{0.00027192}{29}$

$Q = 0.0000093765\, m^3/s$

Also, to find the percentage of the device that needs to filled is,

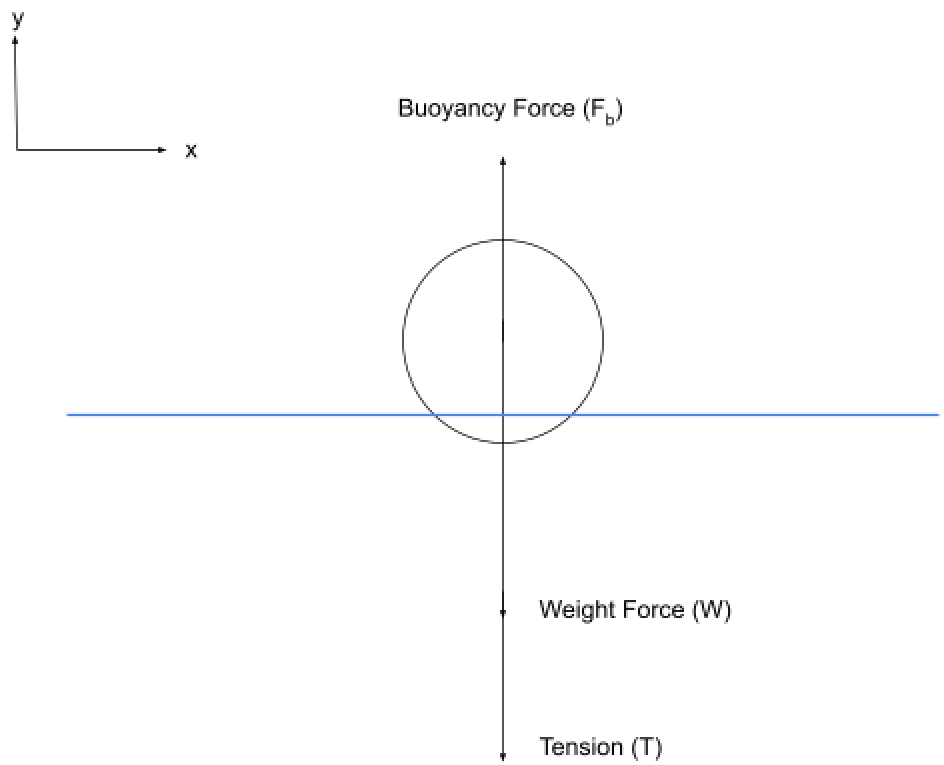
$Filled\ \% = \frac{V_{sink}}{V_{device}}$

$= \frac{0.00027192}{0.00034689} * 100\%$

$= 78.388\%$

Static force analysis on the balloon when the device is at the bottom of the tank:

Below is a diagram of this situation:



Where:

- Mass of the balloon (m) = 4 g = 0.004 kg
- Acceleration due to gravity (g) = 9.81 m/s^2
- Density of water (ρ_{water}) = 999 kg/m^3
- Volume of object submerged underwater ($V_{submerged}$) = 5 cm^3 = 5 x 10^{-6} m^3

Using the force equilibrium equation along the y-axis, $\sum F_y = 0$, the tension force in the string connected to the device and the balloon can be found:

$F_b = W + T$

$T = W - F_b$

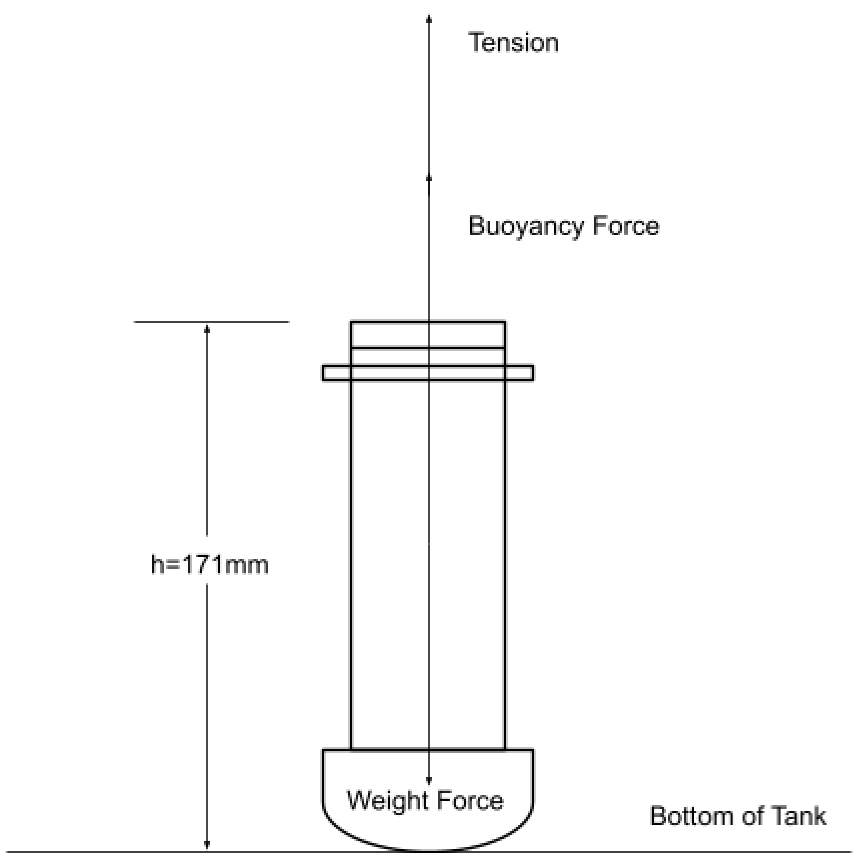
$T = \rho_{water} g V_{submerged} - m_{balloon} g$

$T = (999 \times 9.81 \times 5 \times 10^{-6}) - (0.004 \times 9.81)$

$T = 998.96\, N$

Static force analysis on the device at the bottom of the tank:

Below is a diagram of this situation:



Where:

- $m_{device} = 217\ g = 0.217\ kg$
- $V_{submerged} = V_{device} = \pi r^2 h = \pi \times 25.4^2 \times 171 = 346587\ mm^3 = 0.00034569\ m^3$
- $m_{water\ in\ device} = V_{device} \times \rho_{water} = 0.00034659 \times 999 = 0.34624\ kg$

Again, using force equilibrium along the y-axis, the tension force in the string and acting on the device whilst at the bottom of the tank can be found:

$\sum F_y = 0$

$T + F_b = W$

$T = W - F_b$

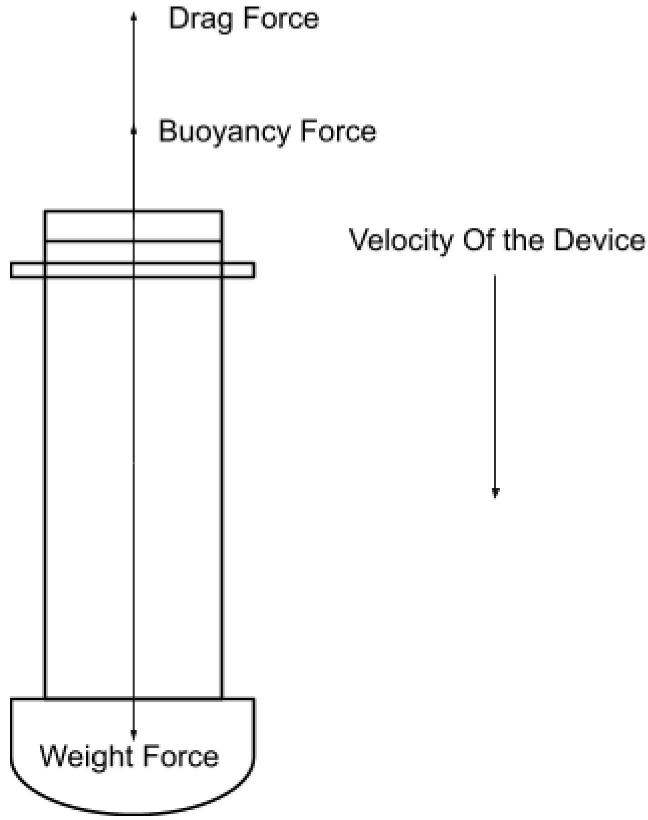
$T = (m_{device} + m_{water\ in\ device})g - \rho_{water} g V_{submerged}$

$T = (0.217 + 0.34624) \times 9.81 - 999 \times 9.81 \times 0.00034659$

$T = 2.1287\ N$

Dynamic force analysis on the device while it is sinking to the bottom of the tank:

Below is a diagram of this situation:



We make an assumption for the drag coefficient, given it is a rounded nose section that is experiencing a drag force:

Rounded nose section with L/H = 2.5/7.5 = 0.333 ≅ 0.5, so C_D = 1.16

The following analysis finds the terminal velocity of the falling device, once again using a force equilibrium along the direction of motion. The terminal velocity is the maximum velocity of the device, where it is no longer accelerating:

$$\sum F_y = 0$$

$$\Rightarrow F_b + F_{drag} - W = 0$$

$$\Rightarrow \rho_{water} g V_{submerged} + \frac{1}{2}\rho_{water} v^2 C_D A - mg = 0$$

Rearranging for the velocity of the falling device (v):

$$v = \sqrt{\frac{2(mg - \rho_{water} g V_{submerged})}{\rho_{water} C_D A}}$$

After substituting in values, the terminal velocity is:

$$v_{terminal} = \sqrt{\frac{2[(0.217+0.34624)\times9.81-999\times9.81\times0.00034659]}{999\times1.16\times(\frac{\pi}{4}\times0.0508^2)}}$$

$$v_{terminal} = 1.3463\ m/s$$

1.4: Material Properties

When figuring out the material that will be most suitable for a prototype sonobuoy it must satisfy some major criteria for it to be a sonobuoy. These criteria include:

- Easy to configure
- Durable (Especially in Water)
- Reusable
- Light
- Affordable

With this in consideration, plastic was the most suitable. As for the grade of plastic, the selections came down to PVC. It was the most convenient type of plastic at the time of construction. PVC is used in toys, pipes, and food packaging (Hardin, 2021), making it very affordable. Hence, solidifying the decision on working with PVC. PVC is used for the hemispherical bottom and the main body of the device.

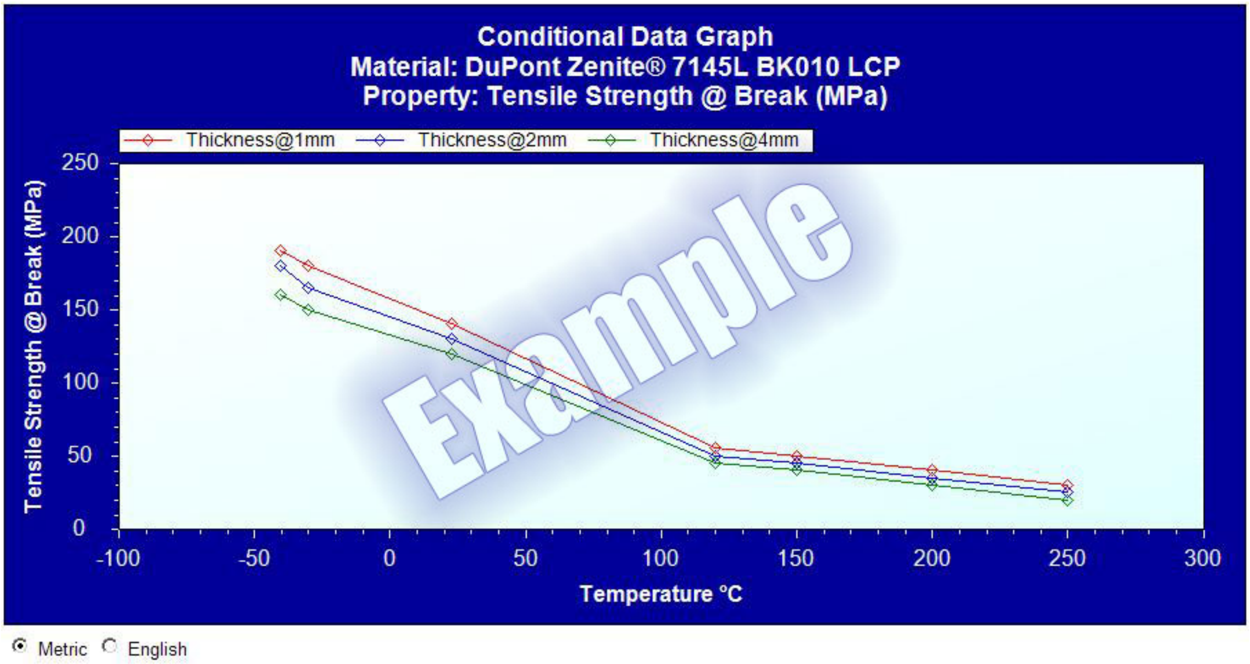


Figure 1: *MatWeb property graph* (matweb, Conditional data graphs, 2022)

From Figure 1, considering that the user environment of the device has a temperature of roughly around 20 degrees Celsius, and the device has an average thickness of 1.5mm, the PVC has a tensile strength of 150MPa and since the pressure of water at 1m is 9.81kpa (Toolbox, 2010), the property of PVC is more than suitable as a prototype. Especially when the device is sitting at the bottom of the tank. For the PVC being used, the grade of PVC used is on the stiffer side of PVC and other plastics. The Young's modulus of the PVC used can range from 1.82GPa to 7.03Gpa (matweb, Overview of materials for PVC, Rigid Grade, 2022). However, being plastic, it is very ductile, proven in figure 2.

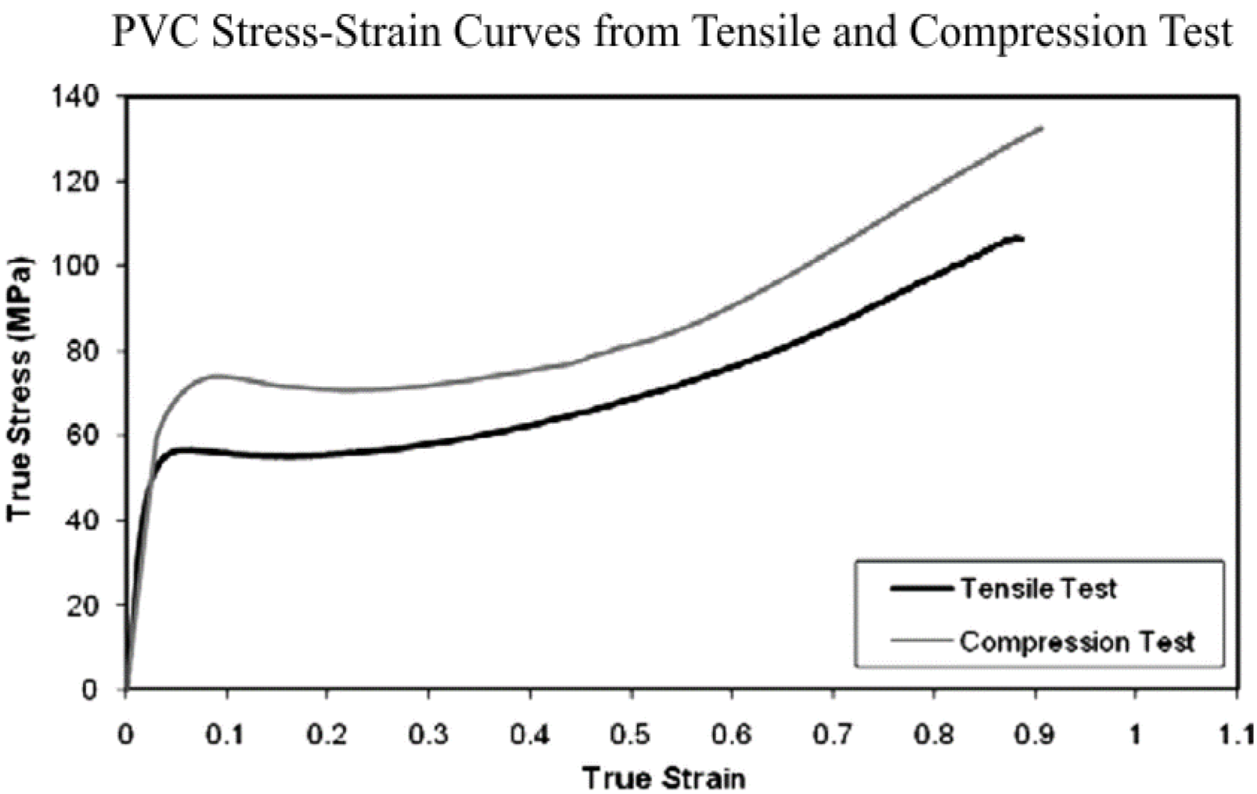


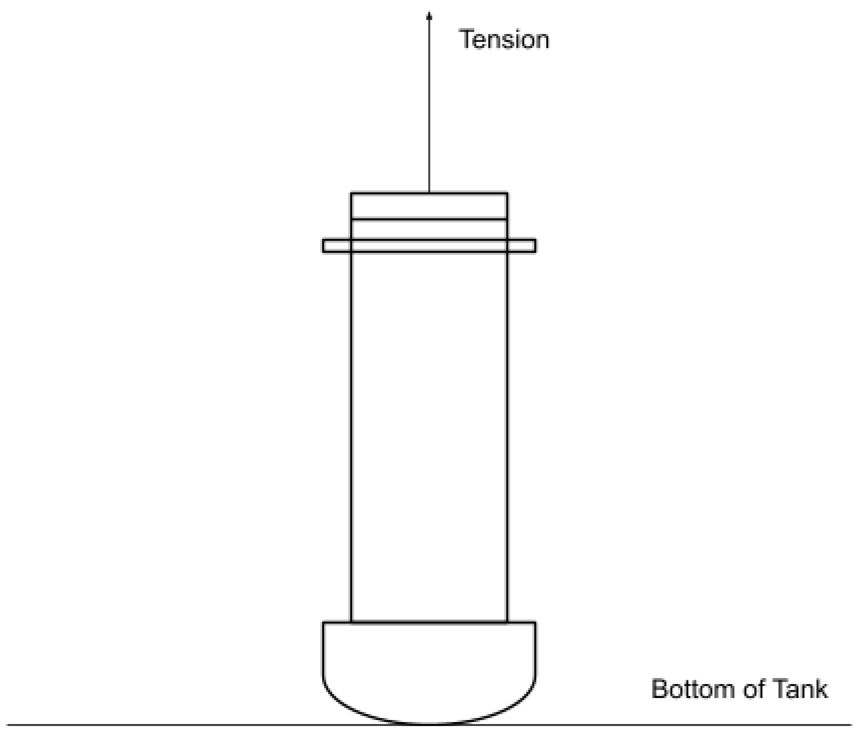
Figure 2: PVC Stress Strain Curve (Alves, 2009)

Further referencing Figure 2, the yield strength is more than 50 MPa for both types of tests. Knowing that the water pressure can be no more than 9.81kpa. The plastic will not go through any deformations. This confirms that the shape of the device can be kept constant and can be reused multiple times. With all these properties, PVC is an appropriate choice of material, satisfying the major criteria for a sonobuoy.

1.5: Stress Analysis

Stress analysis on the device at the bottom of the tank, with no force along the x-axis and when it is directly below the balloon:

Below is a diagram of the situation:



The normal stress in this situation is:

$$\sigma = \frac{F}{A} = \frac{T}{A}$$

$$\sigma = \frac{2.1287}{(\frac{\pi}{4} \times 0.0508^2)} = 1050.3\ Pa$$

Stress analysis on the device on the surface of the water, when the device is partially submerged and impacted by the wave currents and therefore drag force:

Some assumptions must first be made to solve this problem:

- The area (A) is the area affected by the drag force, which is approximated as $h_{device} \times d_{device}$, where 'h' is the height and 'd' is the diameter.
- Velocity (v) of the device due to the wave current will be approximated as v = 0.5 m/s.
- Only drag due to the water will be considered, not due to the air (velocity is too low, so it will be negligible), therefore only the density of water (ρ_{water}) will be used.
- The coefficient of drag will be approximated as C_D = 0.72, since Length/Diameter ratio of the short cylinder shape used in the device is approximately 3.

Using these assumptions, we can complete the following stress analysis:

$$F_{drag} = \frac{1}{2} \rho_{water} v^2 C_D A$$

$$F_{drag} = 0.5 \times 999 \times 0.5^2 \times 0.72 \times 0.171 \times 0.0508 = 0.78103\, N$$

<u>Maximum Moment:</u>

$$M_{max} = L \times F_{drag}$$

$$M_{max} = 0.171 \times 0.78103 = 0.13356\, N \cdot m$$

<u>Second Moment of Area:</u>

$$I = \frac{\pi}{4} r^4$$

$$I = \frac{\pi}{4}\left(\frac{0.0508}{2}\right)^4 = 3.269 \times 10^{-7}\, m^4$$

Bending Stress:

$$\sigma_{max} = \frac{Mc}{I} = \frac{0.13356\times0.171}{3.269\times10^{-7}} = 0.069865\ MPa$$

Maximum Transverse Shear:

$$\tau_{max} = \frac{4V}{3A} = \frac{4\times0.78103}{3\times0.171\times0.0508} = 119.88\ Pa$$

1.6: Predictions and Performance Analysis

Prior to the official testing on Tuesday, as a group we performed roughly 10 tests with varying performance outcomes. For each drop test that we performed we changed aspects of our design including, the weight, buoyancy, and other minor design changes.

Based on our final two tests, we are predicting that our device will drop down into the water and float on its side for roughly 14 - 17 seconds before the top is fully submerged and the device starts to sink. Here, our sink time has been consistent so our prediction is 6 seconds, and we expect it to sit at the bottom without any stability issues.

- **Float Time:** 14 - 17 sec
- **Sink Time:** 6 sec
- **Stable @ Bottom:** yes

1.7: Official Testing Results and Discussion

On the testing day our prototype performed outside of our prediction for the amount of time that it would float on the surface of the water. Our prediction of 14 - 16 seconds was exceeded by 10 seconds as it floated on the water for 29 which was outside of the 15 - 20 second floating requirement.

From the drop, we noticed that the reason for our could maybe be attributed to the balloon attached to our device as both floated over to the corner of the tank while touching each other. This could have slowed down the sinking as the device maybe did not rotate to allow water to fill the top holes quickly enough.

The sinking time was slightly longer than we had predicted but still within the specified range for the assignment so we were pleased with the result. There was a point however where it seemed to sink very slowly and then the sinking rapidly accelerated. This could have been attributed to how internal weights sat inside the device as there were times in testing when the hole that allowed water to flow in would be slightly blocked.

Overall we were pleased with the outcome of the testing considering out of the 3 requirements, we were only outside of 1 of them.

- **Float Time:** 29 seconds
- **Sink Time:** 8 seconds
- **Stable:** yes
- **Prototype Mass:** 223g
- **Prototype Dimensions:** Pass

1.8: Prototype Costs

Part Name	**Quantity**	**Supplier**	**Price per 1 (AUD)**
Balloon Pump	1	Kmart - Anko	$2.00
Duct Tape	1	JackHammer	$5.50
50 Assorted Balloons	1	Kmart	$3.25
Pea Gravel	100g	USyd Lawn	Tuition
Plastic Damper	100mm x 100cm	Recycling Bin	$0.00
Scrap Metal	100g	USyd	Tuition
Total			**$10.75**

Table 1.8.1: Bill of Materials

The costs for building the prototype was very low considering all the materials and parts used are widely accessible and materials found in daily life.

1.9: Bibliography

Aliaxis. (2022). *PVC Proeprties*. Retrieved from Vinidex by Alaixis: https://www.vinidex.com.au/technical-resources/material-properties/pvc-properties/#:~:text=PVC%2DU%20(unplasticised)%20is,is%20resistant%20to%20most%20chemicals.

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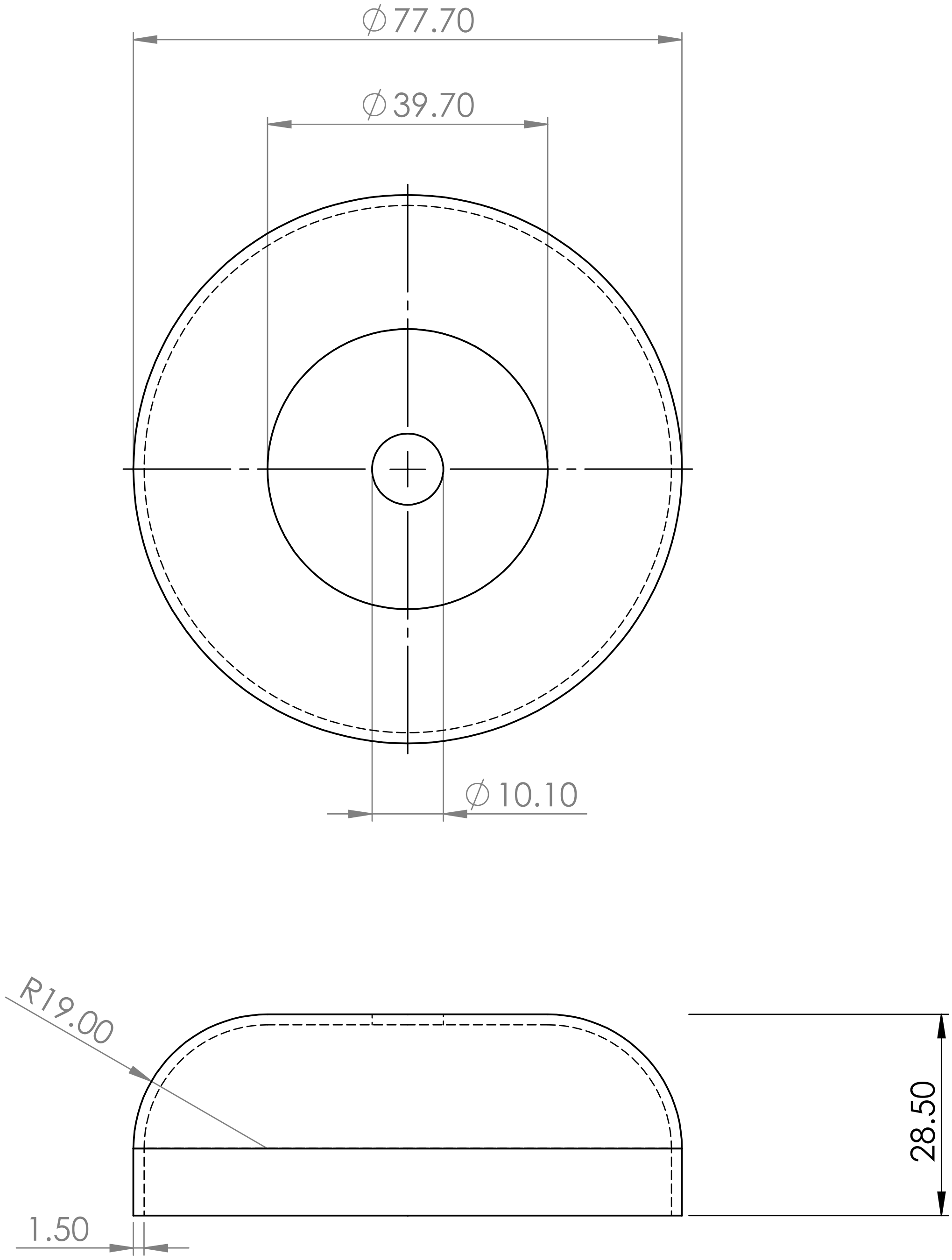
Section 2.0: Engineering Drawing Package

2.1: Detail Drawings



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: +/- 1
ANGULAR:

FINISH: NO SURFACE FINISH

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	R.R.S		25/10/22
CHK'D	R.L		25/10/22
APPV'D			
MFG			
Q.A			

TITLE:

BASE

MATERIAL: PVC

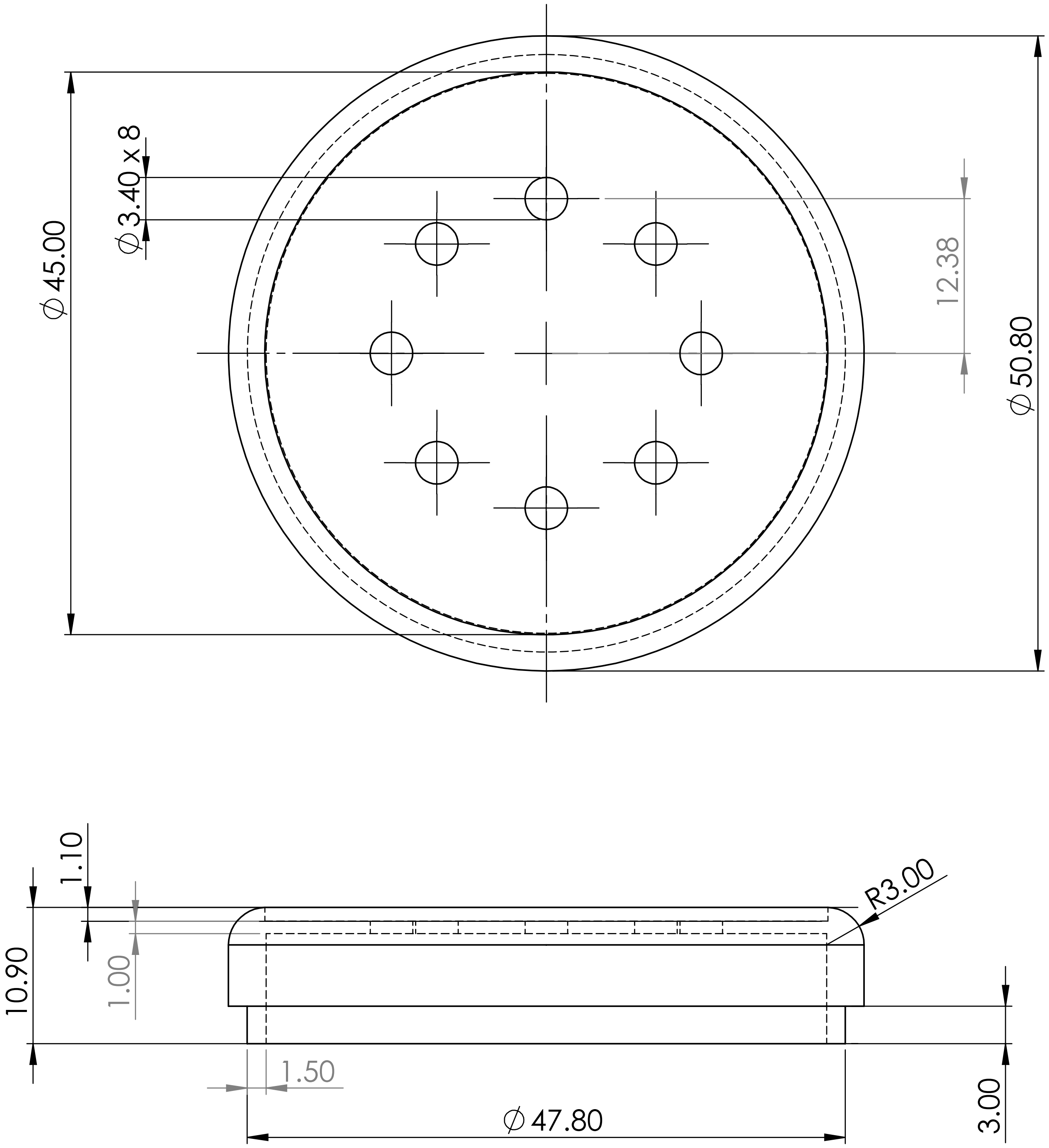
DWG NO. GROUP5-002

A4

WEIGHT:

SCALE:1:1

SHEET 2 OF 3



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +/- 1 ANGULAR:	FINISH: NO SURFACE FINISH	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN	R.R.S		25/10/22
CHK'D	R.L		25/10/22
APPV'D			
MFG			
Q.A			

TITLE: CAP

MATERIAL: PVC

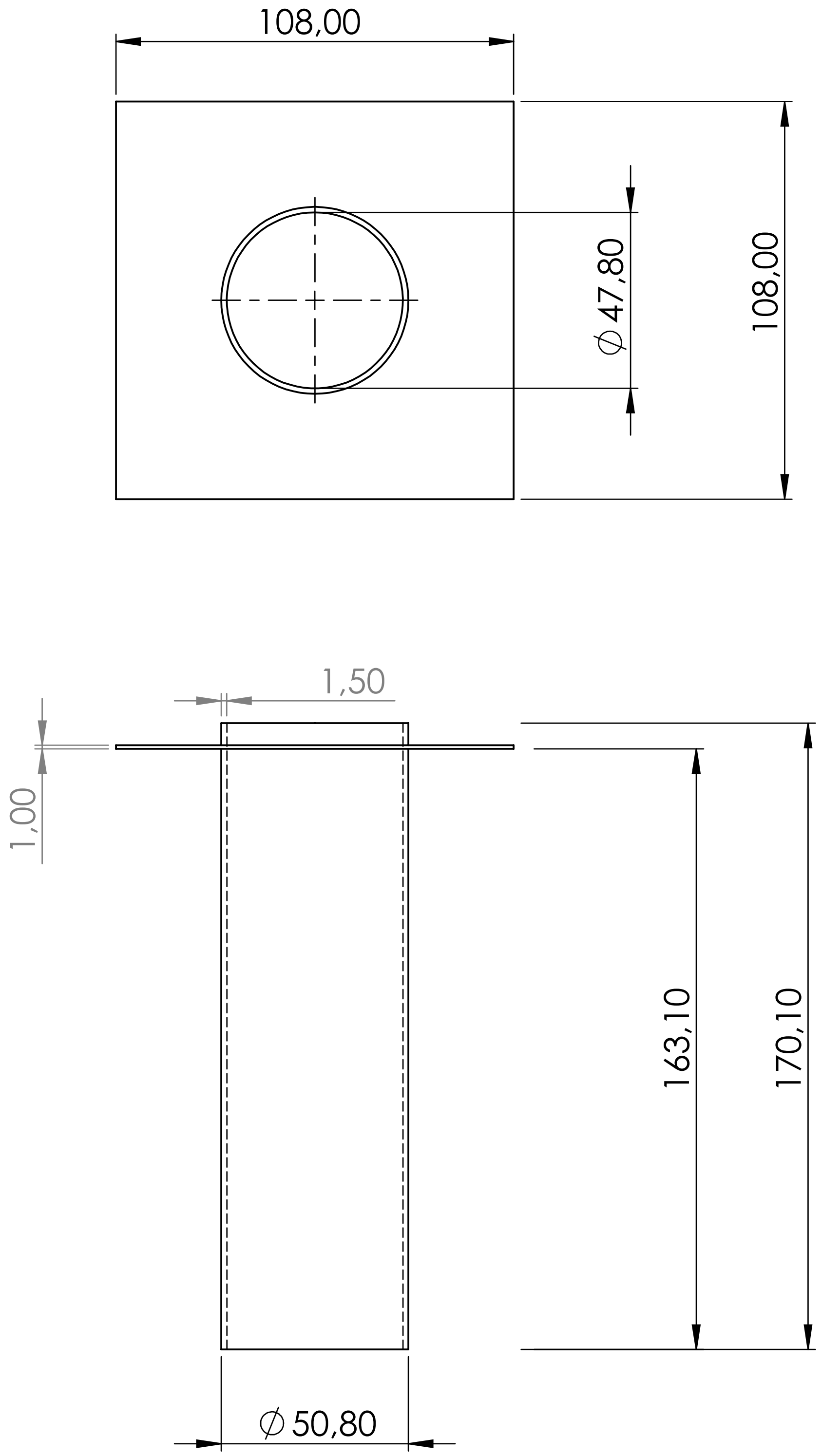
DWG NO. GROUP5-003

A4

WEIGHT:

SCALE:2:1

SHEET 3 OF 3



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: +/- 1 ANGULAR:	FINISH: NO SURFACE FINISH	DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION

	NAME	SIGNATURE	DATE
DRAWN	R.R.S		25/10/22
CHK'D	R.L		25/10/22
APPV'D			
MFG			
Q.A			

TITLE: CYLINDER

MATERIAL: PVC

DWG NO. GROUP5-001

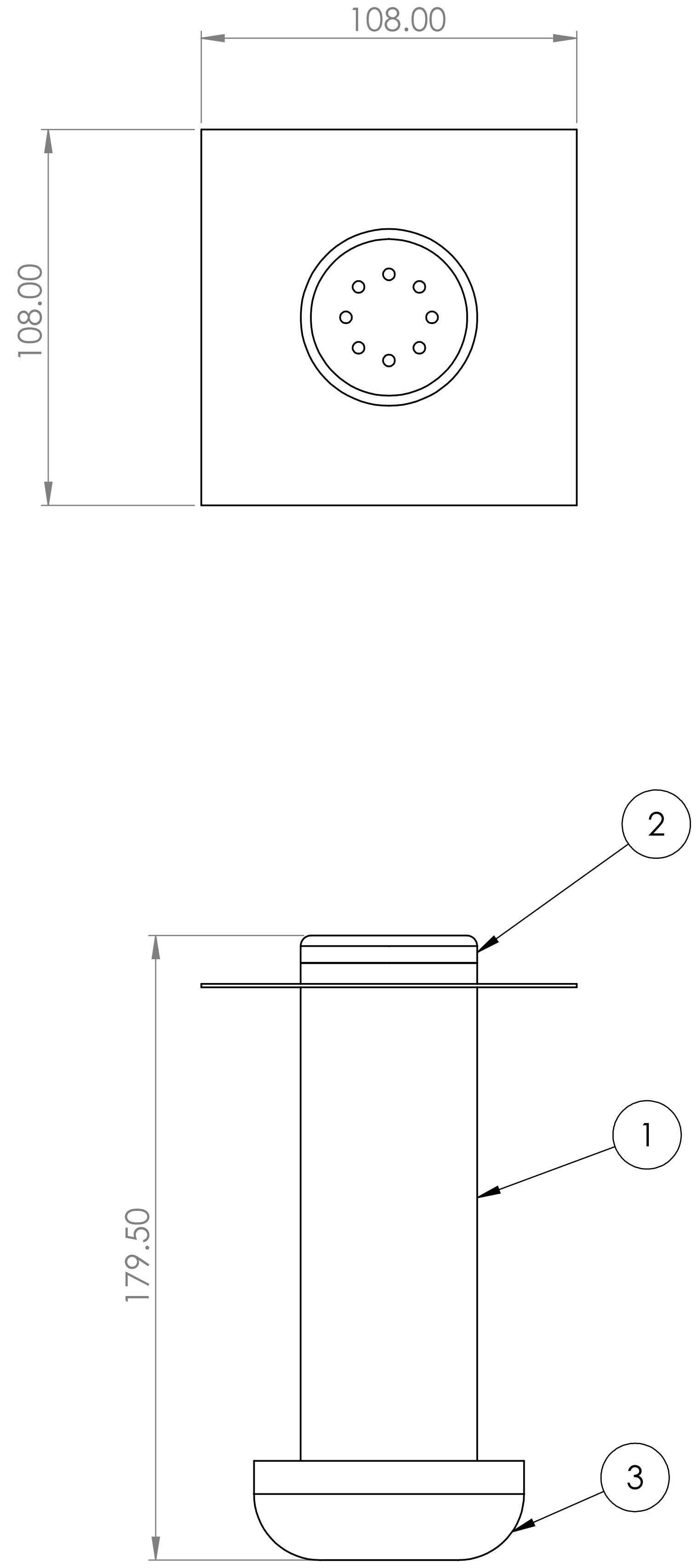
A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 3

2.2: Assembly Drawing



NO.	NAME	QTY	COMMENT
3	BASE	1	PVC
2	CAP	1	PVC
1	CYLINDER	1	PVC

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR: +/- 1
ANGULAR:

FINISH: NO SURFACE FINISH

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	R.R.S		25/10/22
CHK'D	R.L		25/10/22
APPV'D			
MFG			
Q.A			

TITLE:

PROTOTYPE SONOBUOY ASSEMBLY

DWG NO.

GROUP5-003

A3

WEIGHT:

SCALE:1:2

SHEET 1 OF 1

2.3: Application Specifications

To assemble the device, first take the base and connect it to the cylinder with either tape or glue (no specific adhesive required). Next, add 153g of a combination of pea gravel and scrap metal to the inside of the cylinder. This acts as the weight to keep the device upright once at the bottom of the tank while also being the right amount of internal weight to allow for the device to float and sink at the right rate. The cap of the device simply pops onto the top of the cylinder with the floating balloon connected to the cap with 400cm of fishing line. The cap also has a continuous loop of fishing line connected as a place for the carabiner to connect.