DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

University of Strathclyde Engineering

High-Performance Pressure-Based Microfluidic Pump

Interim Report, Group C

Authors: Yoel Amos (202144299), James Carter (202130371), Caelan Gillon (202131157), Juan Pablo Gore (202129786), Nathan Matthews (202100766) & Cameron Robinson (202138468)

Supervisors: Dr Monica Oliveira & Mr Drew Irvine

11th of December 2025

Table of Contents

Table of Figures

Table of Tables

1. Background

The James Weir Fluids Lab (JWFL) investigates the nature of fluid flow at nano-scales under the domain of microfluidics, a research sector with potential applications in medical research, medical diagnostics, food production, manufacturing, and chemistry [1], [2]. Microfluidic chips are commonly constructed using Polydimethylsiloxane (PDMS) on glass microscope slides and have channel widths of 10–100 μm. The complexity of these chips can range from single channels to large 'organ-on-chip' devices, used to simulate biological activities [3]. They require very small, stable and precise flow rates with, ideally, a wide range of control inputs given to the driving method. Some examples include: steps, on/off modulation, waves, and reversible.

The lab currently uses a syringe pump, which is a ball screw assembly that can precisely drive the plunger of a syringe [4]. The flow rate is adjusted accordingly to the speed at which the plunger travels. The fluid is then pushed out the end of the syringe and into the microfluidic chip.

Shortcomings of the syringe pump include:
1. Mechanical movement of the fluid severely limit the response time.
2. Extremely low speeds prevent the motor overcoming the friction of the screw, resulting in plunger slippage and instability.
3. Dynamic movement is impossible due to large settling times.

A pressure driven system would allow the use of fewer moving parts with smaller tolerance and compliance issues. It would provide the chip with a steady, precise, pressure driven flow rate and the ability to set a volumetric flow rate. Prices for these regularly go above £10,000, however, the components themselves could be manufactured for a fraction of the cost [5].

2. Aims & Objectives

The aim of the project is to research, design, manufacture, and test a pressure-based pump for microfluidic experiments. This includes the physical system, control system, UI, and supporting documentation all within the allocated budget. Objectives for the project follow the motivations mentioned previously, with the JWFL requiring specific design criteria such as a range of 0-2 bar, dynamic flow rate capabilities, and scalability. This is represented by milestones such as defining a full Bill of Materials (where components are researched and chosen based on compatibility and the aforementioned requirements), component sourcing, prototyping and software development, testing and iteration, and the final product.

Milestones outwith the physical deliverables include the Statement of Work, Interim report & Oral interview, Final report, relevant documentation for future use of the product. This will include an operational manual, risk assessment, configuration, calibration, upgrade methods, replacement part lists, and the costs to increase the number of available channels. Due to the nature of the project, and dependant on the succuss of the prototype phase, there is potential to increase the project scope. This could be done by increasing the features available to the research team; via software integration, flow reversibility, or upgraded components. Another path could be to increase the number of channels, as scalability is a key design feature that is heavily dependant on budget use.

Alongside physical component sourcing, building and testing, the project will require simulation techniques to be applied to ensure component compatibility and the validation of an in-house pressure regulation system. This involves a functional Simulink model capable of proving the effectiveness of chosen components, as well as integrating control methods (PID) into the system. This allows for testing to begin promptly during the prototyping phase, and for confidence in subsystems before full product testing begins.

3. Achievements

This section will discuss the key milestones which have been achieved so far. These can be broadly categorised into three categories:

1. System design and component selection
2. System modelling and control
3. Electrical hardware and software design

3.1. System Design and Component Selection

The finalisation of the system design was the first priority of the group in the first semester. This required the team to finalise all component and connection decisions, as well as the overall layout of the system.

For pressure regulation, a choice had to be made between an existing pressure (or electro-pneumatic) regulator, with it's own control circuit, or proportional valves, with a control circuit designed by the group. It was decided, due to the price of existing pressure regulators being over half the total budget, that proportional valves would be used.

The flow rate sensor is an essential component and had to be carefully chosen. This enables the product to control the flow rate, as opposed to only pressure like many other systems. The accuracy of this component is the key restraint on the minimum flow rate achievable and how finely the flow rate can be controlled. For this component the group was given a separate budget as the minimum cost exceeded what was allocated to the project. There are many available flow rate sensors on the market which could provide better accuracy, however, the current budget led the team to choose the LG16 [6].

With these components finalised, the full system could be purchased with special care taken for the connections and fittings. The finalised system can be seen in Figure 1, and a complete part list is available in Appendix A.

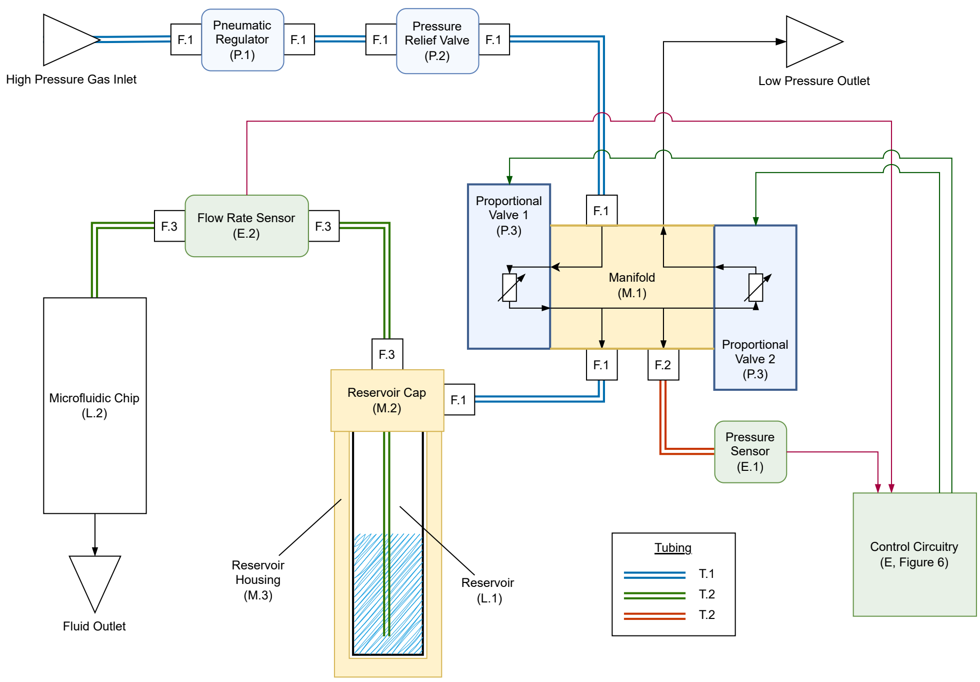
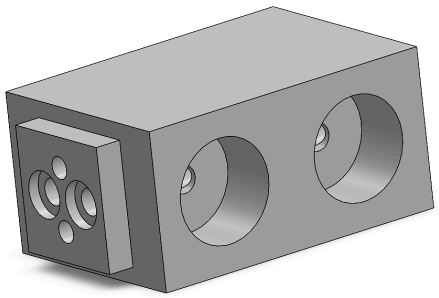
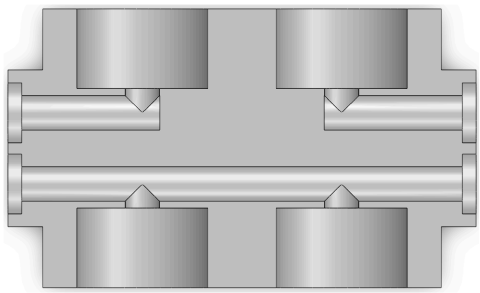


Figure 1: System diagram

With finalised parts, components that required custom manufacturing could then be designed to fit the required connections. This was essential for the manifold, reservoir cap and reservoir housing; shown in Figure 2, Figure 3 and Figure 4 respectively. The technical drawings of these parts are available in Appendix B.



(a) Manifold design



(b) Cross-section

Figure 2: Pressure regulator manifold

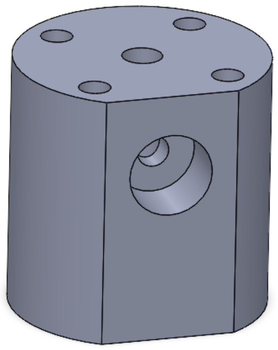


Figure 3: Reservoir cap

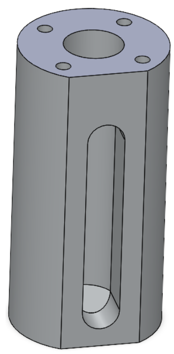


Figure 4: Reservoir housing

3.2. System Modelling and Control

With the hardware chosen, there are numerous avenues for the implementation of the system control. To evaluate the various control methodologies, best practice is typically through the development of a digital twin. A Simulink model has been made using the Simscape fluidics toolbox, simplifying the valves as orifices and the chip as a thin pipe, seen in Figure 5. As an initial model this will be useful to test various controllers, and assess the feasibility of design with our available hardware.

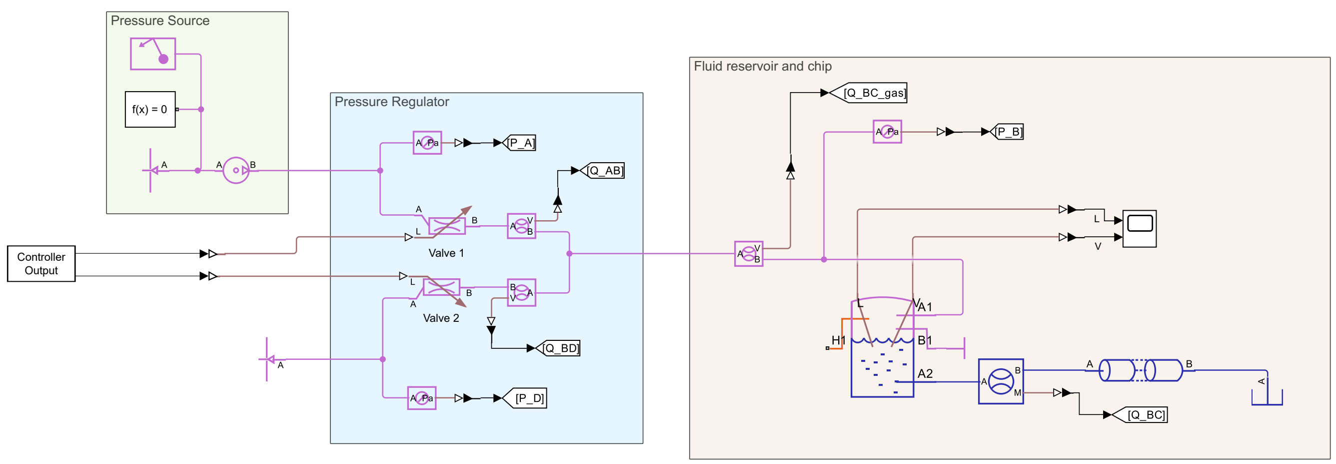


Figure 5: Simulink model (plant)

This model allows for the design of simple controllers, with current tests verifying the feasibility of manually tuned, nested PID-controllers. This operates by using an inner PID loop to control the pressure, and an outer PID loop to control the fluid flow rate, which then calculates the target pressure for the inner loop as seen in Figure 6. PID control is simple and does not require an accurate mathematical model to provide adequate control, making this setup a reliable starting point to implement and test early hardware concepts. The Simulink model is not a completely accurate representation of how the system will work in reality, as components will inherit losses. An example of this, is the valve settling time and sensor noise which will be present. However, once the system is assembled, and these are identified, the fidelity of the simulation can be increased. Ideally, a full mathematical model of the system dynamics will be implemented, allowing for optimal control methods to be used as opposed to manually tuned PIDs, improving control and precision.

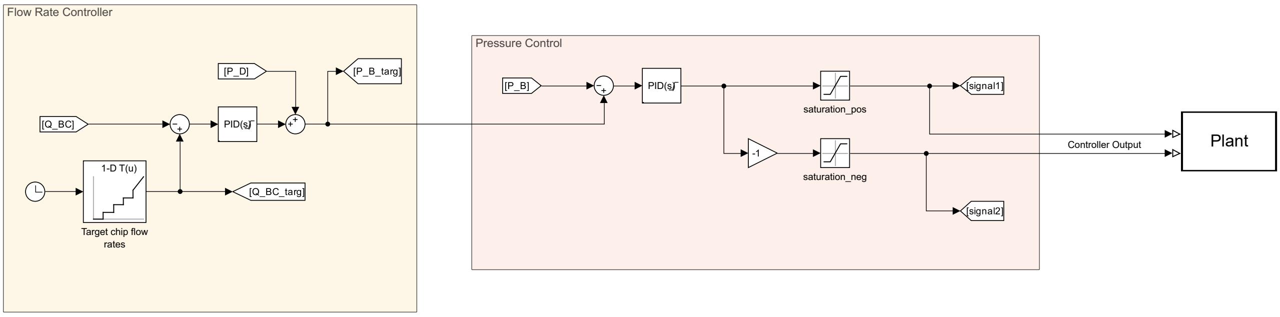


Figure 6: Nested PID control system

There is potential to use more advanced controllers if the system can be modelled mathematically. To do this, the model is simplified into lumped-parameters, treating the proportional valves as variable resistances R_1 and R_2, the reservoir inlets as resistances $R_{r,\text{in}}$ and $R_{r,\text{out}}$ to be found analytically, and the microfluidic chip as a resistance R_c which is unknown and dependent on the user application. The parameters that will be used in the dynamics are shown in Figure 7.

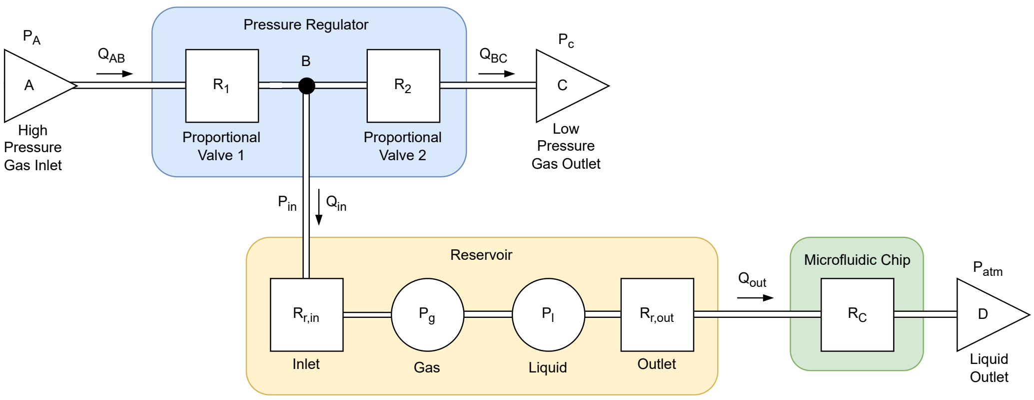


Figure 7: Lumped-parameter system model

Using this model, assuming the density of the gas is constant, the following relationship between pressure and flow rate can be modelled analogous to an electrical circuit, where ΔP is the difference in pressure, Q is the flow rate and R is the fluidic resistance of the component - a form of Hagen–Poiseuille's law [7].

$$\Delta P = QR \tag{1}$$

From Equation 1, the relationship between the flow rate through the chip, Q_{out}, and reservoir gas pressure, P_g, can be evaluated to determine Equation 2.

$$Q_{\text{out}} = \frac{P_g - P_{\text{atm}} + P_{\text{hydro}}}{R_c + R_{r,\text{out}}} \tag{2}$$

The relationship between the pressure coming from the regulator, P_{in}, and the valve resistances is formulated in Equation 3.

$$P_{\text{in}} = \frac{P_g\, R_1\, R_2 + P_A\, R_2\, R_{r,\text{in}} + P_C\, R_1\, R_{r,\text{in}}}{R_1\, R_2 + R_1\, R_{r,\text{in}} + R_2\, R_{r,\text{in}}} \tag{3}$$

Using the ideal gas law, the pressure of the gas in the reservoir, P_g, can be found using the change in mass of the system. This is shown below in Equation 4.

$$P_g = \frac{P_{g,0}\, V_{\text{tot}} - P_{g,0}\, V_{l,0} + \int P_{\text{in}}\, Q_{\text{in}}\, \text{d}t}{V_{\text{tot}} - V_{l,0} + \int Q_{\text{out}}\, \text{d}t} \tag{4}$$

3.3. Electronics and Software

Changes in hardware and setup has resulted in stop-and-start progress of the relevant electronic subsystems. Preliminary research on suitable methods of power for the system reveals that out of the three most common AC-DC adapters (linear regulated, switching regulated and programmable), a linear regulated power supply is superior for the project. Linear power supplies, although inefficient, minimise power supply noise and eliminate the need of a low-pass filter - reducing modes of error in the manufacturing process.

Upon reaching an affirmed understanding of the required system components, the electronic development could fully commence. A general schematic diagram of the electronics was produced, making sure to identify the relevance and properties of each connection. The schematic of the project's current state of design is shown below in Figure 8. Initial testing of the NXP Guage Pressure Sensor revealed the requirement for an instrumentation amplifier, as identified by part number E.8.

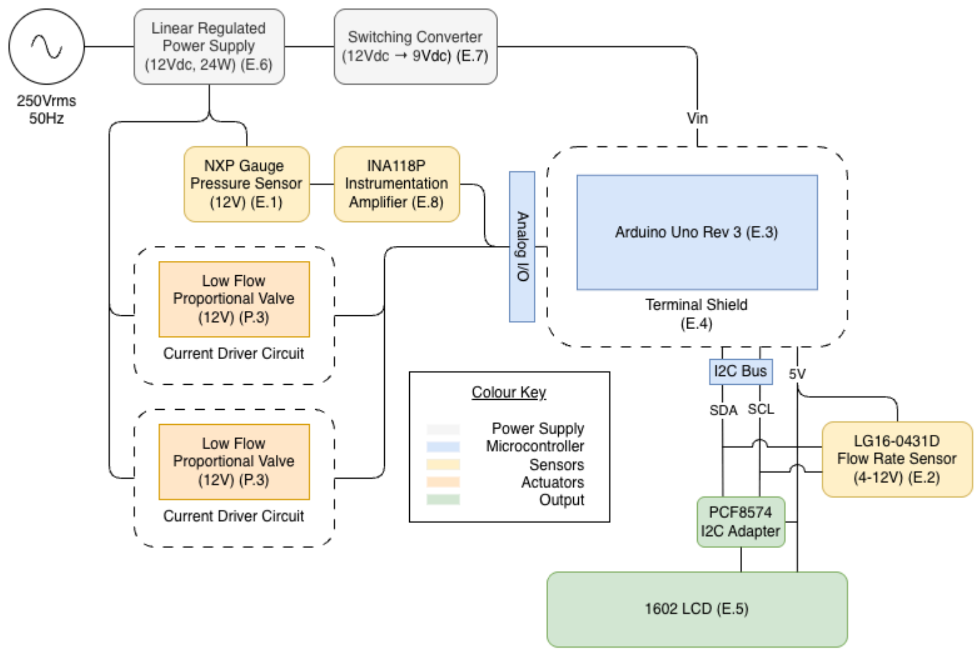


Figure 8: Electronic schematic

4. Progression Plan

The Statement of Work (SoW) presented a Gantt chart and manufacturing plan, which was successfully followed. An additional Gantt chart was created to outline the milestones and plan of operations for the second semester, seen in Figure 9. This timeline describes phases 3, 4 and 5 of the project, as reported in the SoW.

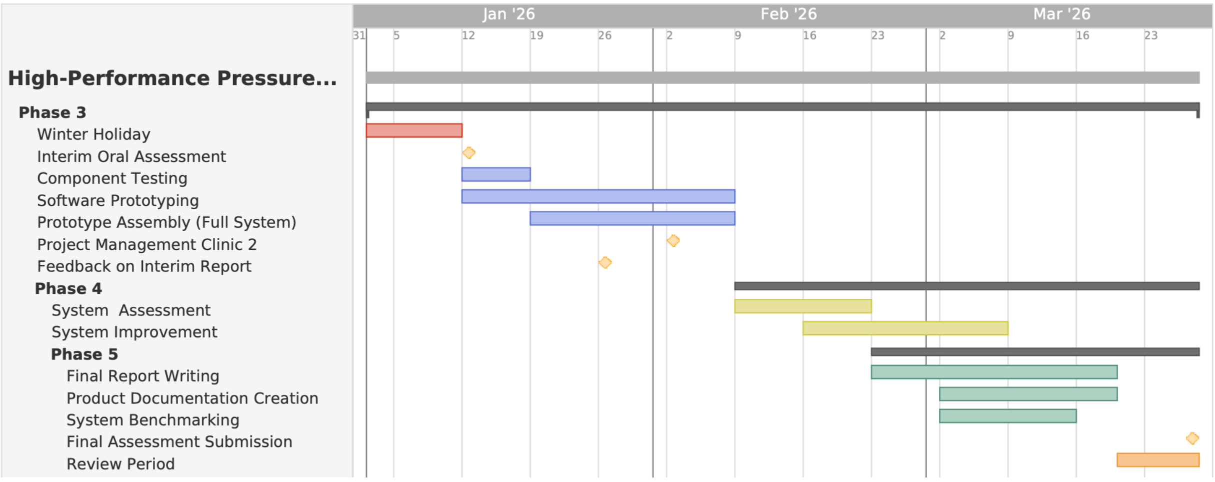


Figure 9: Gantt chart for semester 2

With all essential components acquired, the second semester will primarily focus on the modelling, construction and optimisation of our system. Cost effective component sourcing in the first semester may permit future improvement beyond the initially proposed deliverables; improvements which are likely to manifest as further functionality, performance or accuracy. Therefore, implementation and optimisation are expected to be the most significant and challenging tasks in the second semester.

4.1. Modelling

With a Simulink model being used to validate the functionality of the system, the primary challenge for the control and electronics sub-team is to effectively transfer the controllers to the physical hardware.

In it's most basic form, an implementation of the controller will likely make use of variable struct storage and iterative PID calculations, shown below.

```
int setPoint = 0; // Target pressure

struct PID {
  float error;
  float prevError = ;
  float prevIntegral = 0;

  float proportional;
  float integral;
  float derivative;

  float Kp = f(tbd); // P, I and D constants (tbd)
  float Ki = f(tbd);
  float Kd = f(tbd);
  float out;
```

```
} pid;

// PID Controller
pid.error = instant - setPoint; // Determine current error

pid.proportional = pid.error; // Find P, I and D components
pid.integral = pid.prevIntegral + (dt * pid.error);
pid.derivative = (pid.error - pid.prevError) / dt;

pid.prevError = pid.error; // Save values for next time step
pid.prevIntegral = pid.integral;

pid.out = pid.Kp * pid.proportional + pid.Ki * pid.integral ...
  + pid.Kd * pid.derivative; // Sum P, I and D components
```

In addition to the controller, all sensor data will likely need filtered and pre-processed before being fed to the controller. A high-level framework for software operations is proposed in Figure 10 and serves as the foundation for future software developments.

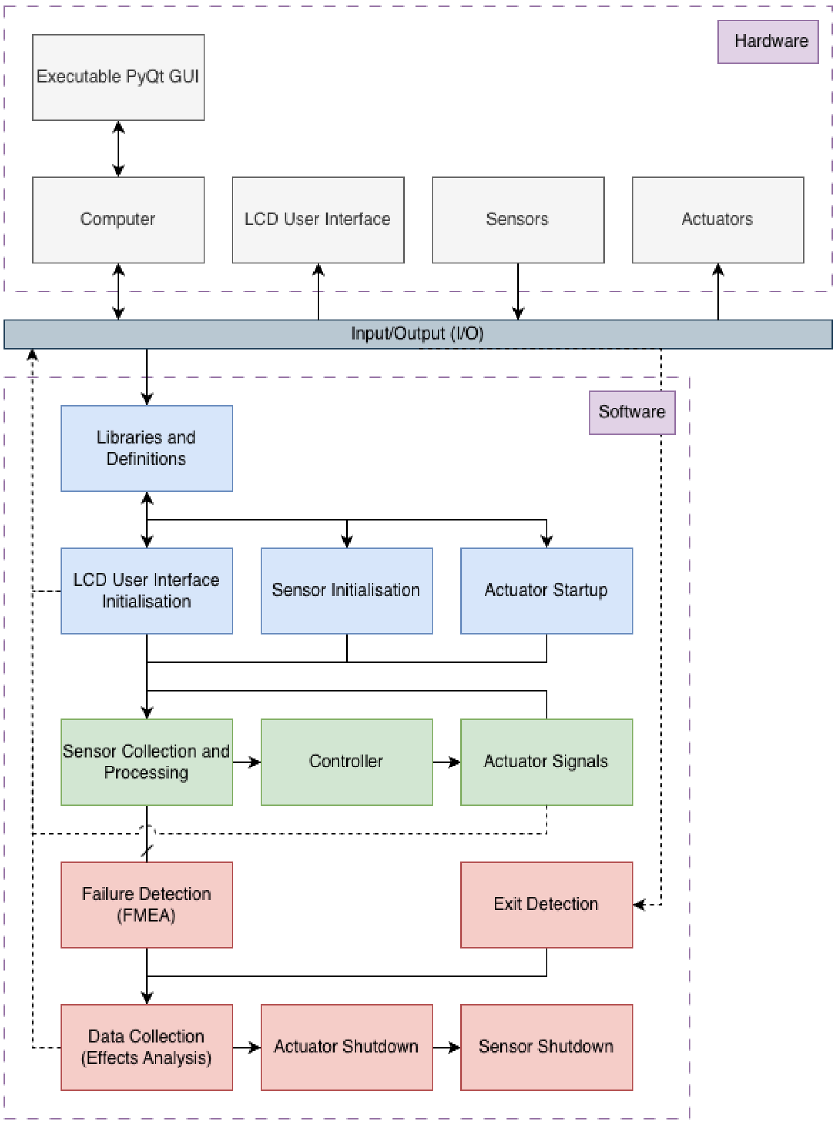


Figure 10: Software framework

4.2. Construction

Construction is the foundation of phase 3 of the project plan. It is difficult to foresee the time this phase requires, partially due to its dependancy on the manufacturing team at James Weir and the delivery time of components.

As seen in Figure 1, the system is segmented and modular which can be clearly divided into pressure, electrical, reservoir and manifold subsystems. The construction will begin with individual subsystems, before proceeding to the overall assembly. This is to ensure that any assembly errors, or undiscovered design flaws, are located and dealt with before wider interactions take place.

To comply with the safety and risk mitigation requirements of JWFL, a gradual approach will be taken to the assembly of these subsystems. The pressure subsystems will begin testing with low pressure ranges, and only once functionality is verified will the team proceed to the proposed operating range. The electronic circuits, crucial to most of the system, will first begin on a solderless breadboard. After verification, permanent soldering may begin. The final system will then be compactly housed, ensuring sure it's portable and repeatable for experiments in JWFL.

4.3. Optimisation

The group intends to optimise and improve the design once the first full system prototype is finished. This is identified in Figure 9 as phase 3, and is similar to the expanding scopes philosophy discussed in the SoW.

Currently, it is impossible for the group to fully comprehend the weight of the optimisation phase as it strongly depends on the severity and number of issues accumulated during the construction phase. It is expected that the optimisation will largely revolve around the controller by iteratively improving the controller and sensor processes.

5. Reflection

To optimise group efficiency, the first week was dedicated to understanding the individual strengths, and matching them to the project's requirements. This involved making key decisions on the roles within the group, mainly who would work best as project manager, technical manager, and other important roles. By defining this, the group would have people working for the others, providing support on planning and deadline management, as well as smaller items such as file management and meeting planning. A key part of the project is communication, and this has been taken very seriously. This is due to the various levels of communication required with supervisors, workshop technicians, third party vendors, as well as inter-group operations. To aid with this, the use of popular platforms such as WhatsApp and Microsoft Teams was crucial to the success of the first semester.

To add clarity, Teams was not the first application of choice, and Notion was initially used during the early research phase. Once research had reached an acceptable level, and the design and procurement of components began, the group discovered that Notion could not handle this as well as required, hence the migration to Teams. A full Bill of Materials was the first deliverable, this required the collaborative efforts of the entire team. Once completed, the individual strengths of members could be utilised (e.g. electronics, control theory, design, writing, communication, etc.) in order to maximise efficiency and complete the promised deliverables in appropriate timeframes.

Risk management is a key consideration to be made in any project. This project involves manufacturing, component costing and procurement, and in-lab work, therefore the need for a fully defined understanding of the risks associated is non negotiable. Towards this effort, a role of 'risks manager' was created and assigned, allowing for one person to take a holistic view of the groups activities. They ensure everything is done safely and protects the group's interests (e.g. planning for the potential of a bought part being delayed). By defining mitigation strategies for the above, the group can work without the significant stress of worrying about things going wrong.

All semester one deliverables were successfully reached within the promised timeframe. This was aided by the dynamics of the entire group and by defining roles, understanding and mitigating risks, and maintaining a high level of group communication.

Bibliography

[1] University of Strathclyde, Department of Mechanical & Aerospace Engineering, 'Fluids'. [Online]. Available: https://www.strath.ac.uk/research/subjects/mechanicalaerospaceengineering/fluids/

[2] G. M. Whitesides, 'The Origins and the Future of Microfluidics', *Nature*, vol. 442, no. 7101, pp. 368–373, July 2006, doi: 10.1038/nature05058.

[3] S. Surina, A. Chmielewska, B. Pratscher, P. Freund, A. Rodríguez-Rojas, and I. A. Burgener, 'Organ-on-a-Chip: A Roadmap for Translational Research in Human and Veterinary Medicine', 2025, doi: 10.3390/ijms262110753.

[4] B. Wijnen, E. J. Hunt, G. C. Anzalone, and J. M. Pearce, 'Open-Source Syringe Pump Library', *Public Library of Science San Francisco*, vol. 9, no. 9, 2014.

[5] Darwin Microfluidics, 'OB1 MK4 Flow Controller – Darwin Microfluidics'. [Online]. Available: https://darwin-microfluidics.com/products/ob1-mk4-flow-controller

[6] Sensiron, 'LG16-1000D'. [Online]. Available: https://sensirion.com/products/catalog/LG16-1000D

[7] J. X. J. Zhang and K. Hoshino, 'Microfluidics and Micro Total Analytical Systems'. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B978145577631300003X

Appendix

A Parts List

Table 1: Purchased components

Label	Brand	Part Name	Part Number
P	**Pressure Components**		
P.1	RS PRO	G 1/4 Pneumatic Regulator	235-1139
P.2	Norigen	V72G Pressure Relief Valve G 1/4	V72G-2GK-NMN
P.3	Parker	VSO Low Flow Miniature Proportional Valve	910-000200-003
F	**Fittings and Adapters**		
F.1	RS PRO	Push-in Fitting, G 1/4 Male to Push In 4mm	197-7671
F.2	Camozzi	6000 Series Male Connector, 6 mm to G 1/4 Male	S6510 6-1/4
F.3	Idex	Flangeless Fitting	
F.3.1	Idex	Flangeless Ferrule, 1/16″ Tubing, 1/4-28 Flat-Bott.	P-200
F.3.2	Idex	Flangeless Male Nut, 1/16″ Tubing, 1/4-28 Flat-Bott.	P-220
T	**Tubing**		
T.1	RS PRO	Silicone, Flexible Tubing, 2mm ID, 4mm OD	273-2515
T.2	SANI-TECH	Ultra-C Sanitary Silicone Tubing, 1/32″IDx1/16″OD	ULTRA-C-030-0
T.3	AFS	6mm OD x 4.5mm ID Metric Nylon Flexible Tubing	BS5409
L	**Lab Equipment**		
L.1	-	10ml Test Tube	-
L.2	-	Microfluidic Chip	-
E	**Electronic Components**		
E.1	NPX	Gauge Pressure Sensor, 200kPa Operating Max	MPX2200GP
E.2	Sensirion	LG16 Liquid Flow Rate Sensor	LG16-0431D
E.3	Arduino	Arduino Uno Rev 3	A000066
E.4	52PI	Screw Terminal Shield for Arduino UNO	EP-0142
E.5	Seeed Studio	Backlight LCD Development Board	104030001
E.6	XP Power	24W Plug-In AC/DC Adapter 12V dc	VEL24US120-UK-JA
E.7	TRACOPOWER	12VDC to 9VDC Switching Regulator	TSR 2-2490
E.8	Texas Instruments	Instrumentation Amplifier	INA118P

Table 2: Manufactured components

M	Part Name	Reference
M.1	Pressure Controller Manifold	Figure 2
M.2	Fluid Reservoir Cap	Figure 3
M.3	Fluid Reservoir Housing	Figure 4

B Technical Drawings

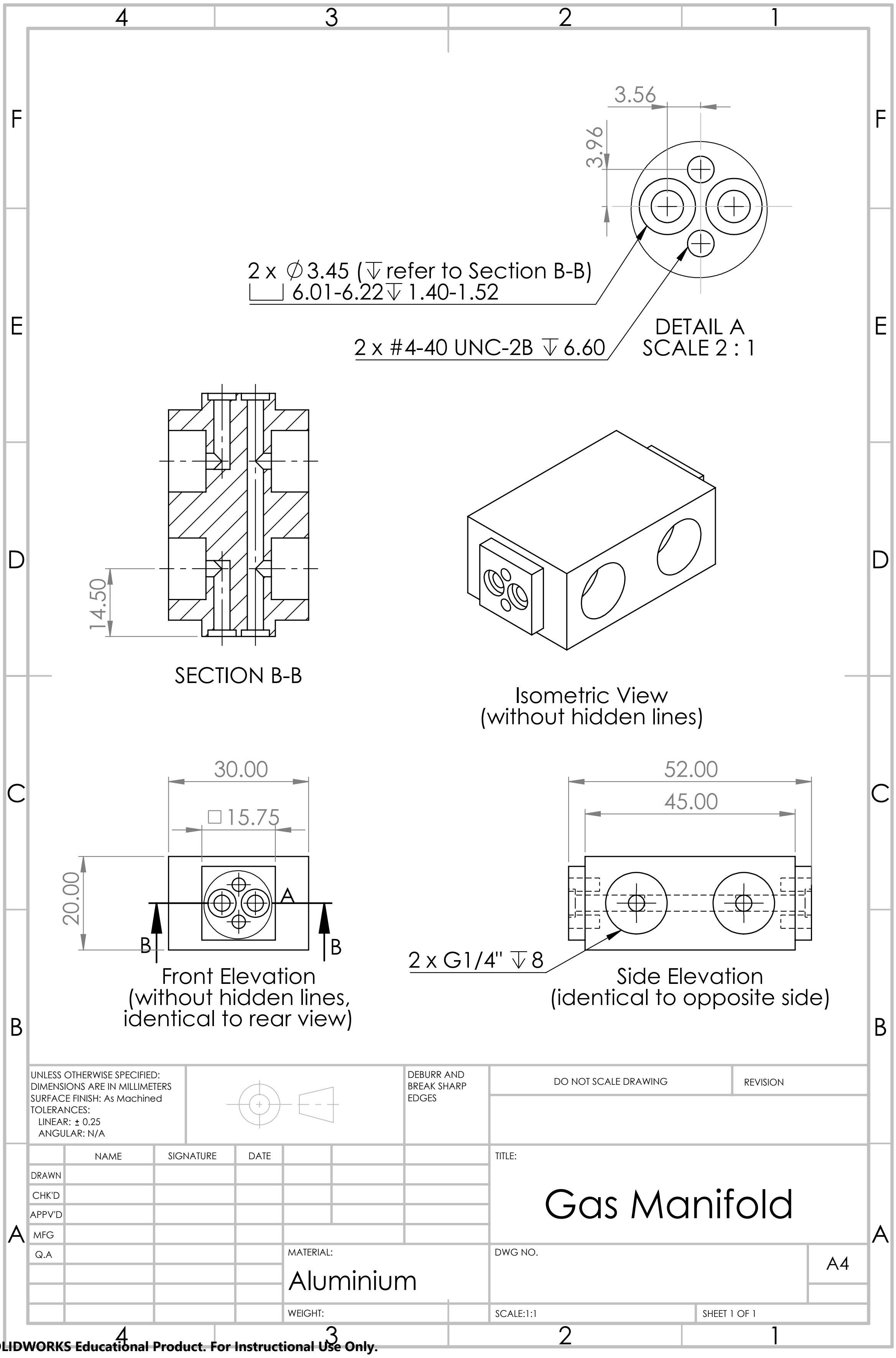


Figure 11: Pressure Regulator Manifold Technical Drawing

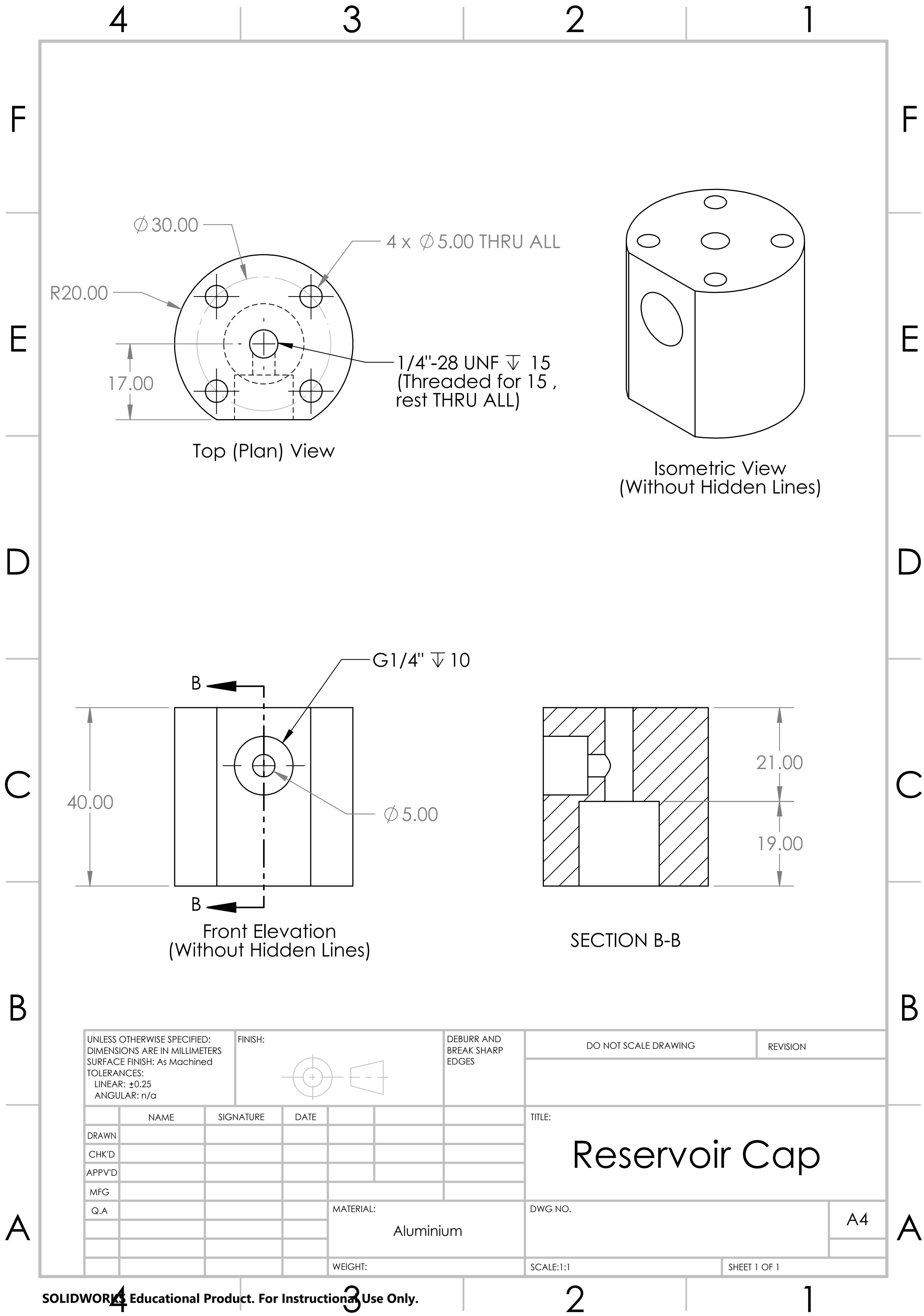


Figure 12: Reservoir Cap Technical Drawing

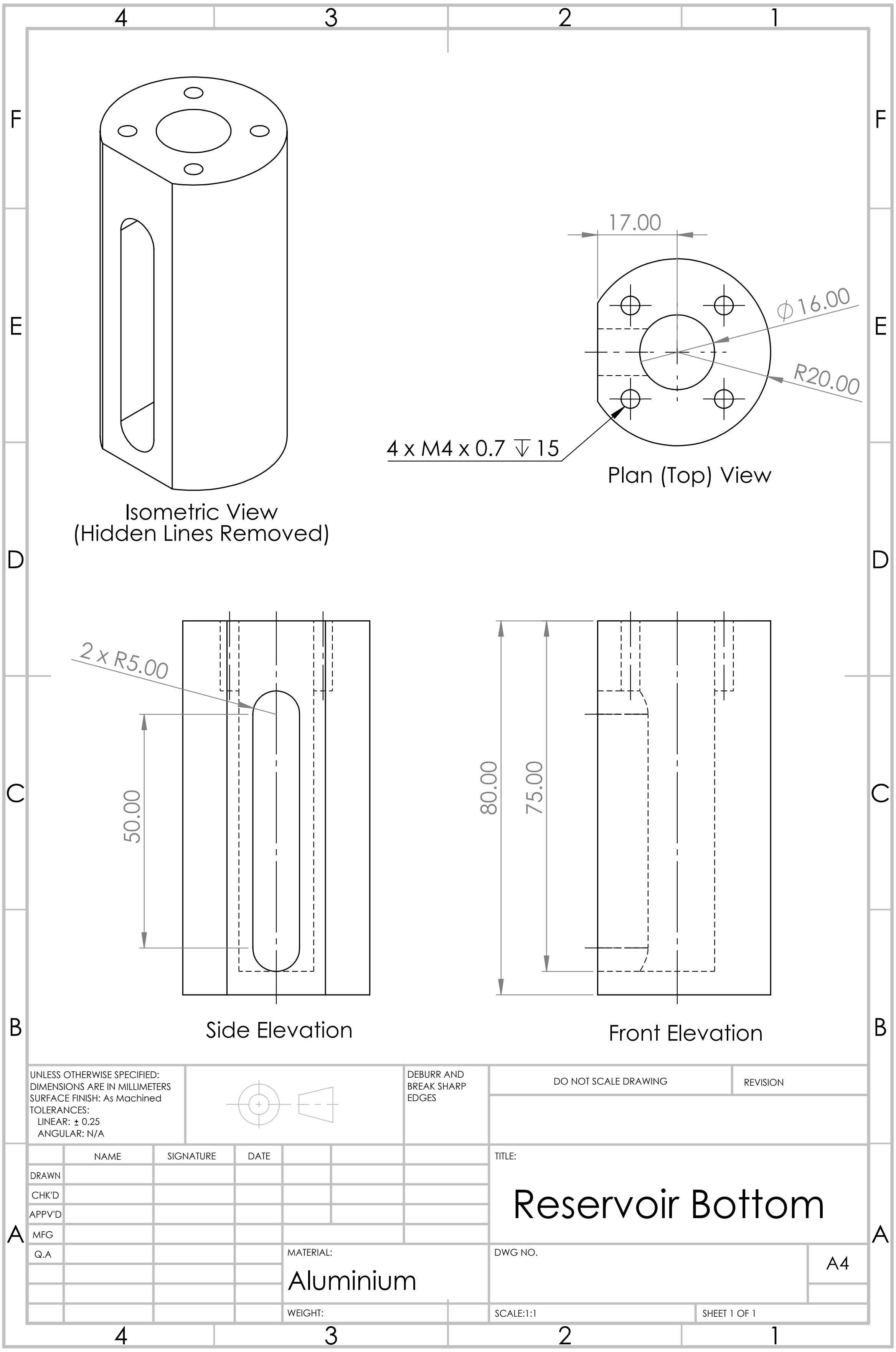


Figure 13: Reservoir Bottom Technical Drawing