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PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

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Senior Design Project Report

Design of spray chamber

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Strict emission regulations for vehicles and advances in fuel injector technology, dictate the need for thorough testing of fuel injectors. In this project, we design an optically accessible testing chamber to investigate the performance of port and direct-injection injectors. The pressure in the chamber is controlled by a vacuum pump and the temperature by a heat gun. Pressure in the chamber is measured by a manometer and temperature by a thermocouple. A pressurized container is used to simulate the fuel pump system. The injector is triggered by a custom-built 555 board. Images of the spray were taken under different ambient conditions at different times after the start of the injection. Results show variation of the spray formation from the designed state as ambient conditions change.

Acknowledgment

The project on designing the spray chamber required a lot of effort and help from a lot of parties. Furthermore, it is the effort, hard work and sincere guldens of the project supervisor Dr. Panos. It was an excitement and great time to receive his ideas and knowledge.

In addition, a lot of gratitude to all the officials of PMU, for allowing us to use the equipment at the university when we needed them. On the other hand, the team effort and hard work was unforgettable. Each member carried a load of the work and shared the knowledge and ideas. The leader of the group give his gratitude to all the four members of the team: Hassan Al-haddad, Qasim ahmed, Fadhil Al-safar and Mohammed Aldhafeeri.

Chapter 1: Introduction

1.1 Project definition

This project is dealing with designing a chamber for testing a fuel injector. Where observing the change in the performance and behavior of the injection with the change of pressure inside the chamber. The importance of this design and testing of the fuel injector chamber it can improve in designing the optimum fuel injector for car engine industries and improve their performance in different pressures. This also can lead in saving money by understanding how injectors behave in different conditions.

1.2 Project objectives

1. Design and manufacture a fuel injector testing chamber (vacuum pump, pressure sensor, and temperature sensor).
2. Fuel injection system design and manufacture (fuel, fuel injector, fuel tank, and triggering chip).
3. Compare with the literature and take photos of the produced spray.

1.3 Project specification

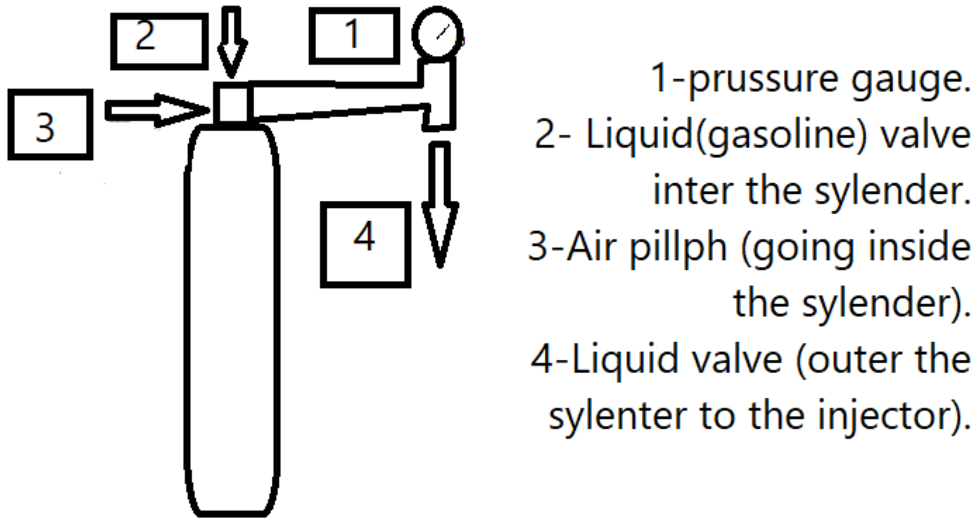


Figure 1: Project diagram

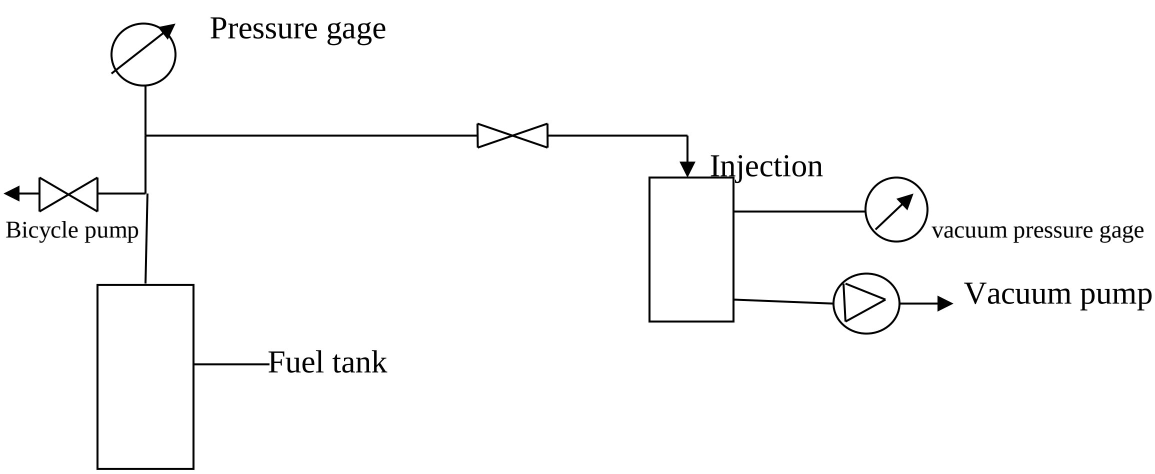


Figure 2: Design layout

Engineering standers

In this project there are many engineering standers that are used to complete the project most of them are for pipe fittings such as NPT, BSP, and ISO for the vacuum pump. In addition IS stander for the fuel tank. SAE stander for the hose connection.

1.4 Application

1. Fuel injection system can be used in engines and improve the combustion process
2. The better performance of the fuel injector the longer the engine can live
3. Fuel injector can improve the fuel consumption of the car making it more economical.

Chapter 2: Literature Review

2.1 Project background

in our modern world many people go to buy brand new cars and have a hard time choosing what to buy specially when it comes to car engine you may see these words it's a v6 3.0 liter and has tuned port fuel injection what does this mean when buying a car. Internal combustion engine idea goes as follow, if you have a small amount of a very high fuel energy fuel like gasoline for example in tiny enclosed space and ignite it a powerful energy is released in the form of expanded gas, the cars today mostly use a four-stroke combustion cycle known as Otto cycle that was invented in 1867 by Nikolaus Otto. Engine main parts are first, the cylinder with the inside piston that moves up and down. Second, is the spark plug that gives a spark to ignite the fuel and air mixture inside the cylinder. Third is the valve which closes and open in the right time to allow air and fuel in and exhaust out of the cylinder. Forth fuel injector which injects the fuel to mix with the air inside the cylinder. (training, 2008). Fuel injection was first introduced in the Otto engines, the purpose of the injection was to have a better pressurization of the fuel in the carburetors at that time. In 1886 an American john P. was granted U.S patent No. 537000 a poppet nozzle which the person claimed that it will burn the fuel as good as the lighter napthas that used in a vaporizer. (Deluca)

2.2 Previous work

An experiment was conducted on port fuel injection to extend the limit of lean combustion by introducing charge stratification. In the experiment it was seen the all injection cases have showing a higher rate of ubHC emission versa the dual injection cases. The average rate open valve B seen 7% higher ubHC emission than closed valve injection on port B. in comparison the dual injection seen 3% less emission for closed valve. The experiment used WAVE model to test NOx emission. See (table1)

Table 1:Experimental and simulated emission levels for dual CVI at 1500 rpm and 1.5 bar GMIEP

AFR	HC experimental ppm	HC simulation ppm	NOx simulation	CO sim
14.7	2262	2100	337	810
15.2	2059	1960	490	245
16.0	2105	2056	490	231
16.6	2397	2450	480	90
17.2	2207	2400	310	73
17.9	2759	2300	271	55
18.7	3130	2425	250	40

The experiment showed a comparison between closed valve injection and open valve at 300 cycles. The experiment used closed valve injection at first than moved to open valve injection after the 130 cycles. The change can be seen by the misfire cycle. See (Figure 3)

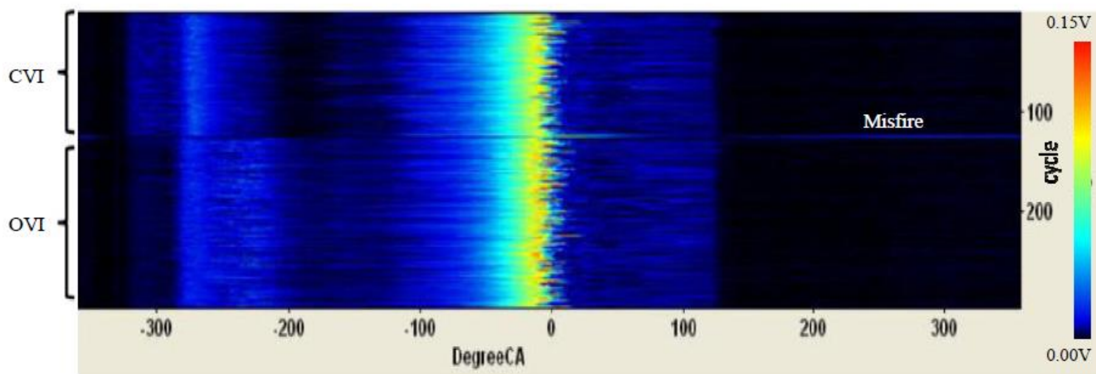


Figure 3: Fuel signal over 300 cycles at the spark plug location. close valve injection vs. open valve injection on port B global AFR 14.7

The research concluded that there was an improvement on the stability of the engine combustion from 1000 rpm at 1 bar up to 1800 rpm at 1.8 bar, combustion improvement was 21:1 AFR to 22:1. (cardosa, 2011)

A study done in Malaysia to develop a fuel injector that are more efficient for motor cycles. The study addressed some issue that needed to be solved, gasoline vapor lock by thermal effect and caused by a higher ambient temperature. Obtaining accurate load indication at a small throttle opening, FI system must operate only by a kick-start. The experiment proposed fuel retrofit that will look similar to conventional fuel injection system. See (Figure 4)

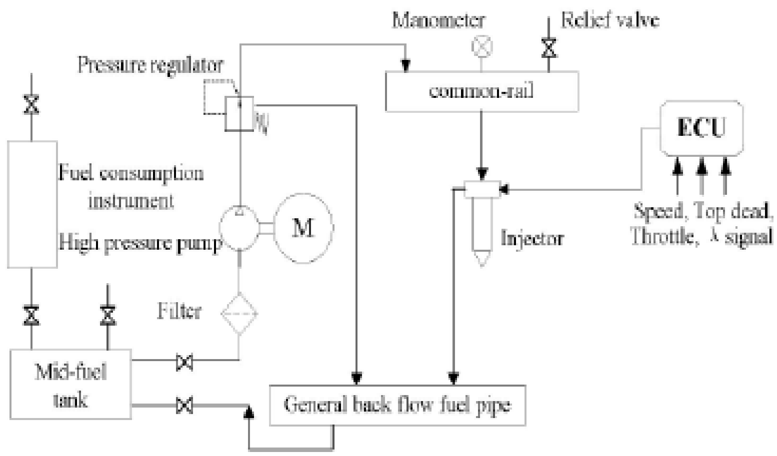


Figure 4: schematic of fuel injection circuit

The experiment was done to test and evaluate a 4-stroke engine operating using carburetor and develop an injector prototype, using the following test. (A.j alimin, 2009)

Table 2: Detail of testing

Items	Description
Number of cylinder	Single
System	4-stroke
Cooling type	Air-cooled
Bore × Stroke	52.4mm × 49.5mm
Compression ratio	8.8:1
Starter	Manual starting
Max. Power (kw/rpm)	5.3 [8000±500]
Max. Torque (Nm/rpm)	7.2 [6000±500]
Lubrication	Oil/splash
Fuelling	Carburetion

Another research used air compressor instead of fuel pump to pressure the fuel forcing the fuel to come out from the fuel tank, after that the fuel evaporate in the inlet port by a velocity spray that is placed in the throttle body. The experiment run a system similar to a standard multi-port injection system, the differences are in the location of the ports of the fuel injector. See

Table 3: Results

Load on Engine (Kg.)	Speed Of Engine (rpm)	Fuel Consumption (Kg/hr)
No load (Idling)	1500	3.05
10	1500	3.32
20	1500	3.57
30	1500	4.12
40	1500	4.88

Load on Engine (Kg.)	Speed of Engine (rpm)	Fuel Consumption (Kg/hr)
No load (Idling)	1500	2.86
10	1500	3.11
20	1500	3.42
30	1500	4.02
40	1500	4.46

The research concluded that using CPFI system the power available at the shaft is possible to save it using the compressor instead of using the pump that take power from the engine. Using CPFI fuel- air ration is maintained. Using the CPFI fuel consumption reduced, and thermal brake efficiency is increased. (george)

2.3 Comparative study

A numerical study was done to find out the effect of using direct injection on the combustion performance. The experiment was setup by taking a single cylinder turbocharger Ricardo E6\MS IDI diesel engine and changing it to a dual fuel operation. The engine was attached to a DC motor 22 Kw and 420 V. the data of 50 consecutive cycles were being measured by in house computer code for processing. The experiment used a software called CATIA to compare the IDI and DI systems. The numerical model used is AVL FIRE CHIMKEN that was developed from previous experiments. The results of the experiment showed maximum in cylinder pressure of the IDI system to be higher than that in DI system, the DI system had an incomplete combustion when the injection timing is off, the combustion for the IDI was complete at all timing. (amin yousefi, 2016). See (figure 5)

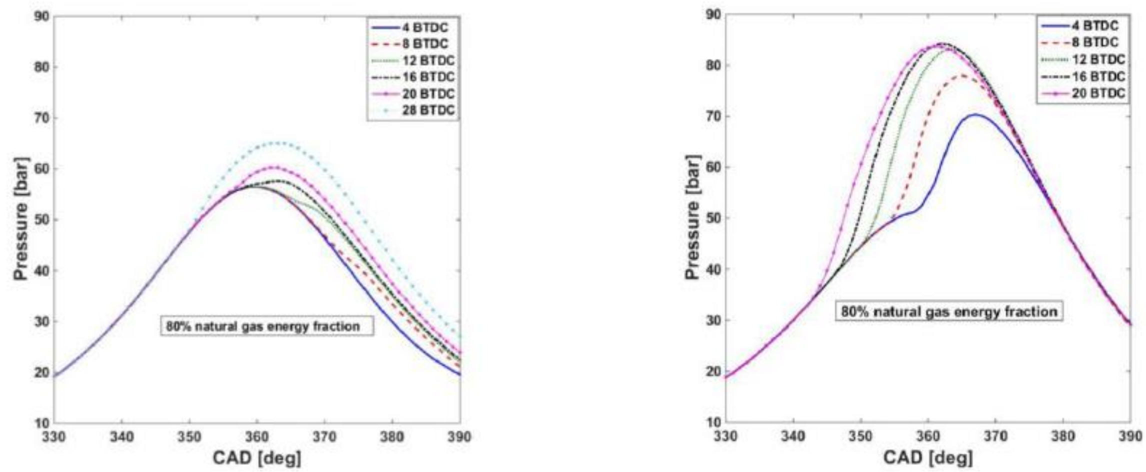


Figure 5: IDI results to the left vs DI in the right

A comparative study was done on direct and indirect injection giving the following results in (Figure 6 and 7)

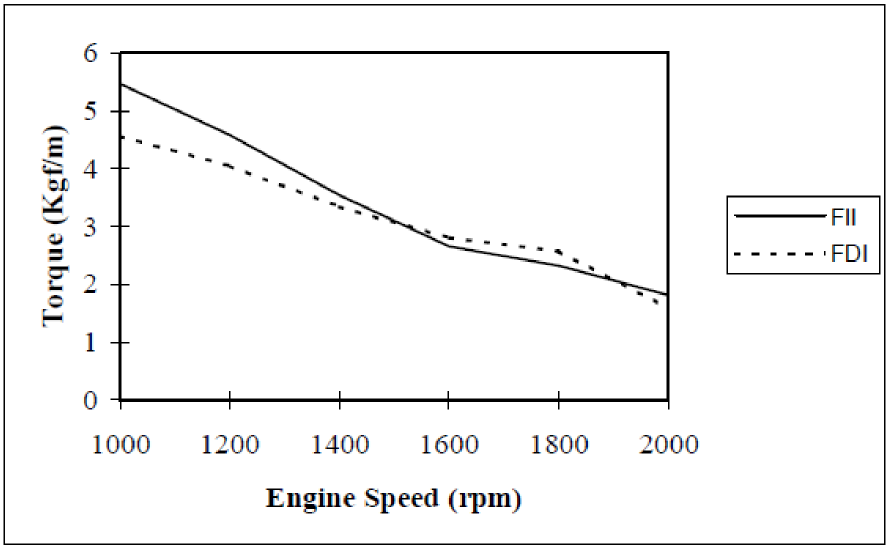


Figure 6: Torque as a function of rotational speed

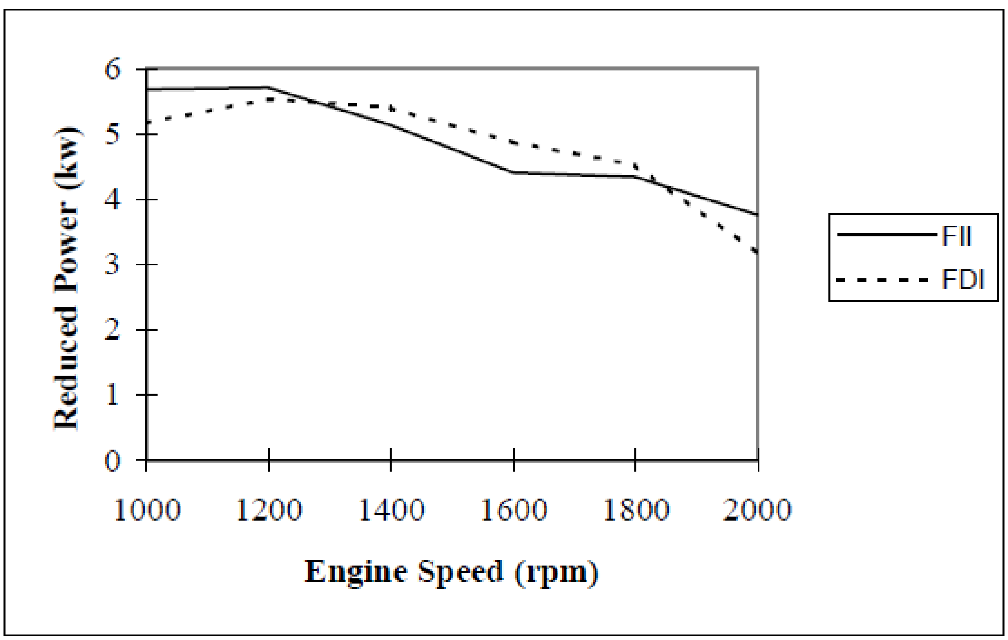


Figure 7:Reduced power as a function of the rotational speed

The experiments conclude that there was a little noticeable use of the energy giving by the fuel at 1000 to 1200 rpm. When controlling the engine by FII, efficiency and power torque decrease at 1400-1800 rpm, and fuel consumption stays equal. (botelho)

Chapter 3: System Design

3.1 Design constrains and design methodology

in table (4) the following parts are used for the manufacturing process and is constrained by 5 parameters which are: size, geometry, safety, weight, and cost

Table 4: Item used in the design

Item	Size	Geometry	Environment	Weight	Cost
chamber	The chamber size was chosen to match the size of a car cylinder in a similar scale dimensions: 20cm*20cm*20cm	Cubic shape Ease of manufacturing Ease of data collection	The pressure inside the chamber should not exceed 5 Pa	The material used is acrylic plastic 25mm thick it is light weight material and strong to hold pressure	1550 SAR
Fuel tank	The fuel tank is chosen to have enough volume to carry enough fuel to conduct the experiment Volume: 1.20 L	Cylindrical shape	The can handle heat and pressure to be safe	Fuel tank is made of steel and weight 3 kg	50 SAR
Fuel injectors	The fuel injector is from a car (non-diesel engine)	Irregular shape	The injector will be tested in 2 different ways 1 sec test and 5 second test	Injectors for cars are very light and easy to work with	233.10 SAR
Vacuum pump	The vacuum pump to have a rating of 5 CFM which is good enough for the testing in the chamber Dimensions: 5.3*12.6*9.2 in	Irregular It has a base for easy installation It has a handle for ease of carrying	The vacuum needed to be quite for comfortable testing it has high torque feature and thermal protection for safe use	The pump weight 10kg	1187.5 SAR
Pressure gauges	The pressure gauges needed to measure the air pressure for the fuel tank and for vacuum pump	Circular 1.Easy to read from 2.Accurate measurement	Oil filled Measures in Bar and inHG	Light weight made of copper alloy	113 SAR

Circuit	The circuit was needed for the triggering the injector Dimension:	Rectangular Easy to build Has a switch control		It is made of plastic and conductive material to connect the component and make the circuit	145 SAR
Power source	The power source works on 220 V that convers it to 12V so it can drive the injectors	Rectangular Easy to install	Works on 220V	4 kg	550 SAR

Injectors in cars engines are essential to have, therefore it is a growing need to have injectors performance and reliability checked and tested. Building the injector test chamber help identifying faults in injectors and their reliability the there are many constraints to designing the test chamber as follow.

1. Geometrical constraints
2. Sustainability
3. Environmental constraints
4. Economic constraints
5. Manufacturing constraints
6. Safety constraints
7. Ethical constraints

Geometrical constraints

The constraints of the geometry in designing the fuel chamber is the difficulty of making a cylindrical shape that matches the size of a car cylinder, especially as the thickness of the acrylic material needed to be 25mm. shaping the acrylic material as a cylindrical design is difficult and expensive. Therefore, the design chosen is a cubic shape for ease of manufacturing and suitable cost, another geometrical constrain is the stresses failures happen because of the cubical shape choosing this shape increase the stresses and chances of failures which required choosing thicker acrylic that is no less than 20mm and have a dimension of 20*20*20 cm to withstand the pressure inside the chamber without failure.

Sustainability

the fuel chamber should have the ability to hold the pressure to conduct testing that enough to find the faults and reliability in any injector. Moreover, it will have an advantage in term of the cost that other testing chamber have this design is cheap and great enough for any person to build and test injectors in it.

Environmental constraints

The environment inside the chamber can have a great effect on the result of testing the injector. The fluctuating in the pressure affects the way injectors spray the fuel which can be unstable specially in real car cylinder when the pressure changes fast and dramatically. Also, temperature effect the result of the testing where the temperature changes with pressure taking accurate measurement can be tricky.

Economic constraints

having a faulty injector in an engine means more fuel conception and more money to spend on fuel, especially with high fuel prices it is not a good idea to ignore a faulty injector and not replace it. A faulty injector will not just make the car consume more fuel but the engine itself might fail which is a great cost added. Therefore, this design is also attempted to look at the ability to manufacture the test chamber at a low cost that people can afford to buy or make it themselves. This way it will save people money in the long run by simply testing their injector system and avoid paying the price of engine failure or paying more money for the excessive fuel consumption.

Manufacturing constraints

This design can be assembled very easily. However, the hardest part in this design is to manufacture the acrylic because of the thickness of the material. Acrylic is a tough material very hard to cut over 10mm thickness, and we needed to have 25mm thick. First it was hard to find a 25mm thick acrylic in Saudi Arabia and then have it cut for manufacturing where a normal saw can't cut it therefore a laser cutter is needed for it.

Safety constraints

When it comes to working with fuel it is a concern to be safe. Thus, it is important that this design follow safety requirement as fuel can ignite easily. Nevertheless, the box chamber must have a safety factor of 2.5 to ensure that the box doesn't fail under pressure the factor of safety is calculated and is under the calculation section. The fuel tank in this design made of steel so it can handle pressure and doesn't fail when pressure and temperature rise. In addition, the hose the is connected to the fuel tank is also taken into consideration to withstand pressure and not burst.

3.2 Engineering design standards

engineering standards are a must to have in order to make calculation, and ease of manufacturing and assembly. The most used standard in this design is NPT for the connections and gauges, and there is also BSP standard for the gauges that is used. The vacuum pump has ISO standard, the hose has SAE 30R6, and the acrylic used in the box has ISO standard. (Table 5) has the list of all the standard this design has.

Table 5: Engineering standards used in the design

Item	Standard
Vacuum pump	ISO
box (fuel chamber)	ISO
Hose	SAE-30R6
Fuel inlet valve	NPT
fuel outlet valve	NPT

Air inlet valve	NPT
Gauge pressure	NPT, BSP
Air filter	BSP
connections	NPT
Fuel tank	IS

3.3 Theory and theoretical calculations

this project has two main component that needs to calculate before starting to manufacture the parts one is the chamber two is the hose. To design this project pressure is a factor to take it into account when calculating also the stresses caused by the pressure is important to avoid failures. In this project FEA are used to help determining the stresses and all the calculation needed for the chamber and the calculation of the hose used by the help of the SAE standard.

Table 6: calculation of the spray chamber property

Property	Value	Units
Elastic Modulus	3000000000	N/m^2
Poisson's Ratio	0.35	N/A
Shear Modulus	890000000	N/m^2
Mass Density	1200	kg/m^3
Tensile Strength	73000000	N/m^2
Compressive Strength		N/m^2
Yield Strength	45000000	N/m^2
Thermal Expansion Coefficient	5.2e-005	/K
Thermal Conductivity	0.21	W/(m·K)

```
Mass properties of Assem1 +
   Configuration: Default
   Coordinate system: -- default --

Mass = 9145.17 grams

Volume = 7620.97 cubic centimeters

Surface area = 7725.70  square centimeters

Center of mass: ( centimeters )
    X = 8.75
    Y = 25.04
    Z = 18.99

Principal axes of inertia and principal moments of inertia: ( grams *  square centimeters )
Taken at the center of mass.
     Ix = (0.71,  0.00, -0.70)      Px = 1312409.45
     Iy = (-0.69,  0.19, -0.70)     Py = 1312490.09
     Iz = (0.14,  0.98,  0.14)      Pz = 1313043.54

Moments of inertia: ( grams *  square centimeters )
Taken at the center of mass and aligned with the output coordinate system.
    Lxx = 1312459.62          Lxy = -73.40              Lxz = -50.46
    Lyx = -73.40              Lyy = 1313023.20          Lyz = -73.87
    Lzx = -50.46              Lzy = -73.87              Lzz = 1312460.27

Moments of inertia: ( grams *  square centimeters )
Taken at the output coordinate system.
    Ixx = 10342999.06         Ixy = 2002972.06          Ixz = 1519097.95
    Iyx = 2002972.06          Iyy = 5310462.20          Iyz = 4347904.94
    Izx = 1519097.95          Izy = 4347904.94          Izz = 7745256.28
```

Equation 1: FEA of the spray chamber

The analysis below show tha maximum stress before the box fail which is at 4.563e+006

Pa. The analysis show that most stresses are at the edges but they don’t reach failure level.

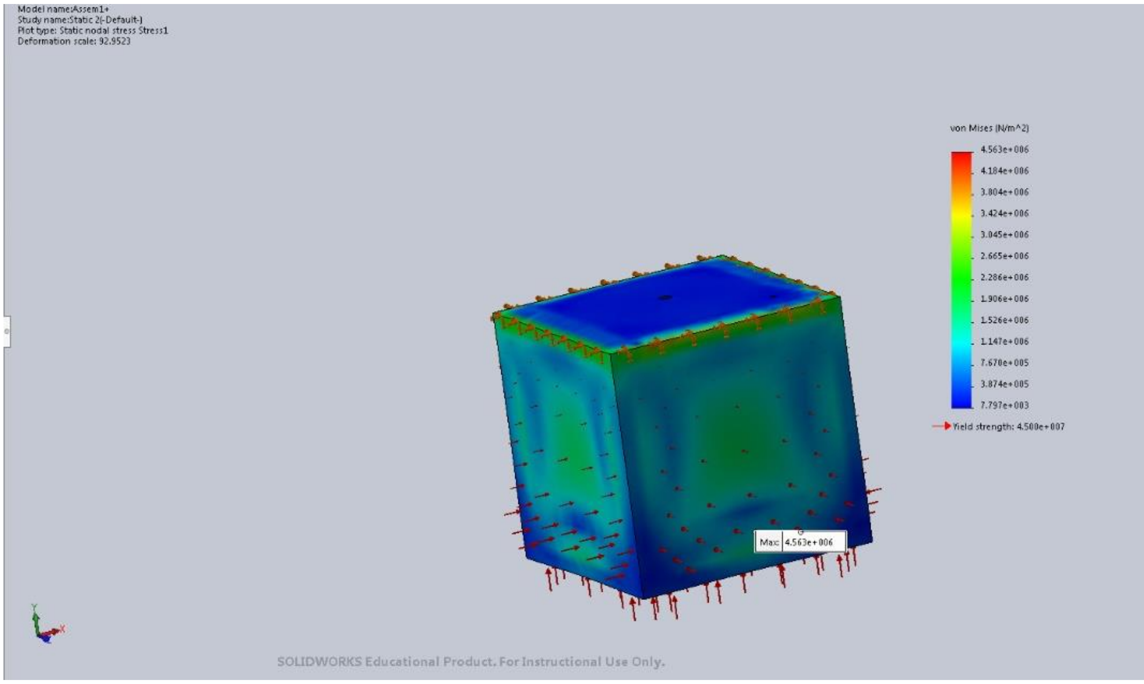
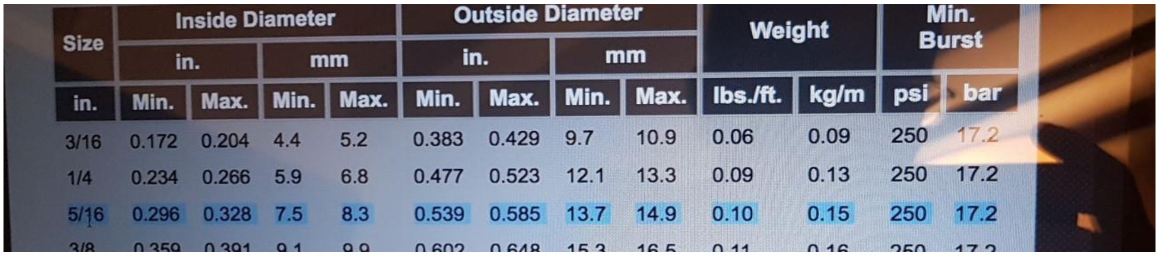


Figure 8: FEA

The hose calculation

(Table 7) below is taking from the SAE-30R6 to help finding the minimum burst pressure.

Table 7: SAE hose standard details



Size	Inside Diameter				Outside Diameter				Weight		Min. Burst	
	in.		mm		in.		mm					
in.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	lbs./ft.	kg/m	psi	bar
3/16	0.172	0.204	4.4	5.2	0.383	0.429	9.7	10.9	0.06	0.09	250	17.2
1/4	0.234	0.266	5.9	6.8	0.477	0.523	12.1	13.3	0.09	0.13	250	17.2
5/16	0.296	0.328	7.5	8.3	0.539	0.585	13.7	14.9	0.10	0.15	250	17.2
3/8	0.359	0.391	9.1	9.9	0.602	0.648	15.3	16.5	0.11	0.16	250	17.2

Table 8:Details of the hose used in the design

Size	Max inside Diameter	Max outside diameter	Weight	Min Burst
5/16 in	8.3mm	14.9mm	0.15 kg/m	17.2 Bar

We get the minimum burst pressure of 17.2 Bar

3.4 Product subsystem and selection of component

Vacuum pump

the vacuum pump one of the essential part of this design. The pump for this design needs to have high CFM rating of free air displacement for a fast vacuum at a rate of 5 CFM for attaining accurate results. Another requirement taken into consideration when selecting the pump was safety the pump has thermal protected motor for durability. The pump was also chosen to be low noise for easier and comfortable data collection.

Fuel chamber (Box)

The main component of this design is the testing chamber. The chamber material was chosen based on many things. First, the material needs to be visible for ease of data recording and observation of the injection spray. Second, the material need to be strong and able to withstand a pressure of 2 bar without failure. Finally, the cost should be as cheap as possible not exceeding 2000 SAR. Therefore, the most suitable material that was found that meets the design needs was acrylic, after doing the FEA it was found that the acrylic thickness and dimensions needed to avoid failure is no less than 20mm thick and must be 20*20*20cm in dimension.

Hose

the hose connects the fuel tank with the injector through the outlet valve of the fuel tank. The hose needed to have the ability to handle pressure without bursting, after looking up the engineering stander of the hose we needed to select SAE 30R6 we found the following information in (Table 9)

Table 9: Hose details

Size	Max inside Diameter	Max outside diameter	Weight	Min Burst
5/16 in	8.3mm	14.9mm	0.15 kg/m	17.2 Bar

17.2 bar is the minimum burst pressure which is excellent for our design requirement the size works fine with the connections and valves and have proper fitting therefore this hose was selected.

Valves

the valves play a major role in controlling the flow of air and fuel inlet and outlet. The valves are made from forged brass has high corrosion resistance, all the valves in the design chosen have the same standard NPT for easy fitment.

Connections

There are few connections used in this design which was needed to connect gauges, fuel line, and vacuum pump the design has 2 T junction made of brass, a flare female connection for the pump and a 90-degree corner connection also they all follow the same standard NPT. The connections were chosen to have easy assembly of all the main parts together.

Air filter

The air filter is essential for the pump, without the air filter the pump will be damaged. It is important to choose air filter that follow the engineering standard for the best filtration. Thus, we chose a filter that has a BSP standard.

Fuel tank

The fuel tank is a major part of the design that was selected based on size, and material. First, in the design testing the 4 injectors going to be in 2 ways a 1second test and a 5 second test the amount of fuel going to be sprayed is quite a lot for these tests therefore we selected a tank that have a volume of 1.2L which is good enough to go through these tests. In addition, material for the tank is steal for handling the pressure and heat.

3.5 Implementation

Fuel tank

to connect the fuel tank with the chamber it needed adjustment to the fuel tank and fabrication. The fuel tank was drilled first to have it fit the outlet valve size ¼ inch after drilling on the bottom side of the tank it needed welding the brass valve with the steel tank which needed a special welding powder to help the welding process called Hielux. Then at the top inlet valve was fitted and gauge pressure was also fitted on top.

Injectors

the injectors are installed through a hole made on the tope side of the chamber. And they are connected through the hose coming from the outlet valve of the fuel tank and controlled by the circuit.

Chamber (box)

The chamber was cut precisely by a laser cutter for a tight fit and put together using silicon to prevent any pressure loss.

Vacuum pump

The vacuum pump is connected to the chamber though a valve and a hose there is also a gauge pressure for measurement connected to it.

Circuit

The circuit was made for controlling the injectors through a 12V from a power source. The circuit made from capacitors, resistors, and a chip called 555 with other components.

It is connected with the injectors through wires and it has on/off switch and a switch to choose 1 sec test or 5 seconds test.

Figure 9: Tank drilling

Figure 10: Powder for welding

Figure 11: Finished fuel tank

Figure 12: Injector

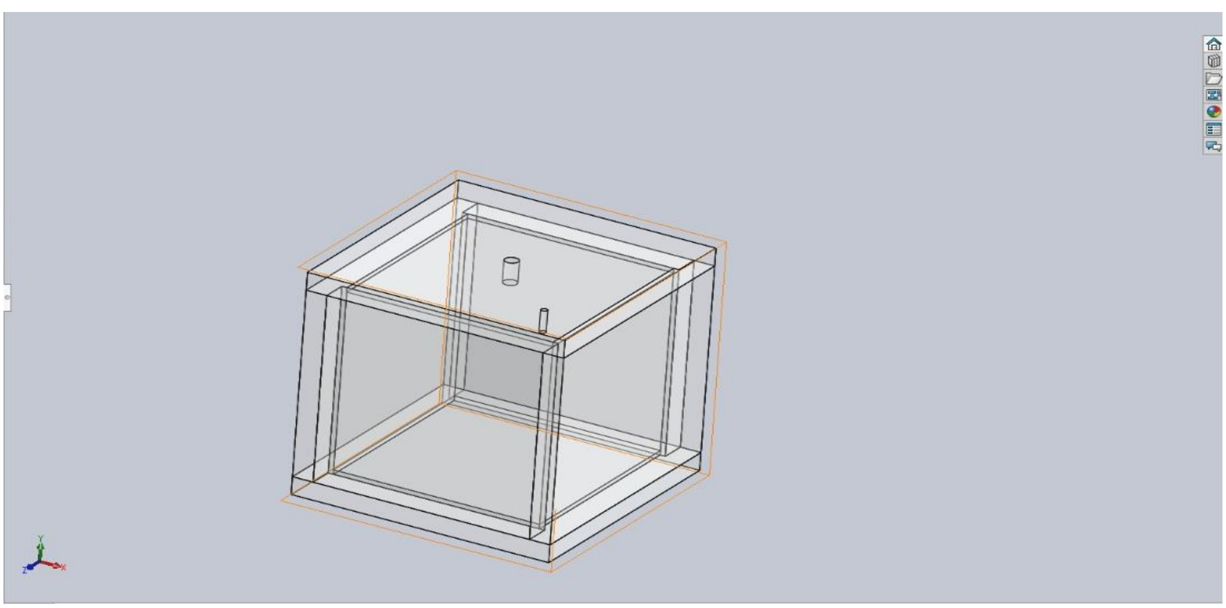


Figure 13: Solidworks drawing of chamber

Chapter 4: System Testing and Analysis

4.1 Experimental set up sensors and data acquisition

Circuit

The circuit is used as a triggering chip to trigger the injector to spray fuel into the chamber. The circuit have switch controls On/OFF also has 1 sec and 5sec switch that will allow the injector to spray fuel for 1 sec or 5 sec.

Specifications:

- It has the 555 chip
- On/Off switch
- 1 sec/5 sec switch
- Small in size

Overall experimental setup

the (figure 14) shows how the experiment is connected together.

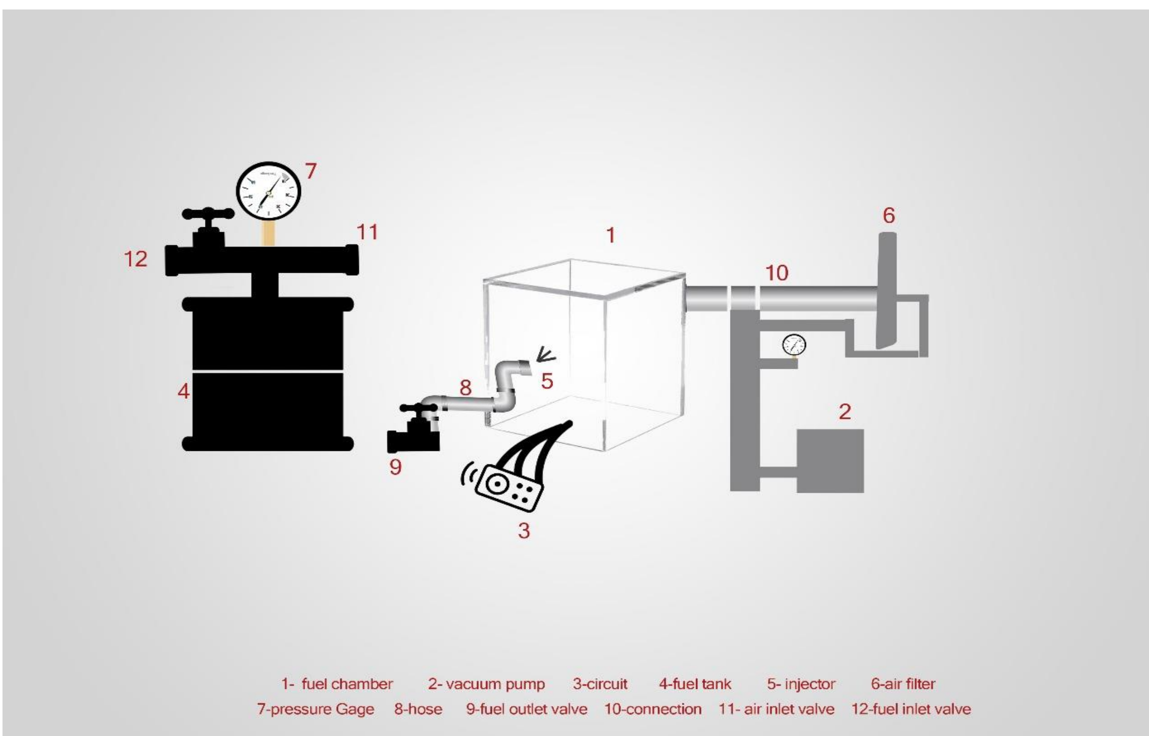


Figure 14: Experiment setup

4.2 Results, analysis and discussion

Experiment Goals

in this experiment the main thing to consider is how the injector behave in different pressure level and temperature, In two different intervals 1 second and 5 seconds. Another goal is to observe if the injector works as it should or is it a faulty injector.

Experiment methodology

1. Filling the fuel tank with 91 octanes through the inlet valve using a glass funnel
2. connect the air inlet valve and connect the pressure gauge to the tank.
3. Connect air inlet to the compressor to rise the pressure up to 1 bar
4. Connecting the fuel tank outlet valve with the injector via hose and fit the injector through the hole in the top of the chamber.
5. Connecting the circuit with the 12V power supply and connecting it to the injector with wires.
6. Connect the vacuum pump with the spray chamber
7. Press the inject button and inject for either 1 or 5 seconds

Data analysis

4.3 Injected quantity

To measure the quantity, we used a 25ml graduated cylinder we injected fuel 4 times 5 second each injection and we got 22 ml, for every injection we had about 5.5 ml injected. See (Figure 15) and (Figure16)

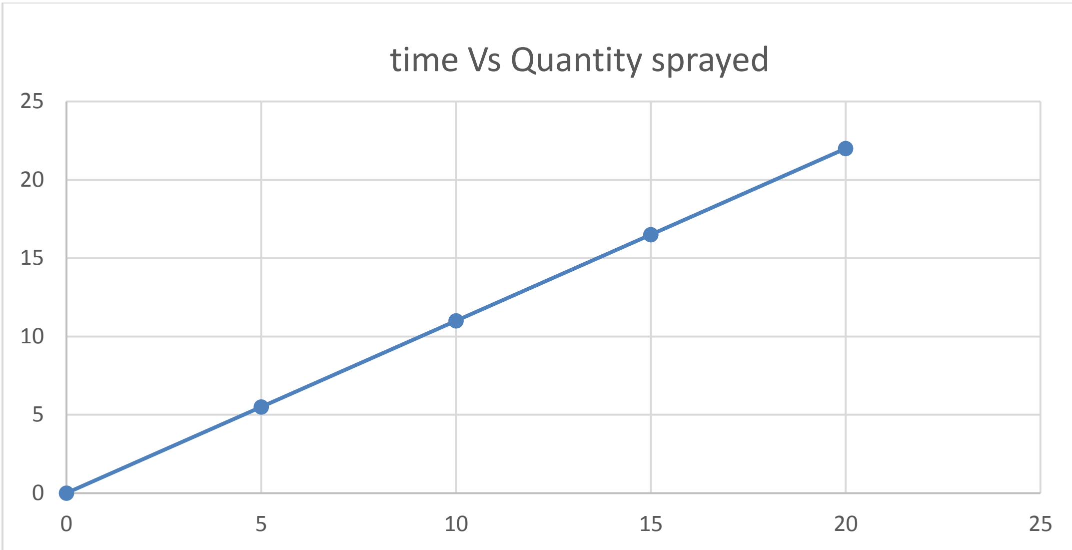


Figure 15: On the left is time in second and in the x axis quantity sprayed in ml

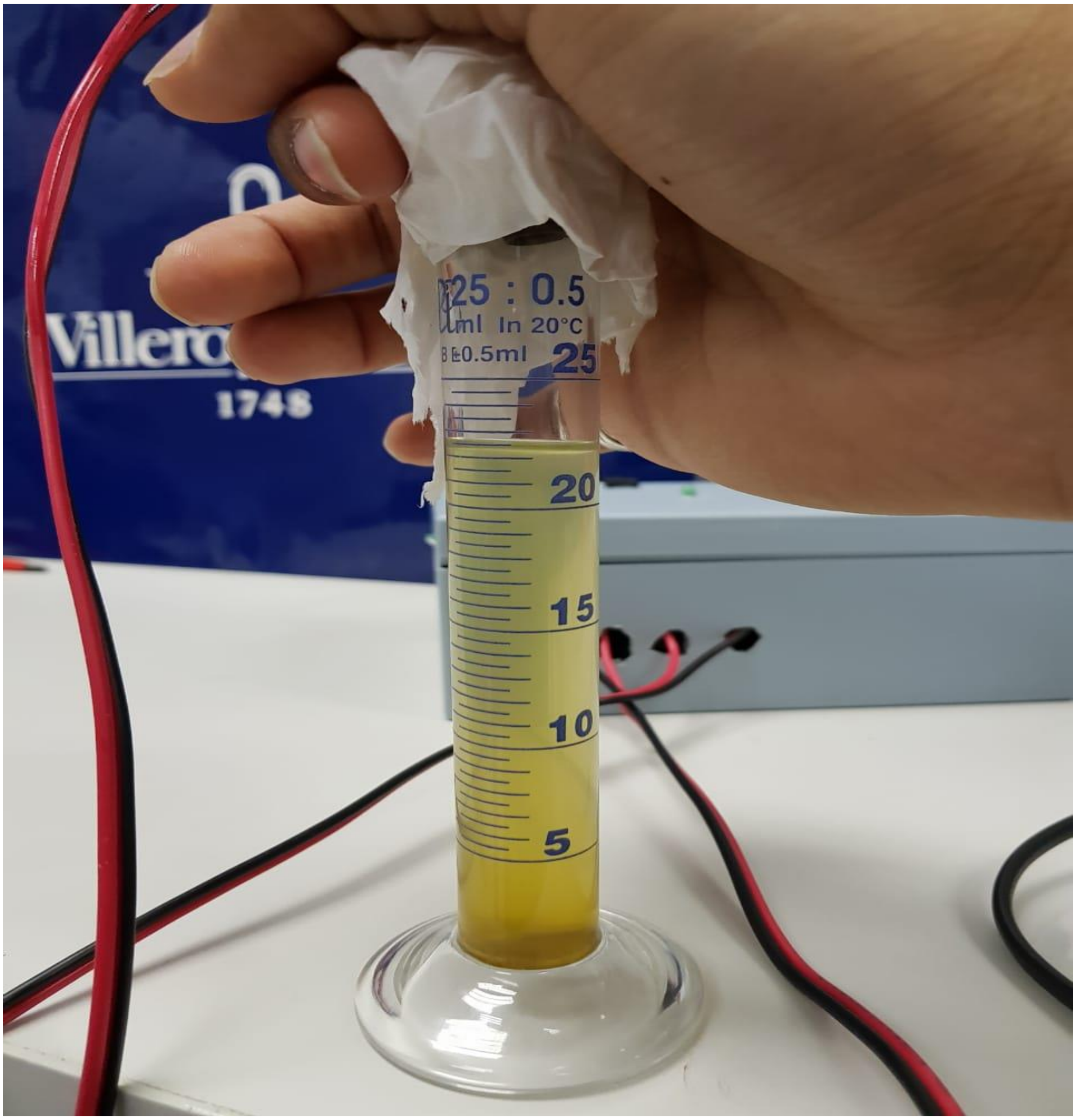


Figure 16: Quantity sprayed by the injector in 20 second

4.4 Spray development

We have tested the injector for 5 seconds and we have got the following images for the spray development in 5 seconds period. The spray starts thin but with every second it mixes with the air and condensate creating a good mixture of fuel and air inside the spray chamber. See figures (17,18,19,20, and 21)

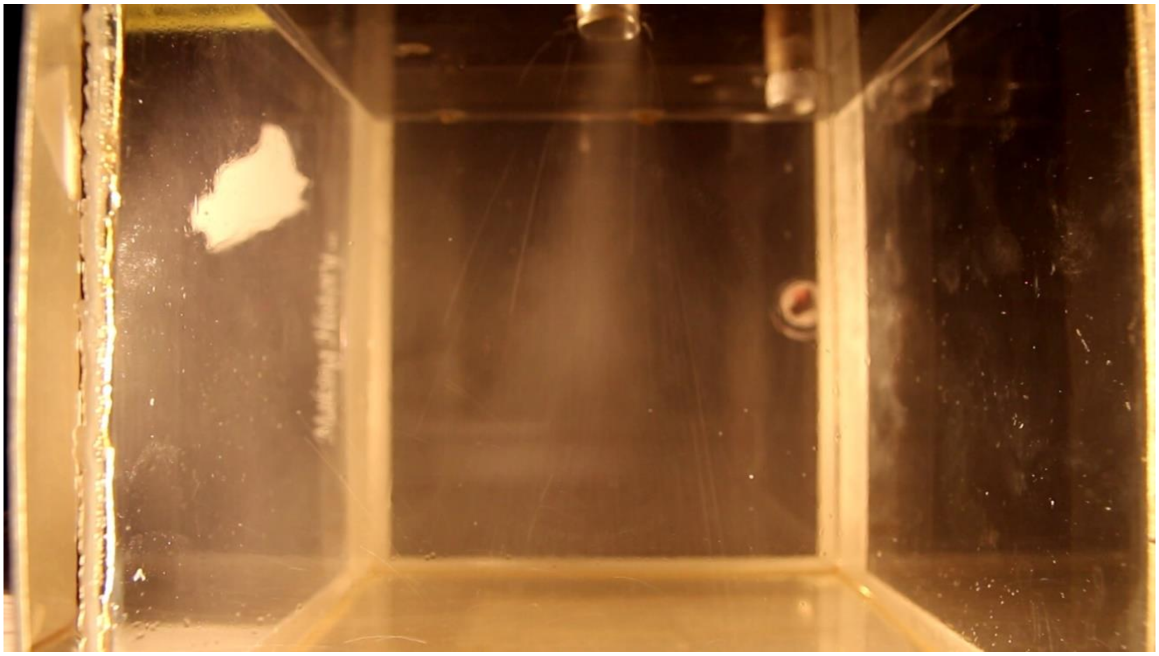


Figure 17: The beginning of the spray

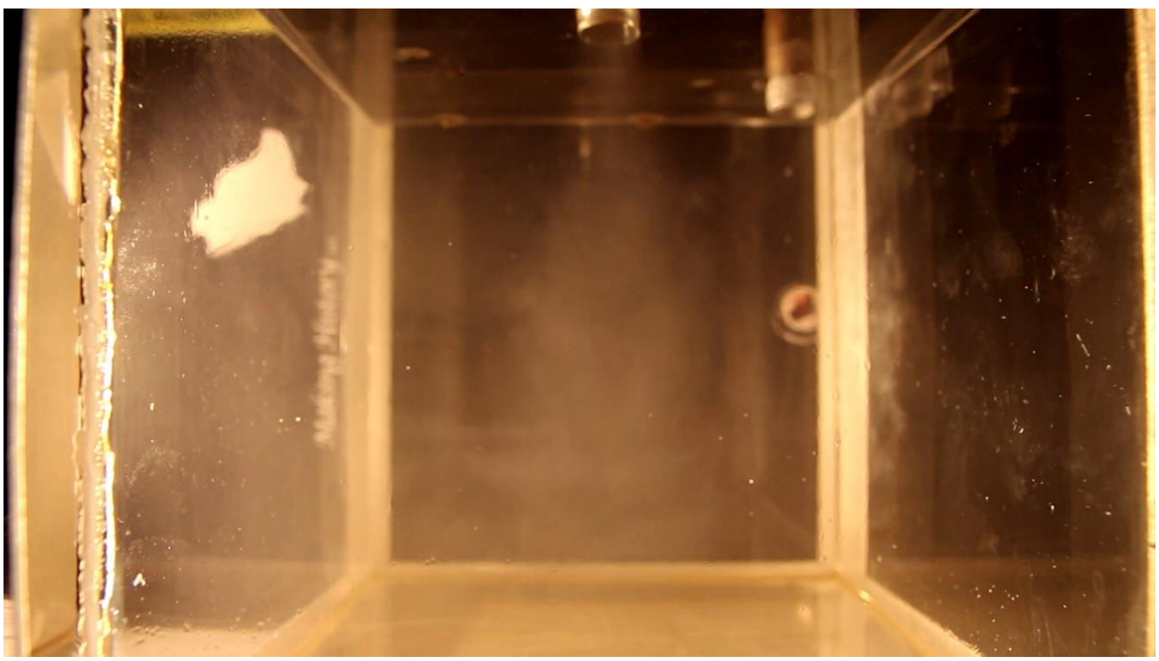


Figure 18: The start of the mix between the fuel and air

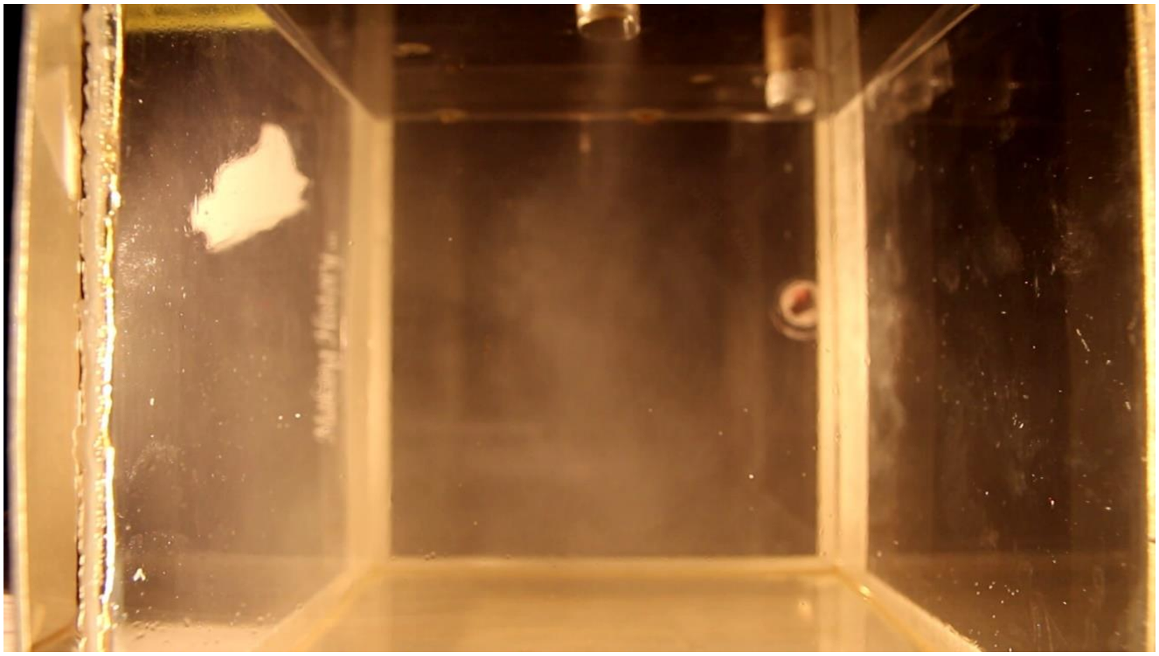


Figure 19: 3ed second showing the mid development of the mixture

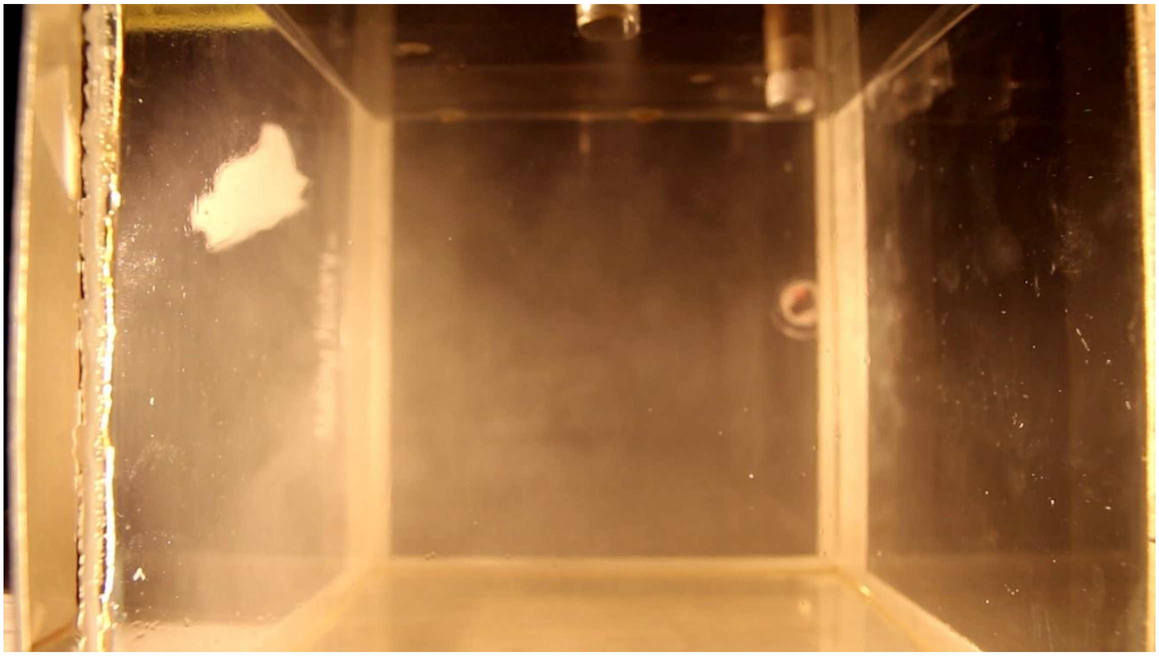


Figure 20: 4th second almost complete mixing

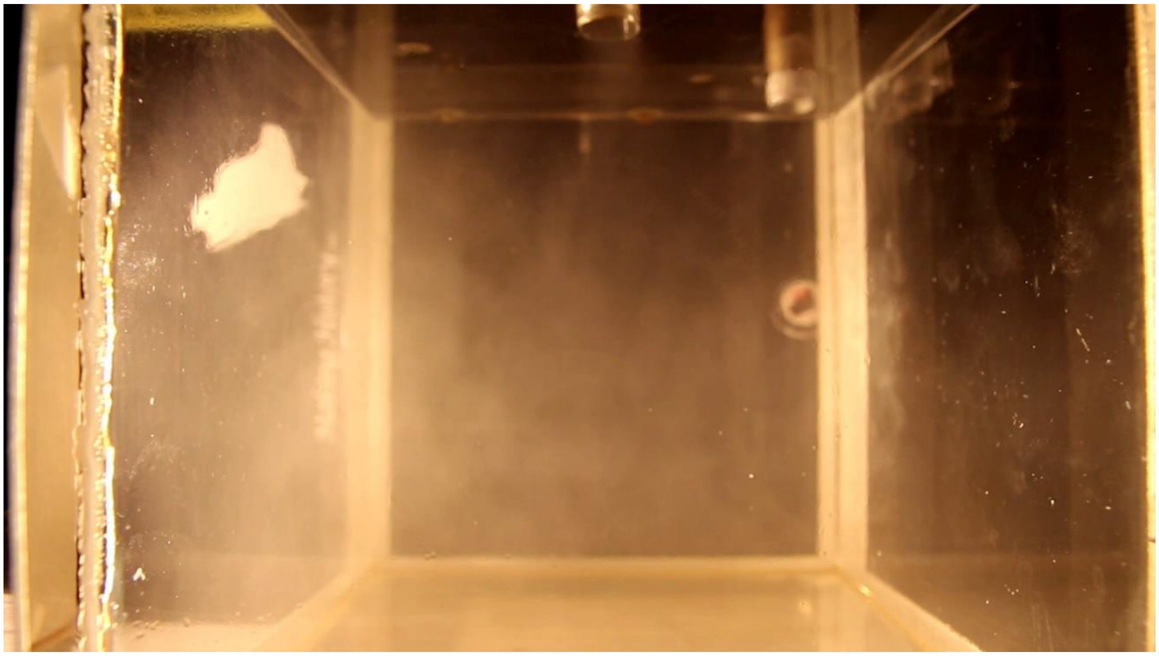


Figure 21: Fully developed mixture of air and fuel

4.5 Analysis

From the results that we got the spray was successfully developed into the desired mixing with the air as it should be in a car cylinder. The quantity sprayed showed a linear relationship with time which proves that the injector works fine as the quantity increase as the same rate with time.

Chapter 5: Project Management

5.1 Project Plan

In this project we teamed up as group of 5. As time is short to complete such project the time was divided for each task to finish on time. The following table illustrate the tasks and time it took to finish.

Table 10: Duration of tasks

No.	Tasks		Start Date	Finish Date	Duration
1	Introduction		February, 20 18	February, 29, 18	9 Days
2	Literature Review	Fuel injection system background	March 1, 18	March 15, 18	15 Days
		Previous work			
		Comparative study			
		Gannt chart			
		Looking for parts			
3	Calculations	Solidworks model	March 15, 18	March 28, 18	13 Days
		Solidworks model testing for failure possibility			
		FEA of chamber calculation			
		Hose calculation using SAE standard			
4	Parts ordering	Connections, injectors, pressure gauges,	March 16, 18	April 4, 18	16 Days

		triggering chip, vacuum pump, acrylic, and hose			
5	Manufacturing	Chamber, and fuel tank	March 10, 18	April, 14 18	32 Days
		Putting the system together			
6	Test the system	Fuel tank testing	April 15, 18	April 23, 18	8 Days
		Chamber testing			
		Fuel injector testing			
7	Conclusion	results	April24, 18	May1, 18	7 Days

5.2 Contribution of Team

For this project there are tasks that assigned only for one member some to more. The group leader and advisor are to give the tasks to the group members. The following table shows who assigned to each task and how much is contributed by the member.

Table 11:: Tasks distribution

No.	Tasks		Assigned to	Contribution
1	Introduction		Hassan Alzory	100%
2	Literature Review	Fuel injection system background	Hassan alzory	100%
		Previous work	Hassan Alzory	100%
		Comparative study	Hassan alzory	100%
		Gannt chart	Hassan alzory	100%
		Looking for parts	Qasim	25%
			Mohammed	25%
			fadhil	25%
			Hassan Alhaddad	25%

3	Calculations	Solidworks model	fadhil	100%
		Solidworks model testing for failure possibility	fadhil	100%
		FEA of chamber calculation	fadhil	100%
		Hose calculation using SAE standard	fadhil	100%
4	Parts ordering	Connections, injectors, pressure gauges, triggering chip, vacuum pump, acrylic, and hose	Hassan Alzory	25%
			Qasim	25%
			Mohammed	25%
			Hassan Alhaddad	25%
5	Manufacturin g	Chamber	Hassan alhaddand	100%
		Fuel tank	Qassim	100%
		Putting the system together	all	100%
6	Test the system	Fuel tank testing	Qassim	100%
		Chamber testing	Hassan Alhaddad	100%
		Fuel injector testing	all	100%
7	Conclusion	results	Hassan Alzory	100%
8	Report writing	All chapters	Hassan alzory	100%

5.3 Project Execution Monitoring

We had many activities during our project period. Some of the activities are continuous and some of them are taking place only one time. Table 12 shows the time for each activity.

Table 12:Table of activities

Time	Activities
Two times a week	Assessment class
Weekly meeting	With group members
weekly meeting	With advisor
Tue, march 27	Midterm presentation
Thu, April 14	Preliminary test
Wed, April 21	Test the system
Tue, may 3	Final presentation

5.4 Challenging and Decision Making

Throughout the project period there were many difficulties and challenges we faced such as:

1. **Buying some of the material and equipment from overseas.**

The first problem we faced is international orders we had to order connection, hose, gauges, and vacuum pump. First, we had to look for a vacuum with a reasonable price that has all the required specification that fit our design it wasn't a problem to find it. However, the shipping to Saudi Arabia was expensive as it was a bit heavy. Another problem that the vacuum pump shipment was put to hold due to misunderstanding that it contains unacceptable material to ship to Saudi Arabia from the U.S. after many e mails sent to the shipping company the misunderstanding was cleared and was sent, and that caused a bit of delay in the expected date that we should have received it. In addition, international ordering takes time therefore we had to order everything early, also we had to send many emails to suppliers to find if there is a cheaper option for the acrylic to manufacture the chamber. The chamber material and manufacturing were done locally because the price is reasonable and time is short so we had to choose the shortest time over the cheapest.

2. **Design problems.**

Additional problem we had designing the chamber, we had to make 7 models in SolidWorks and analyze them to see which one will fail under pressure of 2 bar maximum. After trials and failed design, we had a successful design the has the dimension of 20*20*20 cm and a thickness of 30mm.

3. **Report writing and document.**

in writing the report, we had faced some problems such as time management between other courses and finding time to write the report, we had to take the writing and show it to the advisor for any correction needed to be done so it can meet the standard that the report needs to be at.

5.5 Project Bill of Materials and Budget

The following tables 13 and 14 provide the costs of all the material and equipment that we have purchased and manufactured.

Table 13:Total chamber cost including manufacturing

Company name	thickness	Price in SAR
Simplyplastic	25mm	1584.15 inc VAT & local shipping
acrylicsonline	25mm	2163.75 exc VAT & shipping
kitronik	25mm	Not available
plasticshop	25mm	Not available
bayplastic	25mm	1330 inc local shipping & VAT
Basmat Mosamem	30mm	1550

we have chosen to go with the 30mm from the local shop Basmat Mosamem because it is the cheapest option and the fastest root we can take to save time where in the case of bayplastic we will have to pay for international shipping via Aramex and that will increase the overall cost and time consuming.

Table 14:Parts cost

Part	Price in SAR
Vacuum pump	1187.5
chamber	1550
Fuel injectors	233.10
Connections	68
Hose	15
Pressure gauges	133
Fuel tank	50
Circuit	145
Power supply	550

Chapter 6: Project Analysis

6.1 Lifelong learning

In the period of this project we learned and gained many experience, such as working on software and technology tools, management skills with the team tasks, and design problem solving.

1. **Improving knowledge of software and technological tools**

we had to use many software such as Microsoft office, excel, power point, and solidworks. All this software we have already used however, our knowledge on how to use them professionally has improved a lot.

2. **Management skills**

First management skill we used is time management we had to be precise and professional with our timing for each task first we had to do our Gannt chart. From our Gannt chart we found the fastest root to take to finish the project and we had along the way to adjust it as more tasks had been added. Second skill is team management, there are many tasks for this project that was given to the members by the advisor each member had been giving a task that he was able to accomplish which made the progress efficient.

3. **Problem solving**

We faced many problems along the way of this project, with ordering material internationally, and shipping. However, these problems gave as the skills to solve them as a team and developed our individual skills such as communication skills.

6.2 Impact of Engineering Solutions

The project achieved excellent impact on the society, environment, and economy. We will explain the impact of each of them in details.

Society

One of the project achievements is to have an impact on the society. This project can improve the manufacturing of fuel injectors for car engines and any other engine. Testing the injectors help in determining the quality of the injector this injectors companies can benefit from this design in making better quality products.

Environment

from the environmental side in this project, testing injectors will reduce the chance of having more pollution to the environment. A bad injector will cause bad mixing of fuel which will lead to more pollution to the environment.

Economy

this design is a budget friendly almost anyone can build. The design can be used by injector companies, mechanic shop, or for personal use. As it doesn't cost more than 4000 SAR this design can save people money on fuel consumption and saving car engine from damaged caused by a defected injector by simply testing the injectors.

6.3 Contemporary Issues Addressed

When start talk about the issues that are facing our GCC countries and Saudi Arabia, we face the increase in population, leading to more cars on the road and not to forget that women now will be able to drive cars on the roads of Saudi Arabia means more fuel consumption, more pollution in the air.

Chapter 7: Conclusion and Future Recommendation

7.1 Conclusion

The car injection system stated to develop rapidly since the 4 stock engines were made. The goals of improving the injection system were to have a better engine efficiency, better fuel mixing, and complete burning of fuel. These objectives now days started to look for more improvement such as a better life span of injector. Therefore, the team was motivated to come with a spray chamber that can test injectors effectively. In this research the injectors were tested had proper mixing of fuel with air inside the spray chamber. In addition, injectors showed a linear relationship with time and quantity sprayed.

The unique feature about this project is how cost friendly it is to do compared with another project that are in the field. This project can be done individually, for a car garage to test injector, or it can be done by a researcher as it doesn't cost more than 4000 SAR and it can achieve good results.

In addition, the team gained experiences though out the period of the project. First experience to be noticed working with technological tools such as Microsoft office programs, and SolidWorks designing program for the chamber. Second, the members of the team learned the importance of team work in the engineering field and how much it can make the project easier. Each team member learned to be responsible and on time with the task that had been assigned to each. However there have been a challenge for the team to overcome the short time that was needed to finish the project the team had to be on time otherwise the project might fail to complete.

The knowledge gained from this project very beneficial in many ways, one way it is learned that to have a good working engine it is important to have the proper mixing of fuel with air to have the best combustion. This knowledge achieved by the experiment done on the injector that showed the proper mixing of air and fuel in real demonstration which is a unique experience to have as a mechanical engineering student. An other way the team learned that the amount that injected by the injector have a strong relation ship with time as it is contestant with time.

7.2 Future recommendation

There are many things that can be done to make this project better and enhance it. First taking data about the pressure vs temperature inside the chamber and studying their relationship effect on the system. Second, improving the sealing of the spray chamber from the top and ensure no leakage of air can happen. Third adding the vacuum pump air filter for a healthier testing environment as the gasoline smell leaks out after it is being sucked out of the spray chamber. Forth, it is recommended to study the effect of the spray at a varying pressure to understand how the injector behave in different conditions. Fifth recommendation is testing the amount of spray with different pressure applied with each injection. Finally, it is recommended to adjust the holes on the top cover of the spray chamber for a deeper fitting of injector.

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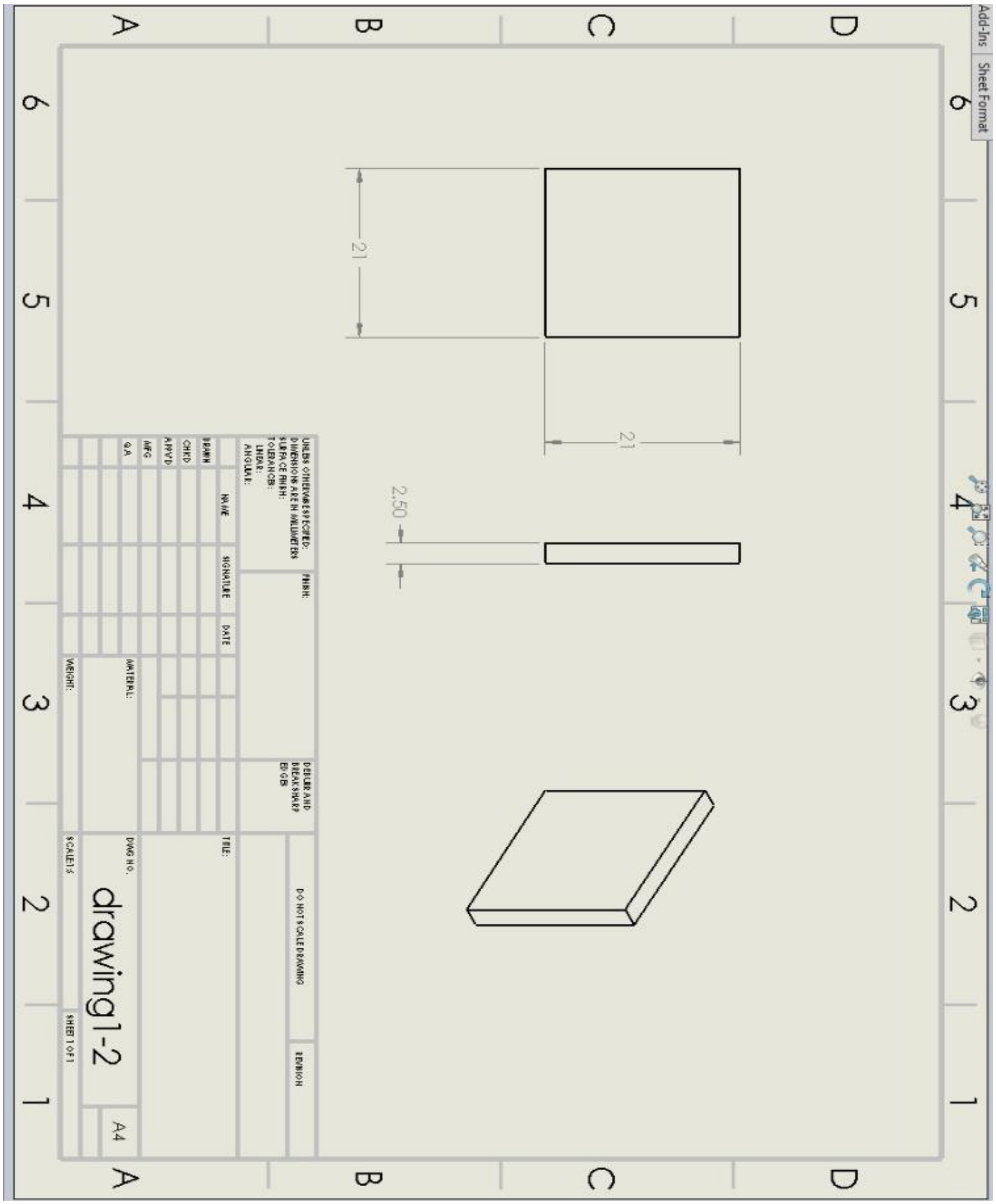
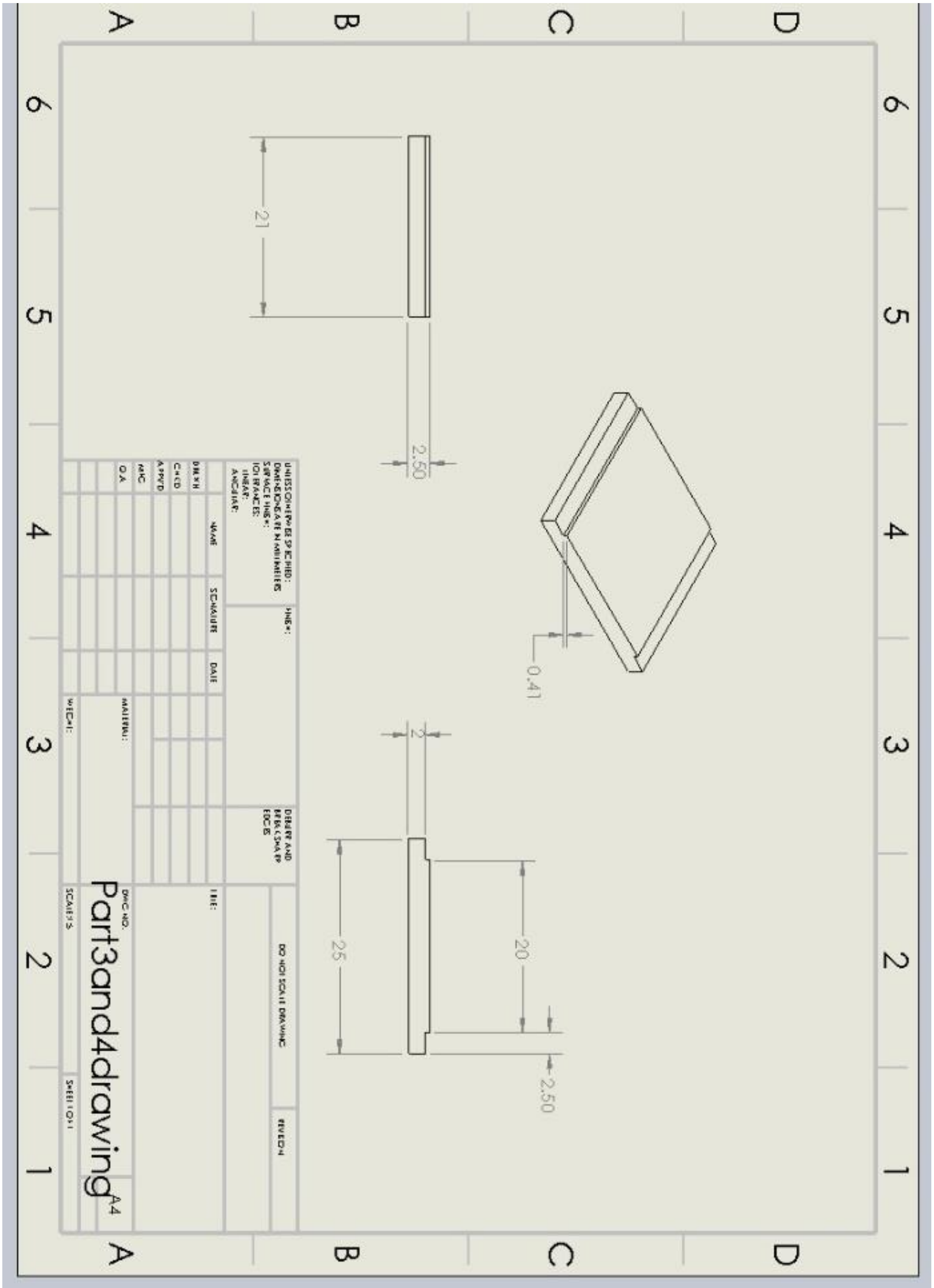
9 Appendix A: SolidWorks Drawings





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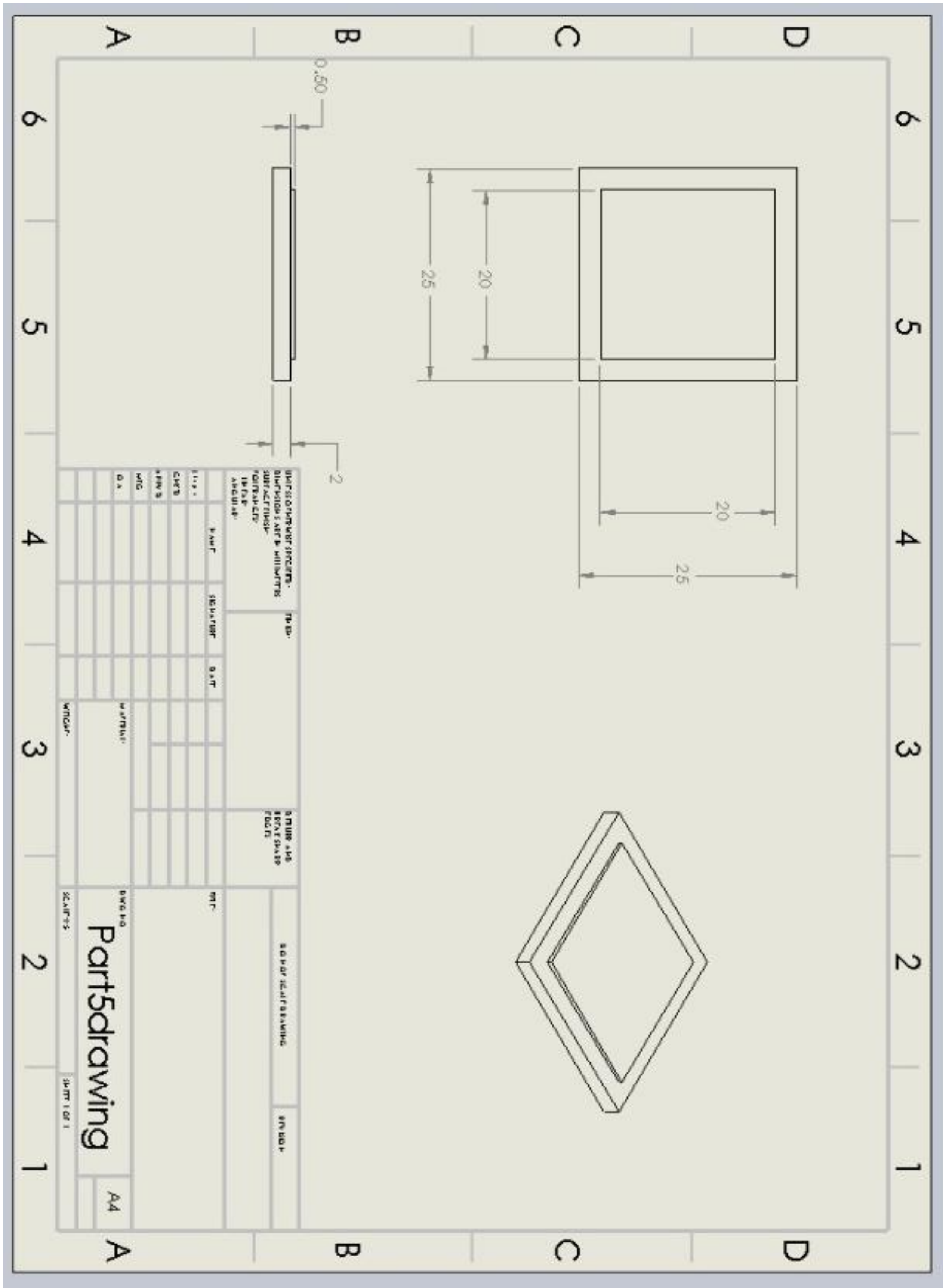
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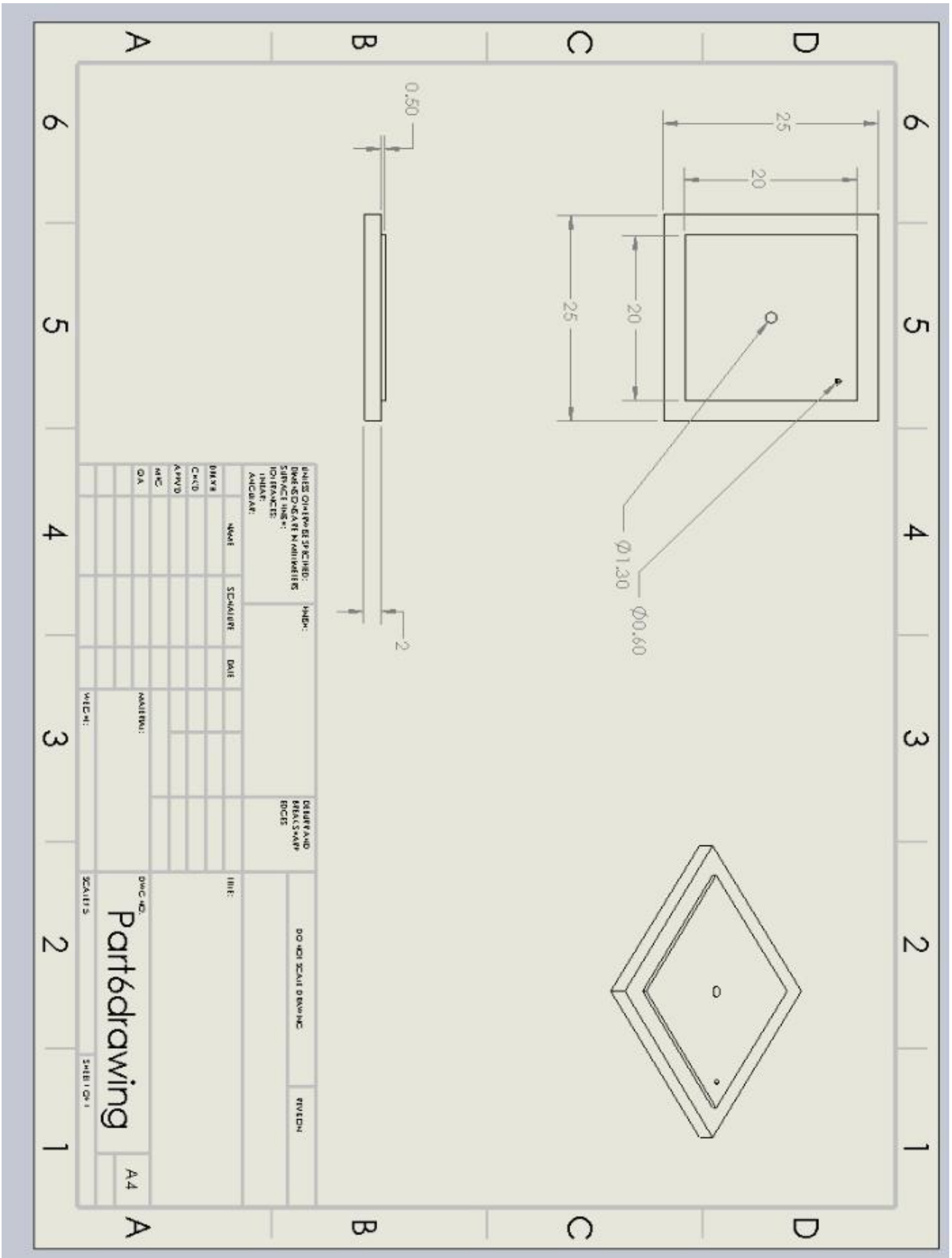

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