MARMARA UNIVERSITY

FACULTY OF ENGINEERING

STRUCTURAL AND CONSEPTUAL DESIGN OF A 3-CYLINDER SMALL SIZE DIESEL ENGINE

MERT CAN AKTAY-150419544

HALIL BOZAN-150419530

GRADUATION PROJECT REPORT

Department of Mechanical Engineering

Supervisor

Prof. Dr. Mehmet Zafer GUL

ISTANBUL, 2024

MARMARA UNIVERSITY

FACULTY OF ENGINEERING

STRUCTURAL AND CONSPTUAL DESIGN OF A 3 CYLINDER SMALL SIZE DIESEL ENGINE

by

Mert Can AKTAY, Halil BOZAN

June 20,2024, Istanbul

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE AT MARMARA UNIVERSITY

Signature of Author(s) ....

Department of Mechanical Engineering

Certified By ....

Project Supervisor, Department of Mechanical Engineering

Accepted By...

Head of the Department of Mechanical Engineering

ACKNOWLEDGEMENT

First of all, I would like to thank my supervisor Prof. Dr. Mehmet Zafer GUL, for the valuable guidance and advice on preparing this thesis and giving me moral and material support.

June, 2024 **Mert Can AKTAY**

Halil BOZAN

TABLE OF CONTENTS

ABSTRACT
This research thesis focuses on the design and development of a 3-cylinder engine. The thesis delves into the history, advantages, and prospects of diesel engines, particularly 3-cylinder designs. It also explores design considerations, fuel systems, and potential applications. The research draws upon various sources, including published articles, expert opinions, and statistical data, to provide a comprehensive understanding of 3-cylinder engines. Based on the findings, 3-cylinder engines are deemed more efficient than their 4-cylinder counterparts, and diesel engines are projected to maintain significant market presence for at least the next two to three decades. Consequently, the thesis presents a novel 3-cylinder engine design, differentiating itself from existing market offerings.

ABBREVIATIONS

DPF	Diesel Particulate Filters
DKW	Dampf-Kraft-Wagen
DOHC	Double Overhead Cam
EU	Europe
EUP	Electronic Unit Pump
ECU	Engine Control Unit
GDI	Gasoline Direct Injection
GHG	Green House Gas
GT	Grand Tourers
HCCI	Homogeneous Charge Compression Ignition
HEV	Hybrid Electric Vehicle
IC	Internal Combustion
MPI	Multiport Injection
MAF	Measure Air Flow
MAP	Mass Air Pressure
MHT	Mild-Hybrid Technology
MPFI	Multi-Point Fuel Injection
MTREC	Multi Throttle Responsive Engine Control
RDE	Real Driving Emissions
NOX	Nitrogen Oxide
PM	Particulate Matter
PFI	Port Fuel Injection
PPS	Pre-Pilot Spray
PS	PFERDE STARKE
RS	Ralli Sport
SCR	Selective Catalytic Reduction
SUV	Sport Utility Vehicle
SI	Spark Ignition
SPFI	Sequential Port Fuel Injection System
SPI	Single Point Injection
TBI	Throttle Body Injection
TDC	Top Dead Center

TDI	Turbocharged Direct Injection
UPS	Unit Pump System
US	United States
VAG	Volkswagen Automobile Group
VTG	Variable Turbo Geometry
VTEC	Variable Valve Timing and Lift Electronic Control System

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Internal combustion engines (ICEs) have revolutionized transportation, powering a vast array of vehicles from automobiles to locomotives. These engines convert chemical energy into mechanical energy through combustion, typically using a mixture of fuel and air. Early ICEs were atmospheric engines, with limited efficiency and power output. However, advancements in the 19th century led to the development of more efficient Four-stroke engines, laying the foundation for modern ICEs. In the 1860s, Nicolaus Otto and Eugen Langen introduced the Otto-Langen engine, marking a significant step forward in ICE technology. Their engine achieved an efficiency of 11%, paving the way for further improvements. Throughout the 19th century, various inventors contributed to the development of ICEs, refining the Four-stroke cycle and laying the groundwork for modern engines. Rudolf Diesel's compression ignition engine, introduced in 1892, revolutionized ICE technology. His design, known as the diesel engine, forms the basis of modern diesel engines today. Diesel's engine offered superior efficiency and torque, making it well-suited for heavy-duty applications. The first internal combustion engines appeared in automobiles around the 1880s, and their popularity has grown ever since. Three-cylinder diesel engines have gained traction in recent years due to their compact size, fuel efficiency, and low emissions. These engines are particularly well-suited for smaller vehicles, such as city cars and subcompact cars. This report delves into the advancements made in three-cylinder diesel engines since their inception and explores the factors contributing to their increasing popularity over the past decade.

2. LITERATURE REVIEW

2.1 SI AND CI ENGINES

Internal combustion engines, which convert energy into mechanical work, can be categorized based on their mixture formation and ignition methods. Two main types of internal combustion engines exist: Otto engines, which employ spark ignition, and Diesel engines, which utilize compression ignition.

2.1.1 SI ENGINE

A Four-stroke petrol engine completes its working cycle in four distinct steps, each requiring two crankshaft revolutions. The first step, known as the suction stroke, involves the intake valve opening before the piston reaches its topmost position, Top Dead Center (TDC). As the piston descends, it draws in a fresh mixture of air and fuel into the cylinder, generating a pressure of approximately 0.7 to 0.9 bar. This incoming mixture mingles with the residual combustion products from the previous cycle.

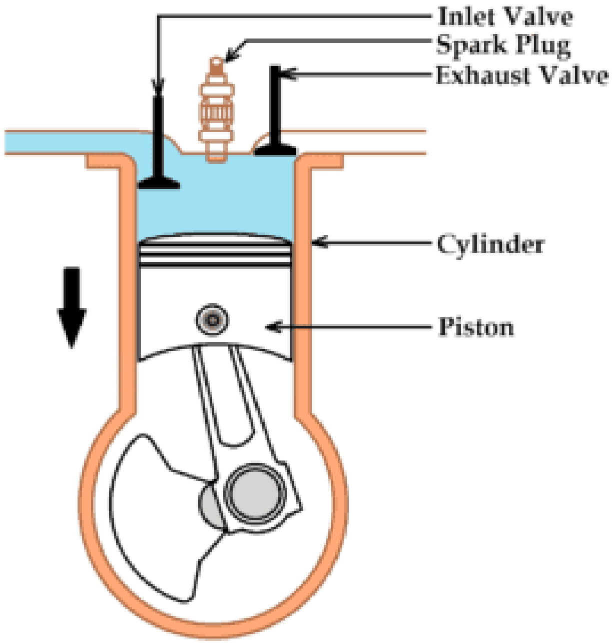

Figure 1 Suction stroke of Engine Cycle.

During the compression stroke, the intake valve closes, and the piston ascends, compressing the air-fuel mixture within the cylinder. This compression leads to a significant increase in pressure, ranging from 11 to 18 bar, and temperature, soaring from 400 to 600 degrees Celsius. As the piston moves upwards, the cylinder chamber's volume diminishes, effectively squeezing the trapped mixture. [1]

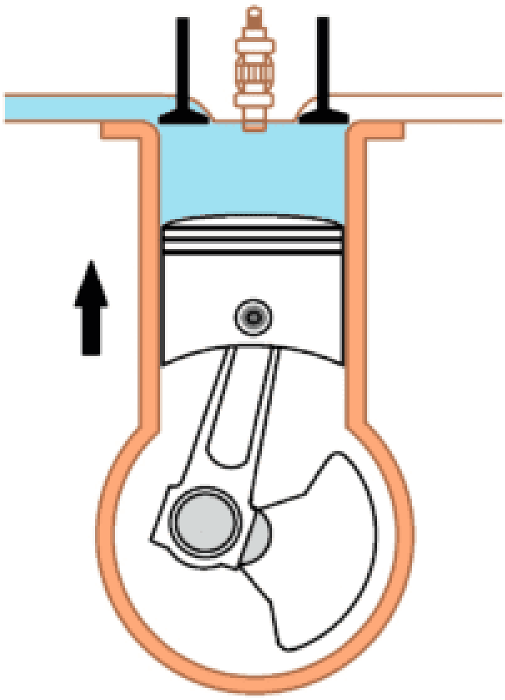

Figure 2 Compression Stroke of Engine Cycle.

Just before the piston reaches TDC again, the compressed air-fuel mixture is ignited by an electric spark plug. This combustion process, known as the power stroke, generates a rapid expansion of the burning gases, pushing the piston downwards and producing useful mechanical work. The combustion gas pressure at the beginning of the expansion stroke reaches 40 to 60 bar, accompanied by a temperature of 2000 to 2500 degrees Celsius.

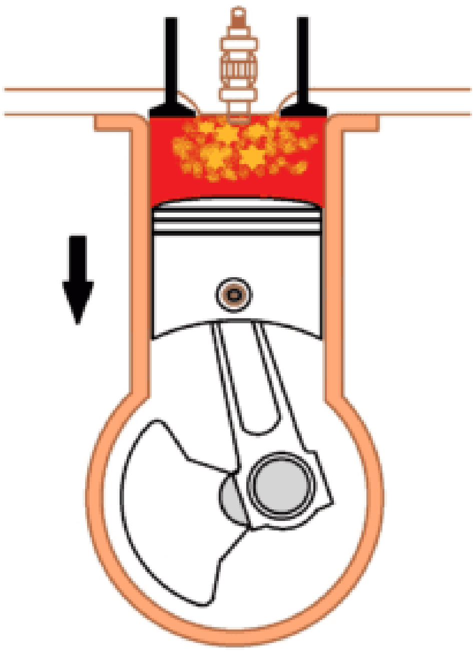

Figure 3 Working Stroke of Engine Cycle.

The exhaust stroke completes the cycle. As the piston ascends once more, it expels the spent combustion gases through the open exhaust valve. The pressure of these exhaust gases ranges from 1.05 to 1.20 bar. Depending on the cylinder charge, the pressure difference between the cylinder and the exhaust can be substantial, leading to the efficient expulsion of a significant portion of the exhaust gases.

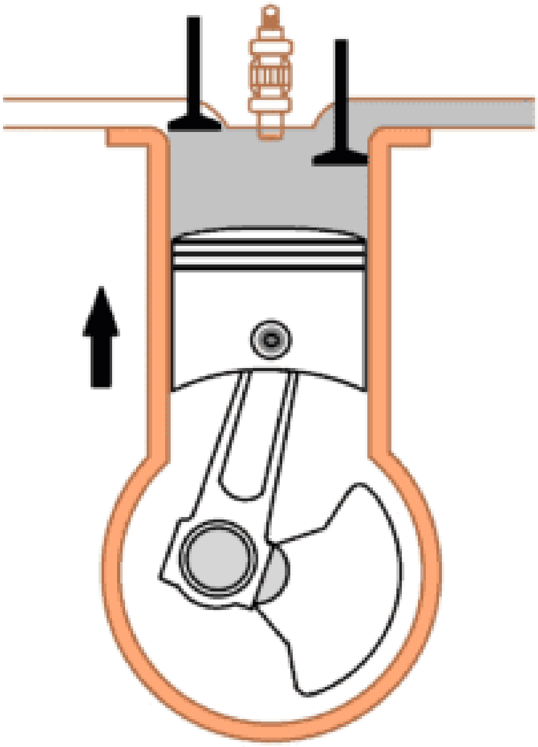

Figure 4 Exhaust Stroke of Engine Cycle.

The high pressures and temperatures experienced within the engine cylinder are crucial for achieving optimal efficiency. These conditions effectively convert the chemical energy stored in the fuel into mechanical work, driving the engine's operation. [2]

2.1.2 CI ENGINE

The four-stroke diesel engine operates in a similar manner to the four-stroke petrol engine, but with some key differences. The cycle starts with the intake stroke, where the intake valve opens, allowing fresh air to be drawn into the cylinder. The pressure in the cylinder drops, creating a partial vacuum that draws in the air. The actual cylinder pressure during this time is typically between 0.7 and 0.85 bar, but in turbocharged engines, it can reach up to 2 bar.

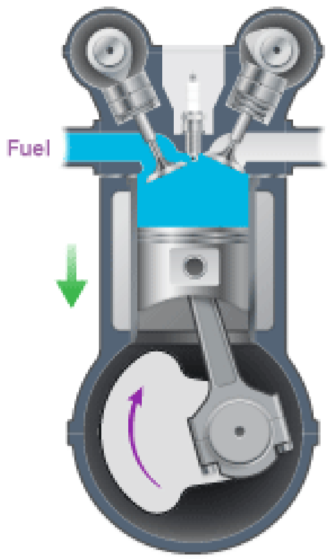

Figure 5 Intake Moment of CI Engine Cycle.

Once the intake valve closes, the compression stroke begins. The piston moves upwards, reducing the volume of air in the cylinder and compressing it to a high pressure. This compression is essential for creating the conditions necessary for combustion. The air pressure at the end of the compression stroke is typically between 30 and 60 bar, and the temperature reaches between 600 and 900 degrees Celsius.

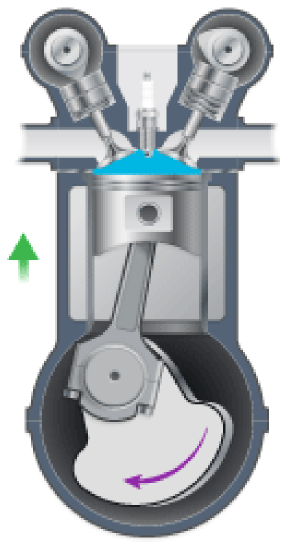

Figure 6 Compression Moment of CI Engine Cycle.

At the end of the compression stroke, fuel is injected into the cylinder through a high-pressure injector. The finely atomized fuel droplets mix with the compressed air, creating a combustible mixture. The heat and pressure in the cylinder cause the fuel to ignite spontaneously, initiating the power stroke.

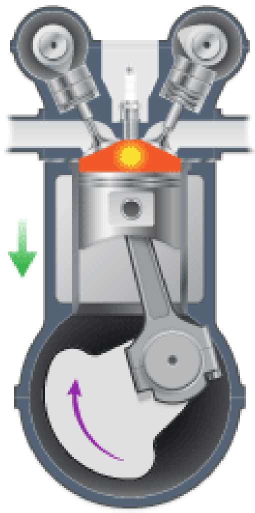

Figure 7 Combustion Moment of CI Engine Cycle.

During the power stroke, the burning fuel expands rapidly, generating a tremendous amount of force that drives the piston downwards. This expansion produces the power that propels the engine. The combustion temperature during the power stroke can reach between 2000 and 2500 degrees Celsius, and the pressure can reach between 60 and 120 bar. [3]

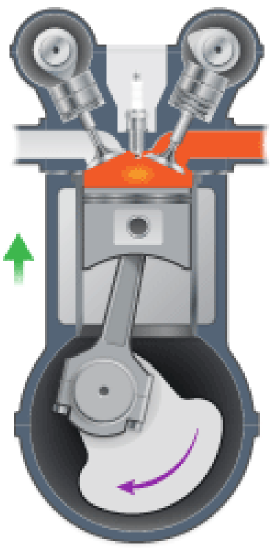

Figure 8 Exhaust Moment of CI Engine Cycle.

After the power stroke, the exhaust stroke follows. The exhaust valve opens, and the piston moves upwards, expelling the spent combustion gases out of the cylinder. The pressure of the exhaust gases is typically between 1.05 and 1.20 bar, and the temperature is between 500 and 600 degrees Celsius.

Once the exhaust gases are expelled, the cycle repeats itself, starting with the intake stroke. This continuous cycle of intake, compression, power, and exhaust is what drives the four-stroke diesel engine.

Table 1 Difference between SI Engine and CI Engine. [4]

	Parameter	**SI Engine**	**CI Engine**
1.	**Definition**	It is an engine in which the spark is used to burn the fuel.	It is an engine in which heat of compressed air is used to burn the fuel.
2.	**Fuel used**	Petrol is used as fuel.	Diesel is used as fuel.
3.	**Operating cycle**	It operates on Otto cycle.	It operates on Diesel cycle.
4.	**Compression ratio**	Low compression ratio.	High compression ratio.
5.	**Thermal efficiency**	High thermal efficiency.	Less thermal efficiency.
6.	**Method of ignition**	Spark plug is used to produce spark for the ignition.	Heat of compressed air is used for the ignition.
7.	**Engine Speed**	High speed engines.	Low speed engines.
8.	**Pressure generated**	Low pressure is generated after combustion.	High pressure is generated after combustion.
9.	**Constant parameter during cycle**	Constant volume cycle.	Constant pressure cycle.
10.	**Intake**	Air + fuel.	Only air.
11.	**Weight of engine**	Si engine has less weight.	CI engine is heavier.
12.	**Noise production**	It produces less noise.	It produces more noise.
13.	**Production of hydrocarbon**	Less Hydrocarbon is produced.	More hydrocarbon is produced.
14.	**Starting**	The starting of SI engine is easy.	The starting of CI engine is difficult.
15.	**Maintenance cost**	Low	High
16.	**Vibration problem**	Less	Very High
17.	**Cost of engine**	Less cost	High cost
18.	**Volume to power ratio**	Less	High
19.	**Fuel supply**	Carburetor	Injector
20.	**Application**	It is used in light commercial vehicles like motorcycle, cars etc.	It is used in heavy duty vehicles likes bus, trucks, ships etc.

3. WHAT IS 3-CYLINDER ENGINE?

In the latter half of the 1980s and throughout the 1990s, three-cylinder engines dominated the roads. However, with the onset of the new centuries, cars equipped with four-cylinder engines reclaimed the automotive market. Presently, automobile manufacturers are increasingly revisiting the production of cars featuring three-cylinder engines, driven by investigations into environmental regulations. These manufacturers are responding to the demand for more environmentally friendly vehicles, as three-cylinder engines offer advantages such as improved fuel efficiency and enhanced power delivery through turbocharging.

Several factors contribute to the resurgence of three-cylinder engines in the automotive landscape:

Reduced Raw Material Usage: One of the primary benefits of a three-cylinder engine is the minimized requirement for raw materials. With one less cylinder, the overall material needed for manufacturing a three-cylinder engine is lower, providing a dual advantage to manufacturers.

Optimized for Fuel Efficiency: From a consumer's standpoint, enhanced fuel efficiency is a key attraction of three-cylinder engines. These engines demonstrate greater fuel efficiency compared to their four-cylinder counterparts of similar size. This efficiency is attributed to reduced frictional losses and a lighter weight. The absence of one-cylinder results in diminished frictional losses caused by metal surfaces interacting within the engine block.

Economical Maintenance and Operation: Generally, three-cylinder engines are more cost-effective to maintain and operate. With fewer cylinders, the total number of engine components is lower. Consequently, there is reduced wear and tear, making maintenance and operation more economical compared to four-cylinder engines.

In summary, the renewed focus on three-cylinder engines by automobile manufacturers stems from their cost-effectiveness, fuel efficiency, and compliance with tightening emission and fuel regulations. These engines represent a strategic response to evolving market demands and environmental considerations.

4. DIESEL ENGINE

A diesel engine is a type of internal-combustion engine that operates by compressing air to a high temperature, causing diesel fuel injected into the cylinder to ignite. The resulting combustion and expansion drive a piston, converting the fuel's energy into mechanical power. Diesel engines are commonly used in freight trucks, large tractors, locomotives, and marine vessels. Some automobiles and electric-power generator set also utilize diesel power. The engine functions by burning fuel injected into the compressed, hot air charge within the cylinder. The key is to heat the air to a temperature higher than the auto-ignition temperature of the injected fuel, leading to spontaneous combustion and energy release.

4.1 THE HISTORY OF DIESEL ENGINE

The diesel engine is an internal combustion engine that operates on the principle of compression ignition. Unlike gasoline engines, which use spark plugs to ignite the fuel mixture, diesel engines use the heat of compression to ignite the fuel. This allows diesel engines to be more fuel-efficient and powerful than gasoline engines, but they also tend to produce more emissions.

The diesel engine was invented by Rudolf Diesel in 1892. Diesel was a German engineer who was looking for a more efficient engine than the gasoline engines that were in use at the time. He experimented with different designs and eventually developed an engine that worked by compressing air to a very high temperature and then injecting fuel into the cylinder. The fuel ignited spontaneously, and the resulting explosion drove the piston down the cylinder.

Diesel engines were originally used in stationary applications, such as power generation and marine propulsion. However, they soon found their way into vehicles, and by the 1930s, they were widely used in trucks and buses. Diesel engines became increasingly popular in the 1970s, as the oil crisis made fuel efficiency a major concern.

Today, diesel engines are used in a wide variety of applications, including:

- Trucks and buses
- Cars
- Construction equipment
- Agricultural machinery
- Marine propulsion
- Railway locomotives

Diesel engines are a popular choice for these applications because of their fuel efficiency and power. However, they also produce more emissions than gasoline engines, and they can be more expensive to maintain.

Here is a timeline of the history of the diesel engine:

- 1892: Rudolf Diesel patents the diesel engine.
- 1909: The first diesel-powered locomotive is built.
- 1924: The first diesel-powered car is built.
- 1930s: Diesel engines become widely used in trucks and buses.
- 1970s: Diesel engines become increasingly popular due to the oil crisis.
- 1990s: Common rail injection systems are developed, which improve the efficiency and emissions of diesel engines.
- 2000s: Diesel engines are increasingly used in cars, due to their fuel efficiency and power.
- 2010s: Diesel emissions become a major concern, and regulations are tightened.
- 2020s: The future of the diesel engine is uncertain, as governments and automakers are looking for ways to reduce emissions.

The diesel engine has had a significant impact on the world. It has made transportation more efficient and affordable, and it has also been used in a wide variety of industrial applications. However, diesel engines also produce emissions that can harm the environment, and they are facing increasing scrutiny from regulators.

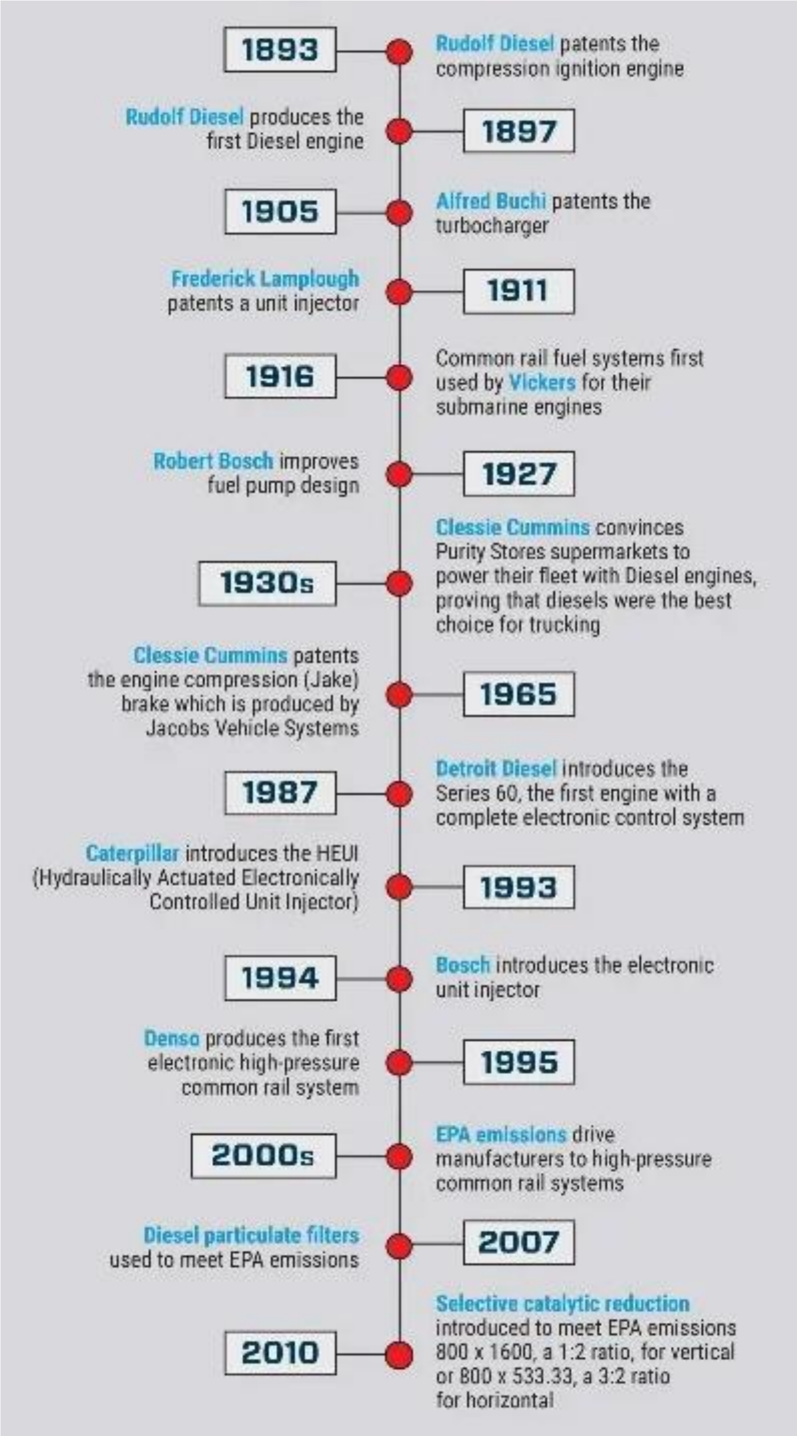

Figure 9 The timeline shows some of the key developments and updates with the diesel engine through the years. [5]

4.2 THE DEVELOPMENT OF DIESEL ENGINE

Seventy-six years have passed since the unveiling of the Mercedes-Benz 260D, the world's first mass-produced diesel passenger car, at the 1936 Berlin Motor Show. While diesel-powered passenger cars were not initially popular compared to gasoline counterparts until the 1950s, manufacturers persisted in their development. Post-World War II, diesel engines gained prominence in passenger cars, especially in taxis due to their cost-effectiveness in harsh driving conditions.

Over the years, advancements in diesel engine technology included the introduction of the first electronic control systems for row-type (in-line) fuel pumps, distributor pumps (star pumps), and both distributor and in-line pumps. Different injection technologies, such as sequential (row-type), distributor pump (star pump), and Common Rail, were employed in diesel engines. In 1985, electronic control systems for distributor and sequential pumps were introduced, and in 1989, the first axial piston pump enabled direct injection at high pressure, leading to more effective combustion, increased output, acceleration, and fuel efficiency.

The transition to the Euro 6 emission standard in 2003 saw the introduction of the Common Rail injection system with "piezo" injectors. This system significantly reduced fuel consumption, exhaust emissions, and engine noise compared to earlier models.

As the industry shifts from Euro 5 to Euro 6 standards, necessitating a reduction of more than half in Nitrogen Oxide (NOX) emissions, recent years have seen tighter fuel consumption reduction targets. Diesel fuel system engineers are currently focused on developing injection systems capable of exceeding 2000 bar pressure to meet stringent emission limits, further enhancing fuel efficiency, and reducing carbon dioxide (CO2) emissions.

5. WILL DIESEL VEHICLER BE USED IN THE FUTURE?

The future of diesel vehicles is uncertain and depends on several factors.

5.1 REGULATIONS AND EMISSIONS STANDARDS

Government around the world are increasingly concerned about air pollution and climate change. As a result, they are implementing stricter emissions standards for vehicles. Diesel engines have traditionally been a major source of air pollution, so they have been a particular focus of these regulations.

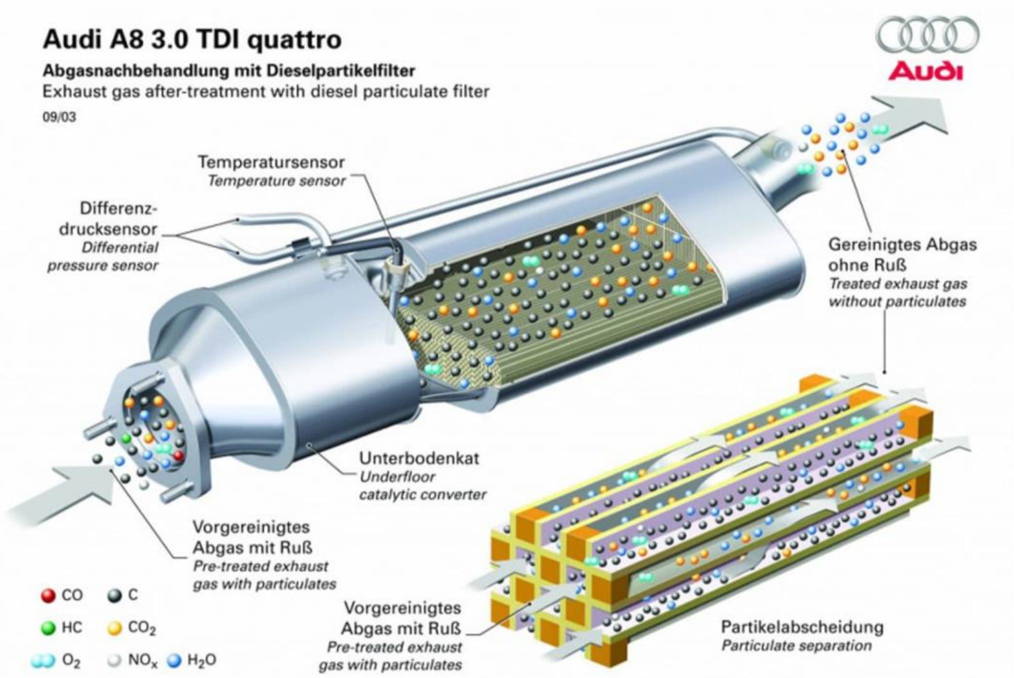

Figure 10 Diesel Engine with an emissions filter.

In the United States, the environmental protection agency (EPA) has set increasingly stringent standards for nitrogen oxide (NOx) and particulate matter (pm) emissions from diesel vehicles. These standards have driven manufacturers to develop cleaner diesel technologies, but they have also made it more difficult for diesel vehicles to meet the standards. [6]

In Europe, the euro 6 emissions standard, which was implemented in 2014, is the most stringent emissions standard in the world. The euro 7 standard, which is expected to be implemented in 2025, is even stricter.

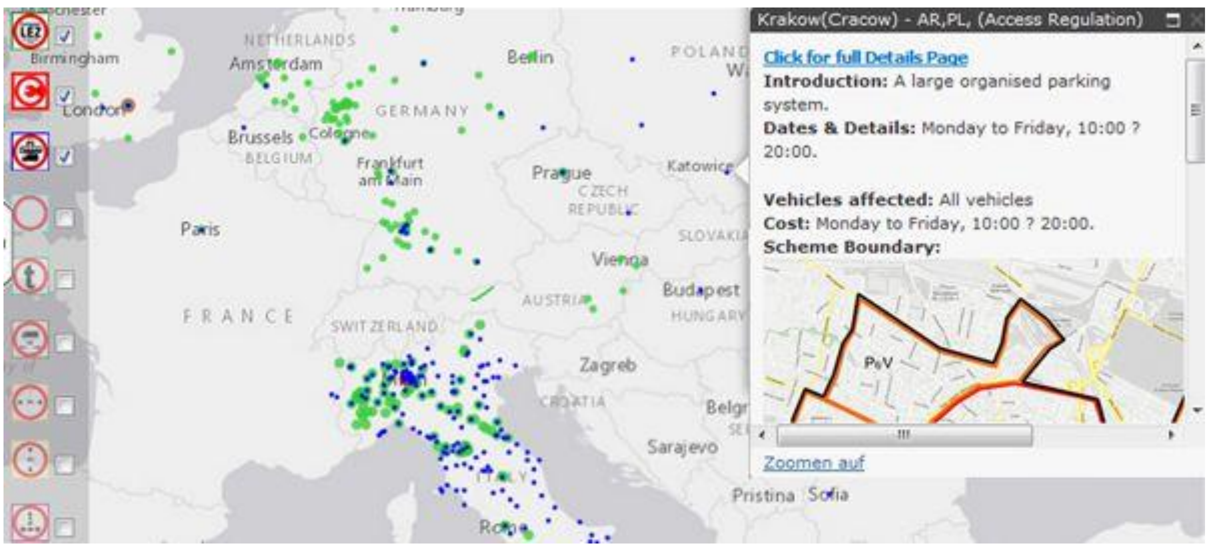

Figure 11 Interactive map of EU vehicle access restriction areas on urbanaccessregulations.eu. [7]

5.2 ADVANCEMENTS IN ELECTRIC VEHICLES (EVS)

The automotive industry is making significant strides in electric vehicle technology. The increasing popularity and advancements in battery technology contribute to the growth of electric vehicles. As EV infrastructure improves and costs decrease, more people may opt for electric alternatives over diesel vehicles.

Figure 12 2019 Tesla Model 3 Performance. [8]

5.3 TECHNOLOGY IMPROVEMENTS IN DIESEL ENGINE

Manufacturers are continuing to invest in developing cleaner diesel technologies. These technologies include:

- Selective catalytic reduction (SCR): SCR systems can reduce NOx emissions by up to 90%.
- Diesel particulate filters (DPFs): DPFs can capture and remove up to 99% of PM.
- Homogeneous charge compression ignition (HCCI): HCCI engines are a type of diesel engine that can achieve lower NOx and PM emissions than traditional diesel engines.

These technologies are helping to mitigate some of the environmental concerns associated with diesel vehicles. However, they are not a silver bullet, and diesel engines will still emit more emission than EVs.

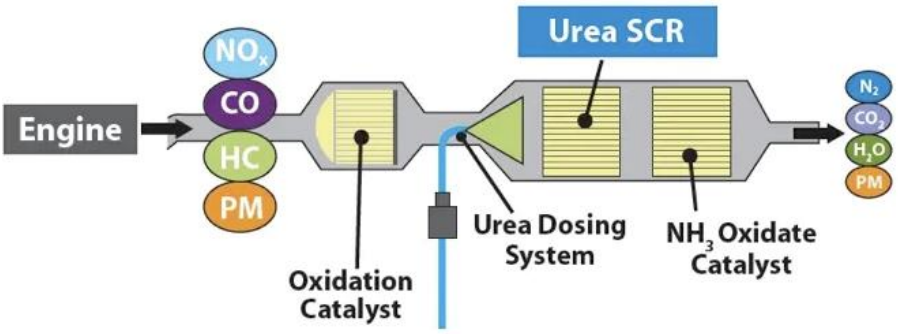

Figure 13 Diesel Engine with a selective catalytic reduction (SCR) system. [9]

5.4 MARKET DEMAND

Consumer preferences play a crucial role in shaping the future of diesel vehicles. If there is sustained demand for diesel vehicles, manufacturers may continue to produce them. However, if consumers increasingly prefer electric or other alternative fuel vehicles, the market for diesel vehicles may decline.

In recent years, there has been a decline in demand for diesel vehicles in some markets, such as the United States. This is due in part to the Volkswagen emissions scandal, which revealed that Volkswagen had cheated on emissions tests for its diesel vehicles. [10]

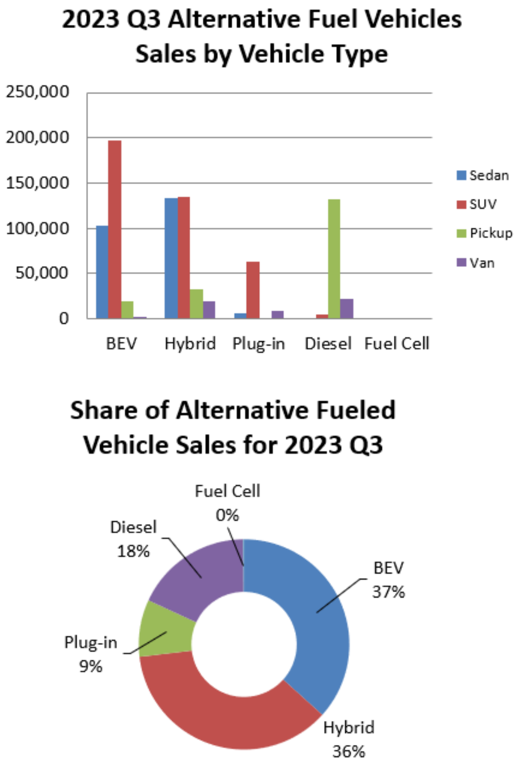

Figure 14 Graph showing the sales of diesel vehicles in the United States from 2023 Q3.

5.5 COMMERCIAL VEHICLES

Diesel engines are still commonly used in commercial vehicles, such as trucks and buses. This is due to their efficiency and long-haul capabilities. The development of electric trucks and buses could challenge diesel's dominance in the commercial vehicle sector, but diesel engines are likely to remain in use for some time to come. [11]

Figure 15 Example truck that Volvo is working on for zero-emission vehicles.

6. INCREASED AFTERMARKET OPPORTUNITIES FOR PASSENGER DIESELS

The aftermarket landscape for passenger diesel vehicles is positioned for substantial growth and continued relevance, even in the face of recent declines in new diesel car sales. The key to this optimistic outlook lies in the extended service life of diesel vehicles, which, on average, exceeds 13 years, coupled with their current average age of approximately 6.7 years. These metrics signify a significant runway for aftermarket services, as the existing fleet of diesel vehicles continues to age.

The European roads currently host over 14 million diesel vehicles that are under three years old, representing a substantial market segment that will progressively require repairs and maintenance services as they accumulate mileage and wear over time. This emerging demand is not only fueled by routine maintenance needs but is also accentuated by the intricacies of modern diesel engine components, particularly common-rail injector systems.

Common-rail injector systems, integral to diesel engines, are subject to faster wear due to their intricate design and the demands of multiple injections at higher fuel pressures. The complexity of these components translates into more sophisticated and costly repairs, creating opportunities within the aftermarket for specialized services and components.

Moreover, the driving behavior of diesel vehicle owners further amplifies the potential for aftermarket services. Diesel drivers, on average, cover more kilometers compared to their gasoline counterparts, resulting in accelerated wear and tear on various vehicle components. This extended usage pattern opens additional avenues for aftermarket businesses specializing in addressing wear-related issues and providing maintenance services tailored to the unique needs of diesel vehicles.

Despite prevailing negative perceptions about diesel in some quarters, the data suggests that diesel vehicles will maintain a considerable market presence. Projections indicate that by 2024, there will be over 113 million diesel passenger cars on European roads, highlighting a sustained demand for aftermarket services well into the future. This scenario underscores the resilience and enduring business volume potential for the passenger diesel aftermarket, making it a viable and lucrative sector for entrepreneurs and service providers for at least the next two decades and likely beyond.

7. WHAT IS THE DESIGN OF 3-CYLINDER ENGINES?

The design of 3-cylinder engines represents a dynamic and diverse field, with engineering choices influenced by various factors such as the type of vehicle, its intended application, and broader considerations of efficiency and performance. Typically configured in an inline arrangement, 3-cylinder engines are characterized by a compact design that aligns the cylinders in a row, contributing to reduced weight and space utilization.

The engine block, a fundamental component, serves as the structural foundation for the cylinders. Materials like cast iron or aluminum are often employed to strike a balance between strength and weight, essential for achieving optimal performance and fuel efficiency. Within this block, the cylinders are meticulously positioned to ensure efficient combustion and power delivery.

The crankshaft, a critical element in the engine's architecture, plays a pivotal role in transforming the reciprocating motion of the pistons into rotational motion. Given the unique firing order of 3-cylinder engines, which can follow patterns like 1-3-2 or 1-2-3, the design of the crankshaft is adapted to maintain balance and minimize inherent vibrations.

To further enhance operational smoothness, manufacturers may incorporate balance shafts or employ advanced technologies aimed at mitigating vibrations that can arise due to the uneven firing intervals inherent in 3-cylinder configurations.

The evolution of 3-cylinder engines is also marked by the integration of advanced engine management systems. These systems, equipped with sophisticated sensors and control mechanisms, optimize crucial parameters such as fuel injection, ignition timing, and air-fuel mixture. This optimization not only enhances overall efficiency but also contributes to better emissions control.

Turbocharging is a common feature in many 3-cylinder engines, particularly in the pursuit of achieving a balance between power output and fuel efficiency. Turbochargers force more air into the cylinders, enabling improved combustion and a consequent increase in power without sacrificing fuel economy.

Applications of 3-cylinder engines are diverse, with these powerplants finding favor in small cars, subcompacts, and even certain motorcycles. Their compact size and reduced complexity make them well-suited for vehicles where space constraints and weight considerations play pivotal roles.

As technology continues to advance, ongoing research and development in the realm of 3-cylinder engines are likely to yield further innovations, shaping the future of these powerplants in the automotive landscape. Whether in pursuit of increased efficiency, reduced emissions, or enhanced performance, the design of 3-cylinder engines remains a dynamic and evolving domain within the automotive engineering landscape.

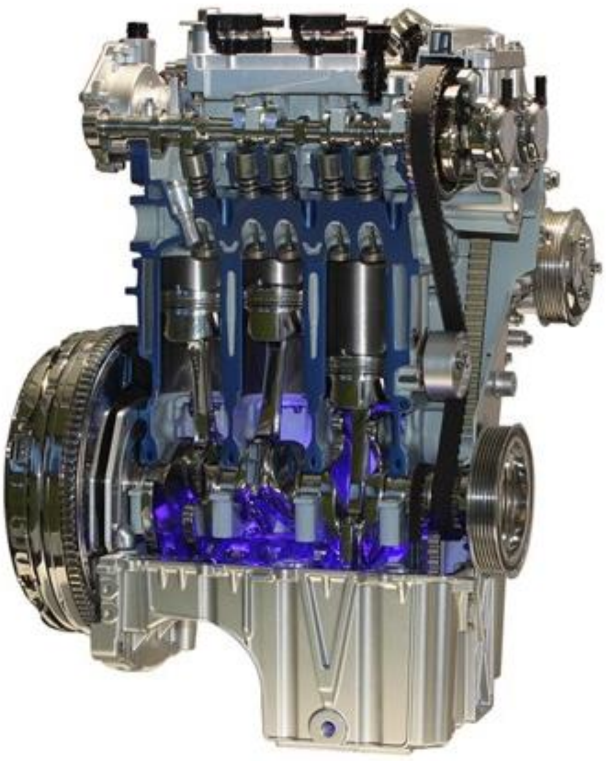

Figure 16 Ford's 1.0-liter EcoBoost Engine. [12]

8. VIBRATION OF 3-CYLINDER

Observations suggest that, at most, 3-cylinder engines exhibit momentary idling. This phenomenon was more pronounced in older naturally aspirated 3-cylinder engines, but it's less noticeable in the new generation turbocharged ones due to improved engine design. When you lift the car hood and inspect, the engine operates in idle mode, marked by a power cut. This practice aims to prevent issues, especially since contemporary 3-cylinders typically have a slightly higher idle speed.

Contrasting this, a 4-cylinder atmospheric engine doesn't have excessively high idling. After warming up, it stabilizes around 500-600 revolutions, unlike 3-cylinders where the cut power might elevate idle speed to 750, 800, or even 900 cycles. However, this elevated cut power comes with a downside – increased vibrations. In 4-cylinders, the opposing movements of pistons in cylinders 3 and 4, when considering the middle of the engine, counteract each other, promoting balance and smooth operation. In 3-cylinders, this isn't the case, and the engine tends to sway slightly due to the asymmetrical movement of pistons, contributing to vibrations. [13]

In older-generation 3-cylinders, a balancing shaft was added to mitigate these vibrations and minimize their perceptibility. This shaft rotated twice for every crankshaft rotation, effectively counteracting the forces generated by the pistons and maintaining a balanced and less vibrational engine operation.

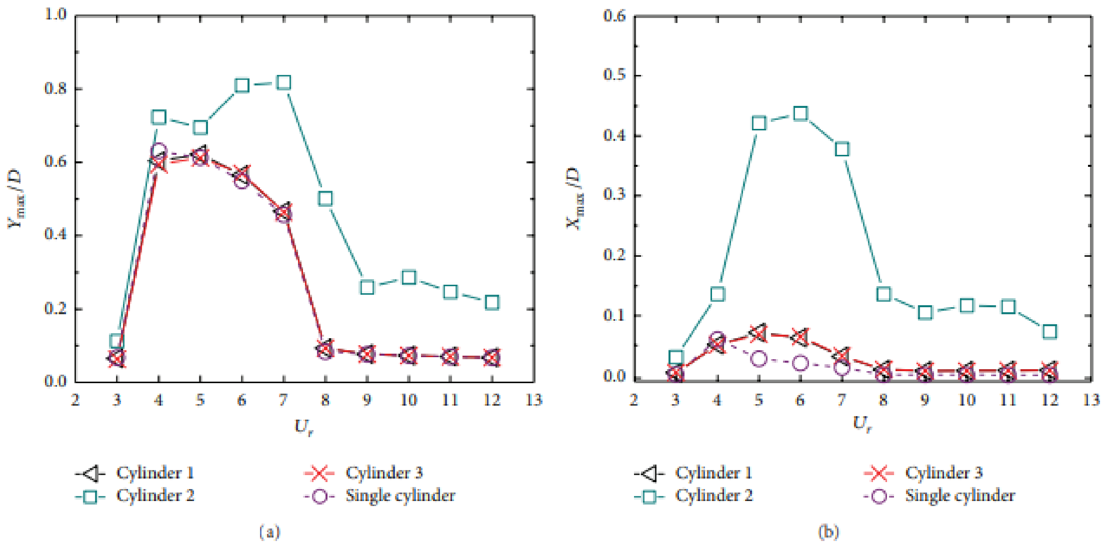

Figure 17 Maximum vibration amplitudes of 3-cylinders as a function of reduced velocity at α 60°: (a) transverse amplitude and (b) in-line amplitude.

9. FUEL INJECTION SYSTEMS IN DIESEL ENGINE

The primary function of the fuel system is to transport fuel from the storage tank to the engine combustion chamber, where it combines with air, vaporizes, undergoes combustion, and generates mechanical power. This system comprises essential components such as injectors, pumps, filters, fuel tanks, and carburetors. The effective operation of each of these elements is crucial for achieving the desired performance of the vehicle. A fuel storage tank is employed to store various types of fuel, including gas, diesel, or petrol.

When the engine requires fuel, a fuel pump draws fuel from the storage tank, moves it through fuel lines, and directs it to the carburetor or injectors. The carburetor or injector then incorporates air from the environment, creating an air-fuel mixture. Once the mixture is prepared, the fuel is transported to the combustion chamber, where the combustion process occurs. The fuel injection system plays a vital role in ensuring the proper supply of fuel to the engine. In summary, the fuel system operates in the following manner:

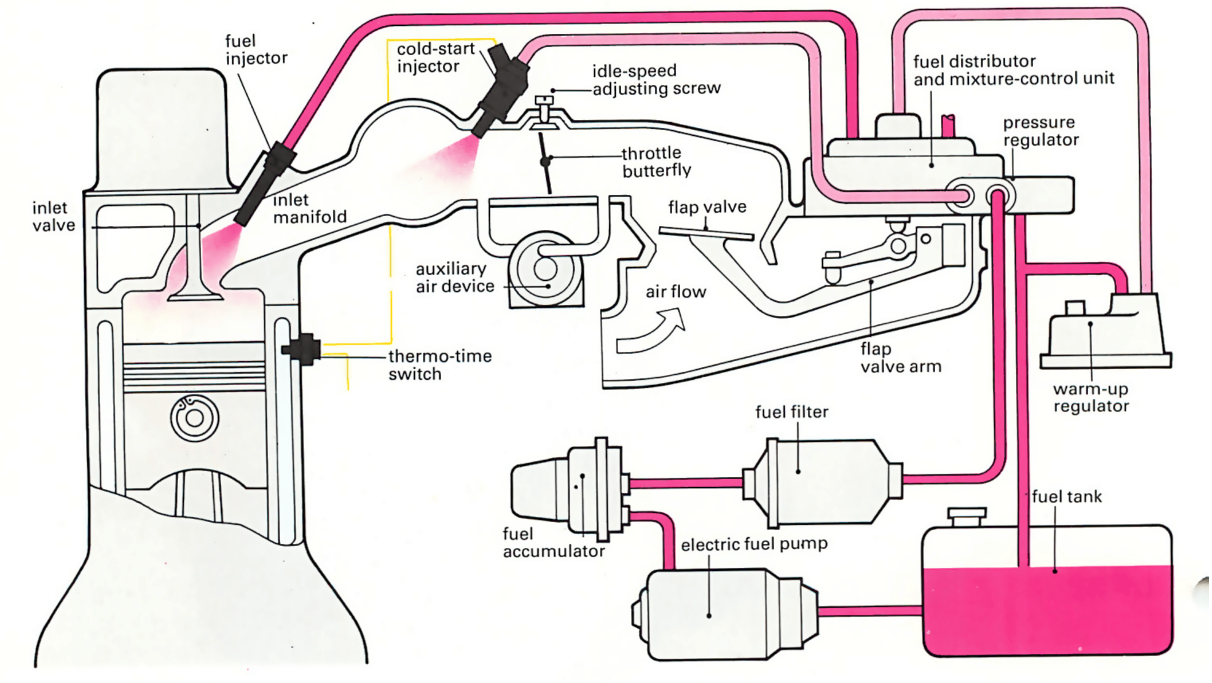

Figure 18 Lucas Mechanical Fuel Injection Diagram of Diesel Engine. [14]

Initially, the fuel pump retrieves fuel from the fuel tank and directs it through a fuel filter designed to eliminate debris. This filtering process serves to prevent clogging in the fuel injector, fuel lines, and carburetor. Once the fuel undergoes filtration, it is transported through the fuel lines to reach the fuel injector. These lines are constructed from durable materials like plastic or metal and are strategically placed beneath the car floor in areas less susceptible to damage from factors such as engine exhaust, weather conditions, road elements, or other components. The operation of the fuel injector varies based on the engine's design. In diesel engines, the fuel injector directly introduces fuel into the combustion chamber. In contrast, for spark-ignition (SI) engines, the injector initially delivers fuel to the carburetor, where it forms an air-fuel mixture before being sent to the combustion chamber. To regulate the fuel injector's pressure, a pressure regulator is employed. Upon entering the carburetor, the fuel is mixed with air drawn from the environment. This mixture is carefully adjusted to meet the engine's requirements before being delivered to the combustion chamber. Within the combustion chamber, the compressed air-fuel mixture undergoes ignition, resulting in the generation of mechanical power.

9.1 TYPES OF FUEL SYSTEM

The fuel system has the following major types:

1. Single-Point

2. Multi-Point System
3. SPFI system
4. Direct Injection system

9.1.1 SINGLE-POINT INJECTION SYSTEM

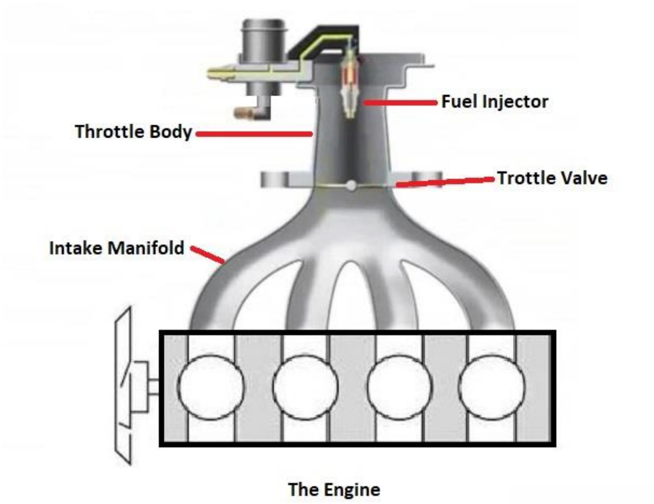

Figure 19 An example of Single Point Injection (SPI). [15]

The single-point injection system, also known as the throttle body injection system, stands out as a prominent type within fuel injection systems. In this configuration, the traditional carburetor is replaced by one or two fuel injectors housed in a throttle body. The throttle body serves as the starting point for the car's engine ventilation system, like its role as the initial point for the intake manifold. Before the introduction of the multi-point injection system, throttle body injection systems served as a viable alternative to basic carburetors.

While not as precise as multi-point injection systems, they exhibit superior efficiency compared to carburetors. Furthermore, the single-point fuel injection system boasts low maintenance and repair requirements, featuring a simpler design than its multi-point counterpart. The associated maintenance and repair costs are notably economical. However, it is essential to acknowledge that the main drawback of this system lies in its lower efficiency and precision when compared to the multi-point unit.

Before the introduction of the multi-point injection system, throttle body injection systems served as a viable alternative to basic carburetors. While these systems may not match the precision of multi-point injection, they exhibit commendable efficiency when compared to traditional carburetors.

Furthermore, the single-point fuel injection system stands out for its minimal maintenance and repair requirements. Its uncomplicated design contrasts with the more intricate multi-point injection system, resulting in lower associated maintenance and repair costs. However, it is crucial to note that the primary drawback of the single-point system lies in its comparative inefficiency and lack of precision when measured against the multi-point unit.

Table 2 The advantages and disadvantages table of single-point injection system.

Advantages	Disadvantages
It has an easy design.	It is less precise than a multi-point unit
It requires low maintenance and service.	It is less efficient than a multi-point injection system.
This system delivers more excellent efficiency than the carburetor system.	

9.1.2 MULTI POINT INJECTION SYSTEM

The multi-point fuel injection system stands out as one of the most widely utilized injection systems, featuring a distinct injector nozzle dedicated to each cylinder. Positioned externally along the air intake, this configuration is commonly referred to as a port injection system.

By siting the injectors on the exterior of each air intake, this design aims to bring the fuel vapor in close proximity to the air intake, ensuring its thorough incorporation into the cylinder. This proximity enhances the efficiency of the combustion process, contributing to improved overall engine performance. [16]

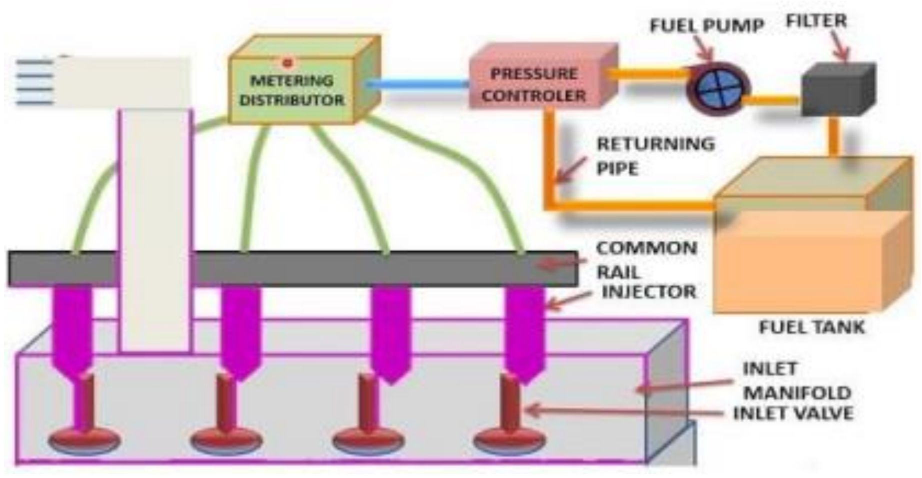

Figure 20 An example diagram of Multi-Point Fuel Injection System.

Table 3 The advantages and disadvantages table of multi-point fuel injection system.

Advantages	Disadvantages
It controls fuel more efficiently than single-point fuel injection or carburetor.	It has a complex design
It reduces the chances of fuel shortening in the intake method.	It has more maintenance and repair costs than the single-point fuel injection system.
It is more precise and efficient than a single-point injection system.	It requires more maintenance.

9.1.3 SEQUENTIAL PORT FUEL INJECTION SYSTEM (SPFI)

The SPFI system, also known as a timed or sequential fuel injection system, differs notably from a multi-point injection system. In a multi-point fuel injection system, all injectors release fuel simultaneously, even during engine idling. This simultaneous injection results in fuel lingering in an orifice for over 148 milliseconds, which, though seemingly brief, can adversely affect efficiency.

In contrast, the SPFI system employs a sequential approach where injection nozzles release fuel individually, corresponding to the requirements of each cylinder. These nozzles inject fuel just prior to the opening of the inlet valve, ensuring a shorter residence time for the fuel. Consequently, this system enhances efficiency and lowers emissions rates. A key advantage of the sequential injection system lies in its precision, surpassing that of a multi-point injection system, ultimately leading to increased engine efficiency.

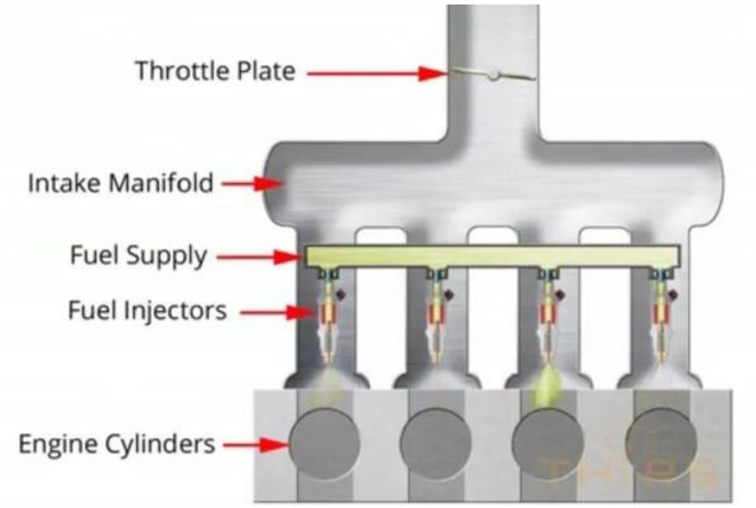

Figure 21 An example of Sequential Fuel Injection. [17]

9.1.4 DIRECT INJECTION SYSTEM

This represents a straightforward yet groundbreaking injection system, known for injecting fuel directly into the combustion chamber after the valves have opened. While direct fuel injection systems have traditionally been prevalent in diesel engines, their popularity has surged in petrol engines of late.

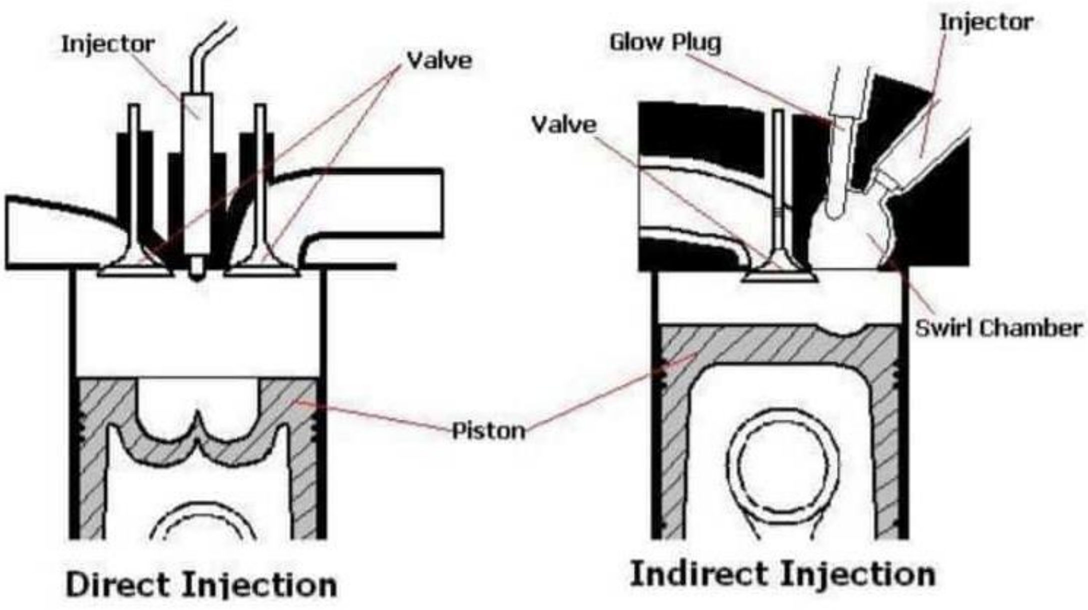

Figure 22 Direct Injection and Indirect Injection System. [18]

9.2 COMPONENTS OF FUEL SYSTEM

The fuel system has the following major parts:

1. Fuel Tank
2. Fuel Pump
3. Fuel Injector
4. Carburetor
5. Fuel Filter
6. Fuel Lines
7. Fuel Gauge
8. Fuel Gauge Sending Unit
9. Emission Vapor Controls
10. Fuel Pressure Regulator

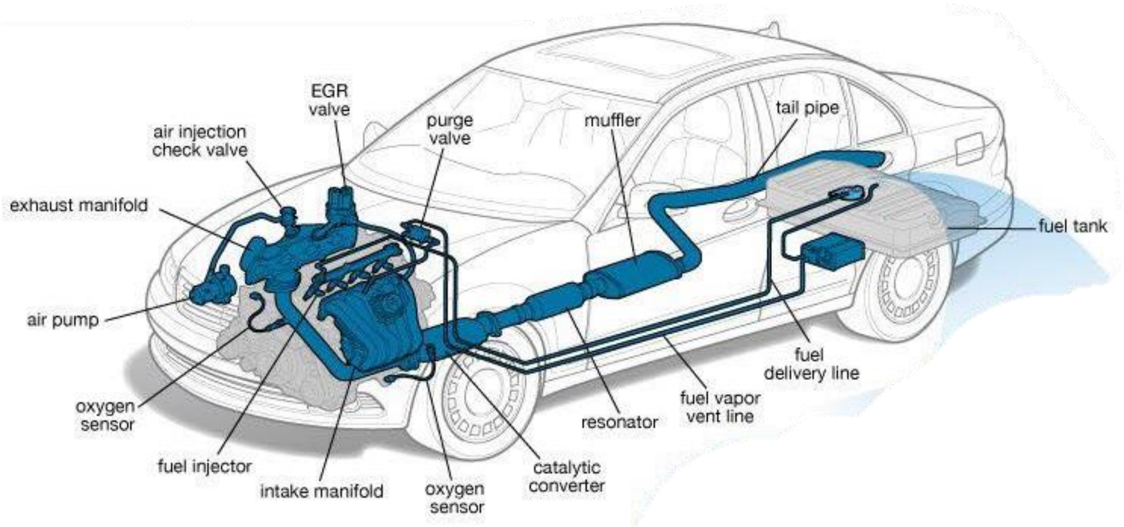

Figure 23 Fuel System Parts in a Car. [19]

1. **Fuel Tank**

A fuel tank serves as the storage unit for fuels like gas, diesel, or petrol. It is a crucial component, and any obstruction or leakage in the fuel tank can impede the proper supply of fuel to the engine's combustion chamber. The effective functioning of the fuel tank significantly impacts the overall performance of the vehicle. To facilitate the delivery of fuel from the fuel tank to either the carburetor or combustion chamber, a fuel pump is employed.

2. **Fuel Pump**

A fuel pump plays a vital role in transferring fuel from the fuel tank to the fuel injector through dedicated fuel lines. In petrol engines, the fuel injector delivers fuel to the carburetor, whereas in diesel engines, the fuel injector directly injects fuel into the combustion chamber. Fuel pumps are broadly categorized into two main types:

- **Mechanical Fuel Pump:** This type is engine-driven, with a chain or belt serving as the linkage between the engine and the fuel pump. The mechanical fuel pump operates in conjunction with the engine's motion.
- **Electric Fuel Pump:** Controlled by an electric fuel injection system, the electric fuel pump is recognized for its enhanced reliability compared to its mechanical counterpart. It exhibits minimal reliability issues and is generally more dependable in various operational conditions.

3. **Fuel Injector**

A fuel injector is utilized to introduce fuel into the combustion chamber of each throttle body or cylinder. Essentially, it functions as a nozzle with a valve that generates a spray of fuel and air droplets. The activation of the fuel injector is orchestrated by a fuel pump, drawing fuel from its source. The injection process of the fuel injector is contingent on the engine's characteristics.

In the context of a diesel engine, the fuel injector directly injects fuel into the combustion chamber. Conversely, for a petrol engine, the fuel injector initiates the injection process by delivering fuel to the carburetor. In this scenario, the carburetor mixes the fuel with air, forming an air-fuel mixture, which is then transferred to the combustion chamber.

4. **Carburetor**

The carburetor is predominantly employed in petrol engines, serving a primary function in the fuel system by creating an air-fuel mixture. When the fuel injector introduces fuel into the carburetor, the carburetor simultaneously draws in air from the surrounding environment. This incoming air is then blended with the injected fuel, producing a well-mixed fuel-air combination. Following this thorough mixing process, the carburetor directs the fuel-air mixture into the engine's combustion chamber, where it undergoes the combustion process.

5. **Fuel Filter**

The fuel filter is a crucial component in ensuring the effective functioning of the fuel supply system. Given the precision required by fuel injectors, they are highly susceptible to damage from debris. In vehicles equipped with fuel injection systems, electric fuel pumps are commonly employed. Positioned between the fuel pump and fuel tank, the fuel filter serves as a protective barrier.

As fuel is drawn from the tank, it undergoes an initial filtration process within the fuel filter. This stage is vital for removing solid contaminants from the fuel before it reaches the fuel pump. The filtered fuel is then delivered to the fuel pump, safeguarding it from potential damage caused by debris and contributing to the overall reliability of the fuel supply system.

6. **Fuel Lines**

These lines serve as the crucial connectors within the entirety of the fuel system, facilitating the transport of fuel from the tank to the engine. The fuel system employs a combination of flexible hoses and steel lines for this purpose. It is important to note that when undertaking repairs or replacements on steel fuel lines, it is advisable to refrain from using copper or aluminum materials. Opting for steel ensures compatibility and durability.

Similarly, when replacing the flexible rubber hose within the fuel system, it is essential to use the appropriate type of hose. During the replacement process, extra caution should be taken to meticulously disconnect all hoses from the exhaust system. This careful approach helps maintain the integrity of the fuel system and ensures a seamless and effective operation.

7. Fuel Gauge

The dashboard of your car features a fuel gauge connected to the fuel tank, providing the driver with a real-time indication of the fuel quantity. In conventional vehicles, these fuel gauges were unable to precisely display the exact amount of fuel in the tank. If you happen to be driving a classic car for the first time, it's important to familiarize yourself with the system's level of accuracy.

This component of the fuel system serves a crucial role in alleviating the inconvenience of unexpectedly running out of gas, sparing drivers from the hassle of rushing to a gas station. The fuel gauge is a valuable tool that enhances the overall driving experience by offering clear insights into the fuel levels, allowing for better planning and management of refueling needs.

8. Fuel Gauge Sending Unit

When it comes to the fuel system, one of the primary concerns often lies with the sending unit, which, at best, can be considered a flawed design. The precision of this unit is most reliable when the fuel level falls between 1/4 and 3/4 of the tank's capacity. As the tank approaches its limits, whether full or empty, the accuracy of the fuel level display tends to diminish, presenting a notable drawback in the functionality of the sending unit.

9. Emission Vapor Control

These controls are utilized in conjunction with fuel return lines to prevent the discharge of petrol vapors into the surrounding air. Failure to address this issue can lead to several undesirable consequences: A strong gasoline odor permeating the interior of the car, The potential ignition of gasoline fumes, resulting in a hazardous situation and adverse effects on the environment due to the release of harmful substances.

10. Fuel Pressure Regulator

This component within the fuel delivery system ensures the maintenance of an optimal pressure level. Primarily employed in fuel-injected vehicles, this unit is crucial because fuel injectors generate higher pressure compared to carburetors. Its role is to guarantee that the system maintains the necessary pressure for efficient fuel injection.

9.3 ADVANTAGES AND DISADVANTAGES OF FUEL INJECTION SYSTEM

Table 4 The advantages and disadvantages table of fuel injection system.

Advantages	Disadvantages
It offers better fuel efficiency.	It has high repairing and maintenance costs.
It prevents the engine from damage.	The parts of this system have a high cost.
The fuel injection system increases the engine service life.	A fuel injection system has many parts, including a fuel tank, fuel pump, fuel lines, and fuel injector. Therefore, this system increases the weight of the vehicle.
It increases the engine and vehicle performance.	
It increases engine efficiency.	

9.4 FUEL SYSTEM OF DIESEL ENGINE

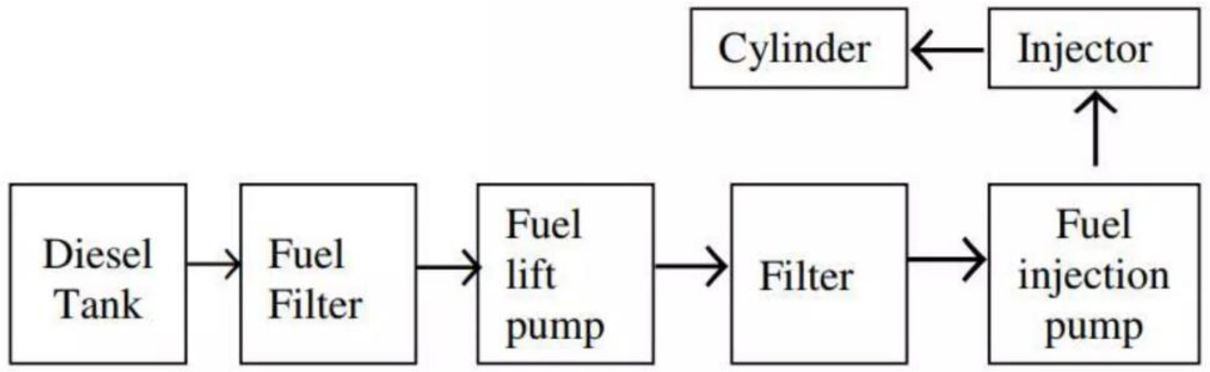

Figure 24 Diagram of Fuel in Diesel Engine. [20]

During the operation of the engine, fuel flows naturally from the fuel tank to the primary filter, where coarse impurities are filtered out with the assistance of gravity. Subsequently, the fuel is then drawn by a fuel transfer pump and directed towards the fuel injection pump through a secondary fuel filter. The fuel injection pump, operating under high pressure, then supplies the injectors via high-pressure pipes. These injectors play a critical role in atomizing the fuel and delivering it into the combustion chamber of the engine.

It's worth noting that the fuel injection pump receives an ample supply of fuel. Any excess fuel is efficiently diverted to the intake side of the fuel transfer pump through a relief valve, ensuring a smooth and regulated flow within the fuel system.

Figure 25 Sections on Fuel Filter used in Diesel Engine.

Efficient operation of the fuel system hinges on two critical conditions: firstly, the fuel oil must maintain cleanliness, devoid of water, suspended dirt, sand, or any foreign contaminants. Secondly, the fuel injection pump must generate the appropriate pressure to ensure the diesel fuel undergoes optimal atomization by the injectors. This atomization should occur at the right time and in the correct quantity within the engine cylinder. It is also imperative to filter the fuel before introducing it into the tank. By adhering to these precautions, around ninety percent of potential diesel engine issues can be preemptively eliminated. [21]

9.4.1 THE COMPONENTS OF DIESEL FUEL SYSTEMS

A fundamental diesel fuel system comprises five essential components: the tank, fuel transfer pump, filters, injection pump, and injection nozzles. Typically constructed from aluminum alloys or sheet metal, diesel fuel tanks are engineered to withstand the corrosive nature of diesel fuel over an extended period.

The fuel transfer pump plays a pivotal role in drawing diesel fuel from the tank and transporting it to the injection pump. Positioned externally or at the rear of the injection pump, transfer pumps can also be occasionally situated within the tank itself.

Given that diesel, like gasoline, inevitably contains contaminants that can compromise the combustion system, filters are strategically placed between the transfer pump and injection system. These filters effectively remove dirt and other impurities, safeguarding the fuel injection system from potential damage.

The injection pump assumes the task of compressing the fuel in preparation for injection, while injection nozzles spray diesel into the combustion chamber of the cylinders. Within this chamber, the car transforms the ensuing miniature combustions (explosions) into mechanical energy, propelling the vehicle forward.

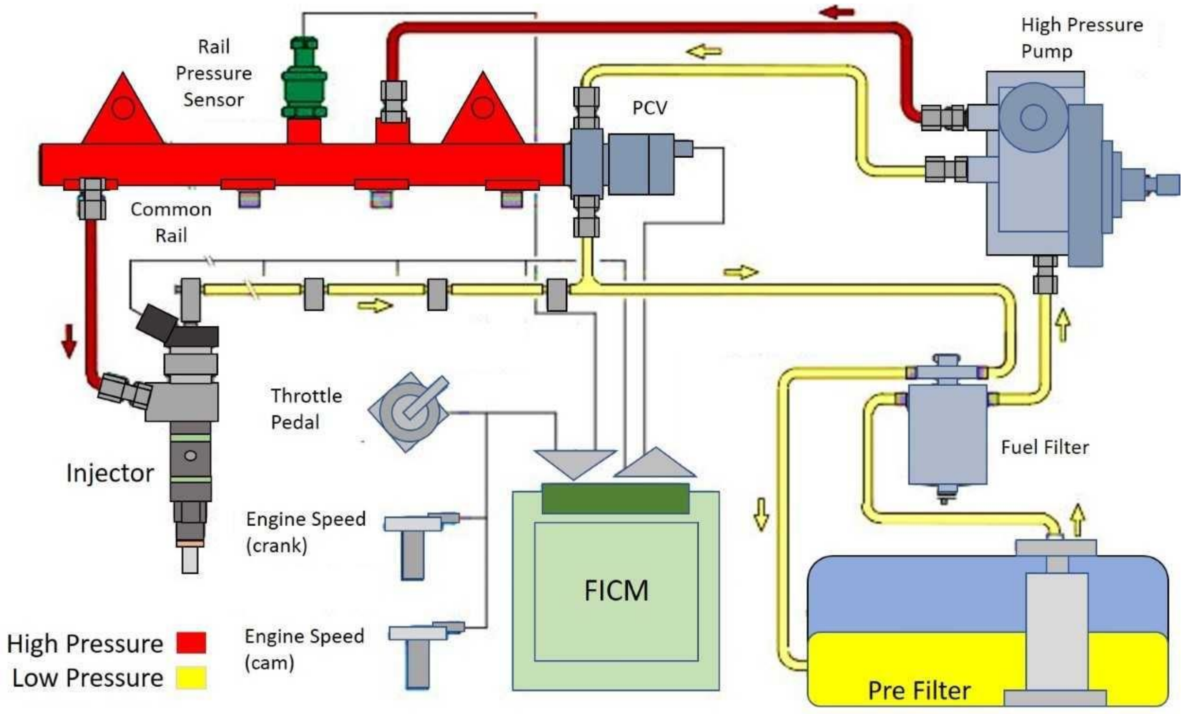

Figure 26 An example diagram of Diesel Fuel Systems. [22]

10. WHO USE 3-CYLINDER ENGINES?

3-cylinder engines are a popular choice for a variety of vehicles due to their compact size, fuel efficiency, and lively performance. They are commonly used in small cars, city cars, motorcycles, ATVs, and UTVs.

10.1 SMALL CARS

3-cylinder engines have become a popular choice for small cars due to their compact size, fuel efficiency, and lively performance. These engines offer a compelling alternative to traditional 4-cylinder powertrains, particularly for city dwellers who prioritize maneuverability and eco-friendliness.

One of the key advantages of 3-cylinder engines in small cars is their compact size. This allows for a more spacious interior and a more flexible engine layout, enabling designers to create stylish and practical vehicles. The reduced weight of the engine also contributes to improved handling and fuel economy.

Figure 27 Ford Fiesta ST-Line.

Fuel efficiency is another major benefit of 3-cylinder engines in small cars. With fewer cylinders to power, these engines consume less fuel, reducing emissions and lowering overall operating costs. Advanced technologies such as direct injection and turbocharging further enhance fuel efficiency, making 3-cylinder engines even more appealing to eco-conscious drivers.

Despite their smaller size, 3-cylinder engines deliver surprisingly lively performance. Modern engine technology, including sophisticated valve timing and boost control systems, enables these engines to produce adequate power for city driving and even spirited highway cruising.

Examples of small cars that utilize 3-cylinder engines include the Ford Fiesta, Toyota Yaris, and Chevrolet Spark. These vehicles demonstrate the versatility and effectiveness of cylinder powertrain in the compact car segment. [23]

Figure 28 Hyundai i20 Ultimate.

10.2 CITY CARS

3-cylinder engines are particularly well-suited for city cars, where ease of maneuverability and fuel efficiency are paramount. The compact size and responsive nature of 3-cylinder engines make them ideal for navigating tight city streets and parking spaces.

City cars often face challenges in urban environments, such as frequent stop-and-go traffic and limited parking options. 3-cylinder engines excel in these conditions, providing ample power for quick acceleration and smooth low-speed maneuvering. Their fuel efficiency also shines in city driving, reducing fuel consumption, and minimizing emissions.

The Smart ForTwo, Fiat 500, and Honda Fit are prime examples of city cars that benefit from 3-cylinder engines. These vehicles demonstrate the ability of 3-cylinder powertrains to enhance practicality and environmental friendliness in urban settings.

Figure 29 2008 Smart Fortwo Passion convertible (US). [24]

10.3 MOTORCYCLES

3-cylinder engines have also found a niche in the motorcycle industry, particularly in sport bikes and touring bikes. These engines offer a balance of power, smoothness, and fuel efficiency, making them suitable for a variety of riding styles.

In sport bikes, 3-cylinder engines provide a thrilling blend of power and agility. Their high-revving nature and responsive power delivery enable riders to experience exhilarating acceleration and precise handling. The compact size and lightweight construction of 3-cylinder engines also contribute to the sporty character of these bikes.

Touring bikes, on the other hand, demand a more refined and comfortable riding experience. 3-cylinder engines excel in this regard, delivering smooth, vibration-free power delivery that reduces fatigue on long-distance rides. Their fuel efficiency also extends the range of touring bikes, making them ideal for extended journeys.

Examples of motorcycles that utilize 3-cylinder engines include the Triumph Daytona 675, Triumph Speed Triple 1050, and Yamaha MT-09. These bikes demonstrate the versatility of 3-cylinder powertrains in both sport and touring applications.

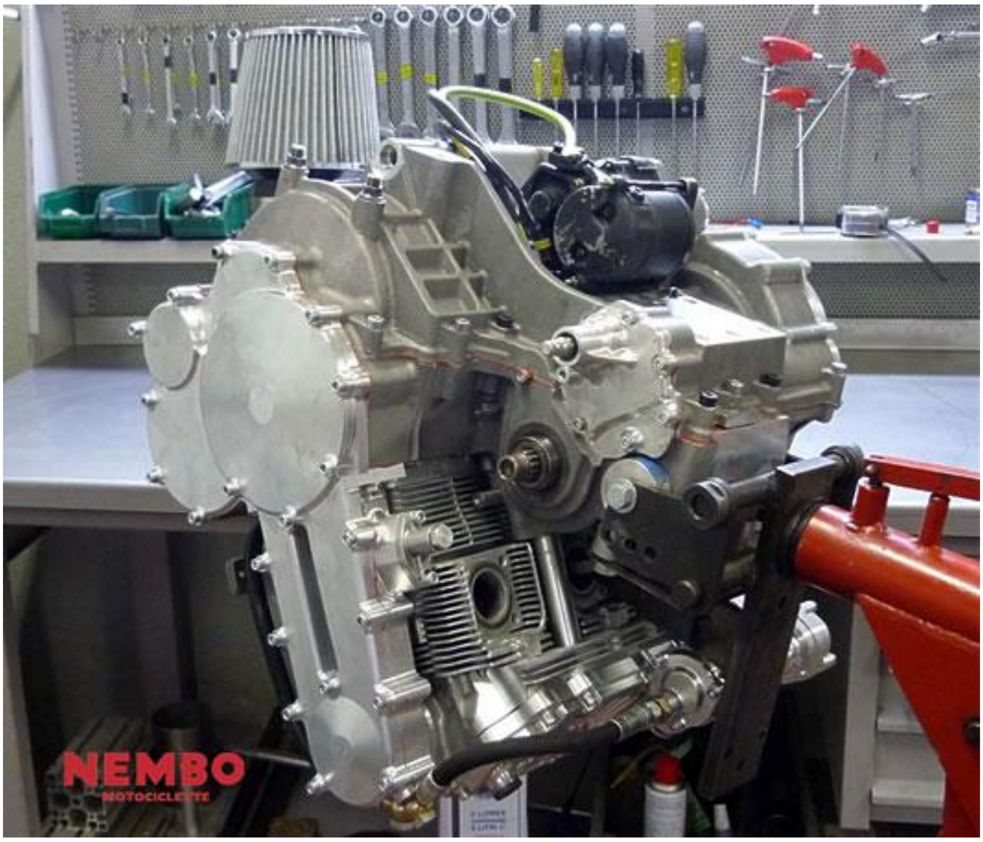

Figure 30 Nembo Motorcycle inverted 3-cylinder motorcycle engine. [25]

10.4 ATVS AND UTVS

3-cylinder engines have also gained popularity in all-terrain vehicles (ATVs) and utility terrain vehicles (UTVs). These engines provide the power and torque needed for off-road adventures while maintaining fuel efficiency and maneuverability.

ATVs and UTVs often operate in challenging environments, requiring robust and reliable powertrains. 3-cylinder engines are well-suited for these conditions, offering a combination of durability and performance. Their smooth power delivery and ample torque make them ideal for navigating rough terrain, climbing hills, and hauling loads.

The Polaris Sportsman XP 1000, Can-Am Outlander 650, and Yamaha Wolverine RMAX 1000 are examples of ATVs and UTVs that utilize 3-cylinder engines. These vehicles demonstrate the versatility and effectiveness of 3-cylinder powertrains in off-road applications.

In conclusion, 3-cylinder engines have become an asset in a wide range of vehicles, from small cars and city cars to motorcycles and ATVs/UTVs. Their compact size, fuel efficiency, and lively performance make them a compelling choice for drivers seeking a balance of practicality, eco-friendliness, and driving enjoyment.

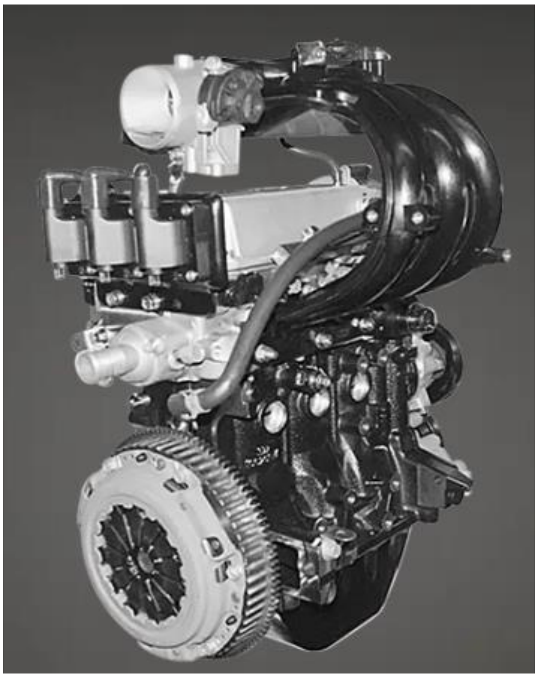

Figure 31 Chery 3-cyclinder 800cc UTV-ATV Engine.

• TECHNICAL PARAMETER

Displacement (L)	0.812
Bore x Stroke (mm)	72 x 66.5
Compression Ratio	9.5:1
Max. Net Power /Speed (kW/rpm)	38/6000
Max. Net Torque /Speed (Nm/rpm)	68/3500 – 4500
Specific Power (kW/L)	46.8
Dimension (mm)	495 x 470 x 699
Weight (kg)	76
Emission	EPA / EU

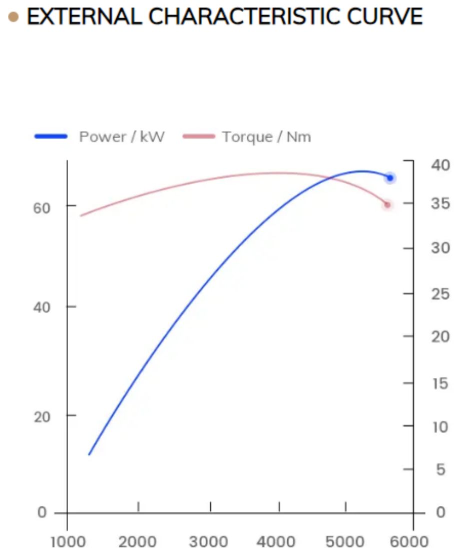

Figure 32 Parameters of the Chery 3-cyclinder 800cc UTV-ATV Engine. [26]

11. WHY COMPANIES START TO PREFER 3-CYLINDER ENGINE INSTEAD OF 4-CYLINDER ENGINE

The decision by automotive companies to favor 3-cylinder engines over 4-cylinder engines is driven by a complex interplay of factors that align with evolving industry dynamics, environmental considerations, and shifting consumer preferences.

11.1 FUEL EFFICIENCY

One of the primary drivers behind the preference for 3-cylinder engines is their inherent fuel efficiency. The smaller size and reduced internal friction contribute to improved fuel economy, a crucial aspect as the industry navigates towards greener and more sustainable practices. Additionally, the lower displacement and reduced weight often result in lower emissions, aligning with stringent global emissions standards.

11.2 WEIGHT REDUCTION AND HANDLING

The inherent lightweight nature of 3-cylinder engines contributes to an overall reduction in vehicle weight. This not only enhances fuel efficiency but also positively impacts vehicle handling, providing a more agile and responsive driving experience. Weight reduction is particularly crucial as companies explore ways to improve energy efficiency and meet environmental targets.

Figure 33 Volvo's new 3-cyclinder motor produces up to 180 hp. Turbocharging is a key part of Volvo's plans for the engine. [27]

11.3 COMPACT DESIGN AND VERSATILITY

The compact size of 3-cylinder engines allows for more versatile vehicle designs, making them well-suited for smaller cars and urban vehicles. This adaptability is essential as urbanization trends and the demand for compact city cars continue to rise. The versatility of these engines extends beyond traditional cars to motorcycles and off-road vehicles, showcasing their applicability across diverse vehicle categories.

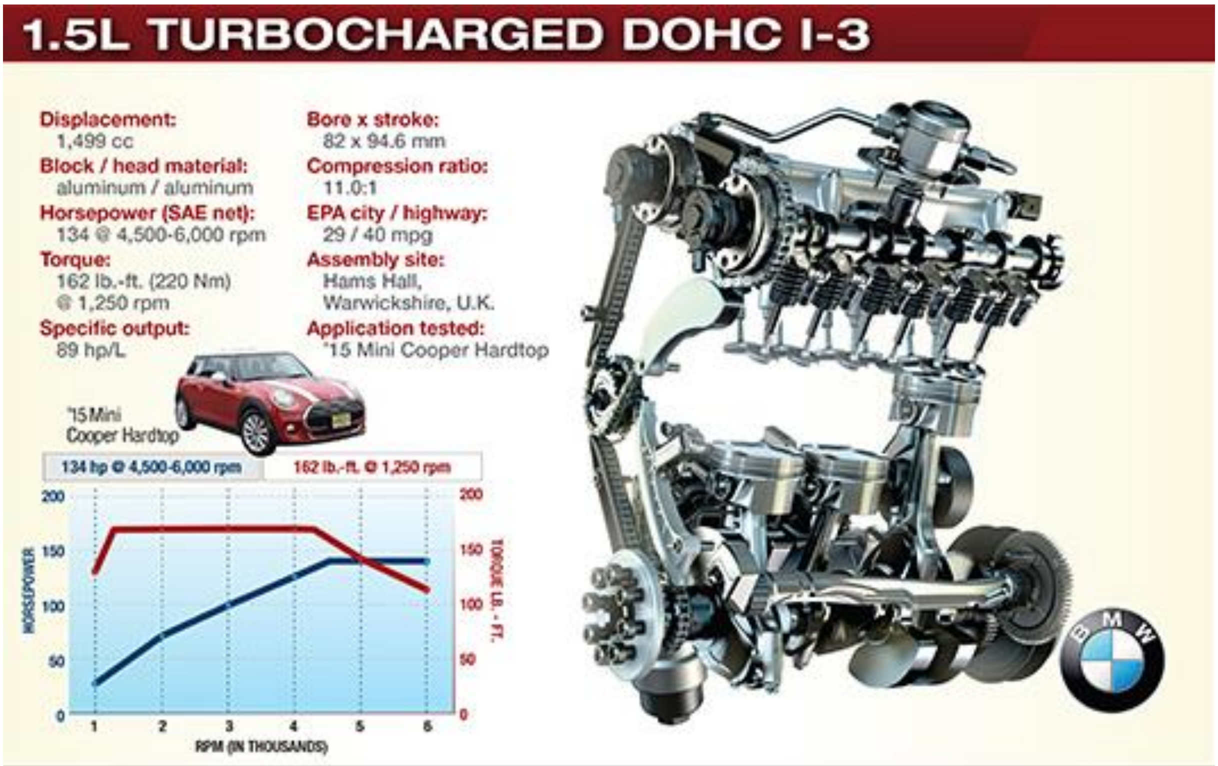

Figure 34 Mighty Mini 3-cylinder Features BMW's Latest Technology, 2015. [28]

11.4 COST SAVINGS AND AFFORDABILITY

The production of 3-cylinder engines is often less complex and less expensive than that of 4-cylinder engines. This cost-effectiveness enables automakers to offer more affordable vehicles, appealing to a broader consumer base. Affordability is a critical factor in attracting consumers, especially in markets where price sensitivity is high.

11.5 URBAN MOBILITY FOCUS AND CONSUMER TRENDS

With an increasing focus on urban mobility solutions, 3-cylinder engines are well-suited for smaller, fuel-efficient cars ideal for urban commuting. Consumer preferences are shifting towards compact, environmentally friendly vehicles, and 3-cylinder engines align with this trend, providing an optimal balance between size, efficiency, and performance.

11.6 TECHNOLOGICAL ADVANCEMENTS AND PERFORMANCE OPTIMIZATION

Advances in engine technology, particularly the integration of turbocharging, have significantly enhanced the performance of 3-cylinder engines. Turbocharged variants can deliver power levels comparable to some 4-cylinder engines while maintaining efficiency. This technological evolution has played a crucial role in making 3-cylinder engines more competitive in terms of performance.

Figure 35 3-Cylinder, Direct Injection and Turbocharged Diesel Engine (D703TE0.F3S).

Table 5 Characteristics of the D703TE0.F3S Diesel Engine Motor. It is 4-stroke diesel engine with direct injection, mechanical pump and turbocharger. [29]

Type	diesel
Number of cylinders	3-cylinder
Technology	turbocharged, direct injection, mechanically carbureted
Product applications	for fire fighting pumps
Cooling system	water cooling
Other characteristics	4-stroke, compact, low-noise
Power	53 kW (72.06 hp)
Torque	237 Nm (174.8022 ft.lb)
Rotational speed	1,600 rpm (10,053.1 rad.min-1)
Displacement	2.1 l (0.555 gal)
Weight	215 kg (473.99 lb)
Length	792 mm (31.2 in)
Width	586 mm (23.1 in)
Height	796 mm (31.3 in)

11.7 ADAPTATION TO MARKET TRENDS

Automotive companies are proactively adapting to market trends that prioritize innovation, sustainability, and technological advancements. The versatility of 3-cylinder engines allows manufacturers to align their offerings with current market demands, catering to a diverse range of consumer needs and driving conditions.

11.8 VARIETY OF APPLICATIONS AND INDUSTRY DYNAMICS

The adaptability of 3-cylinder engines across a variety of vehicles, from compact cars to motorcycles and off-road vehicles, makes them a versatile choice. Automotive companies, recognizing the diverse needs of consumers and the changing landscape of transportation, are leveraging 3-cylinder engines to create a broad spectrum of vehicles that cater to different market segments and industry dynamics.

12. 3-CYLINDER ADVANTAGES & DISADVANTAGES

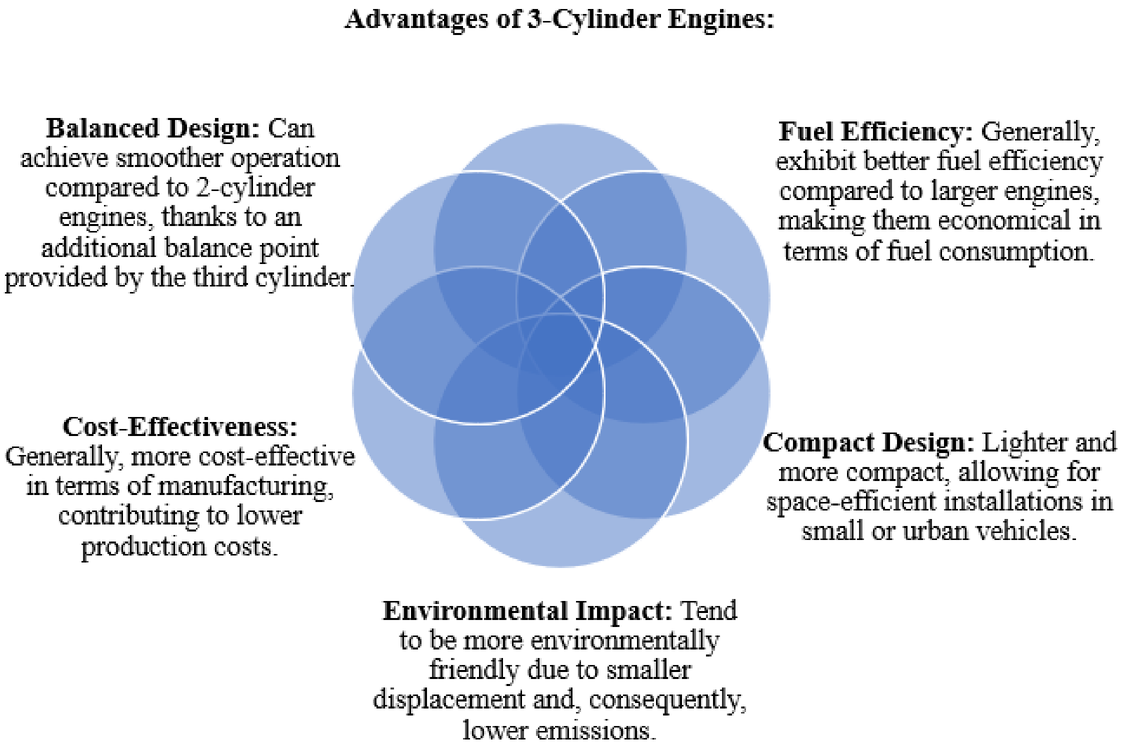

Figure 36 The Advantages diagram of 3-Cylinder Engines.

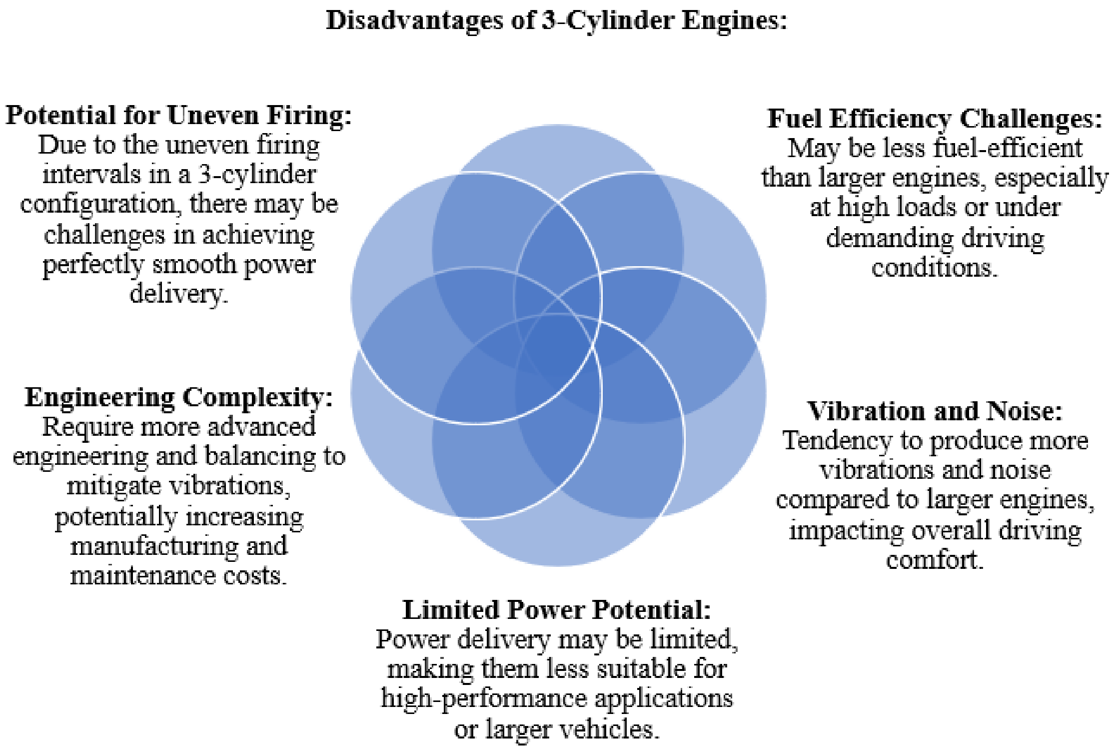

Figure 37 The Disadvantages of 3-Cylinder Engines.

13. MULTIVALVE DESIGN

The multi-valve engine design incorporates three, four, or five valves per cylinder, aiming to enhance performance in internal combustion engines. In a four-stroke engine, each cylinder requires a minimum of two valves: one for air (and often fuel) intake and another for the exhaust of combustion gases. By increasing the number of valves, the engine improves the flow of intake and exhaust gases, leading to enhanced combustion, volumetric efficiency, and power output.

The advantages of multi-valve engines include optimal spark plug placement for ideal flame propagation, smaller valves with lower reciprocating mass reducing wear on cam lobes, and the ability to operate at higher RPM without valve bounce. Some engines open each intake valve at slightly different times, increasing turbulence and improving air-fuel mixing at low engine speeds. Additionally, more valves provide extra cooling to the cylinder head.

However, there are drawbacks to multi-valve engines, such as increased manufacturing costs and a potential rise in oil consumption due to more valve stem seals. Some engines, like certain single overhead cam (SOHC) multi-valve engines, use a single fork-shaped rocker arm to drive two valves, reducing the number of cam lobes and manufacturing costs.

Different configurations of multi-valve cylinder heads include:

13.1 THREE-VALVE CYLINDER HEAD

Features one large exhaust valve and two smaller intake valves, offering better breathing than a two-valve head. Common in the late 1980s and early 1990s, it's still used in some Ford vehicles.

Figure 38 Three-Valve (2 intake and 1 exhaust valve). [30]

13.2 FOUR-VALVE CYLINDER HEAD

The most common type with two exhaust valves and two similar or slightly larger inlet valves, providing good breathing suitable for high-power outputs.

Figure 39 Four-Valve (2 intake and 2 exhaust). [31]

13.3 FIVE-VALVE CYLINDER HEAD

Less common, with two exhaust valves and three inlet valves of similar size, allowing excellent breathing and theoretically high RPM and power outputs. However, its cost-effectiveness compared to four-valve designs has been questioned.

Beyond five valves, increasing their number decreases the total valve area as a proportion of the cylinder bore, potentially impacting engine performance. The effective areas as percentages of cylinder bore for different valve quantities are provided in the table.

- 2 = 50%
- 3 = 64%
- 4 = 68%
- 5 = 68%
- 6 = 66%
- 7 = 64%
- 8 = 61%

It's important to note that these considerations are based on general principles, and practical design choices may vary based on specific engineering requirements and advancements, such as the impact of direct injection on cylinder head design. Examples of engines with different valve configurations, including five-valve designs, are cited from manufacturers like AUDI AG, Ferrari, and Toyota in collaboration with Yamaha.

Figure 40 Five-Valve (3 intake and 2 exhaust). [32]

14. EXAMPLES OF 3-CYLINDER ENGINE

14.1 FORD FIESTA ECO BOOST

The Ford Fiesta EcoBoost is a line of turbocharged three-cylinder engines known for their impressive fuel efficiency, power, and compact size. It has been a popular choice for drivers looking for a fun-to-drive and economical car and has been awarded "International Engine of the Year" multiple times. The Ford EcoBoost technology uses a combination of turbocharging and direct injection to optimize power and fuel efficiency. The Fiesta EcoBoost 1.0L engine was developed in partnership with Ford's European engineering team. The EcoBoost technology has been applied to various Ford engines, including the 1.5L, 2.0L, and 2.3L EcoBoost engines.

Figure 41 Ford Fiesta EcoBOOST 1.0L. [33]

Table 6 Specifications of Ford Fiesta EcoBoost 1.0L engine.

FORD FIESTA ECO BOOST 1.0L	
TYPE OF ICE	4-Stroke Cycle, Spark Ignition
CYLINDER BLOCK MATERIAL	Aluminum Alloy
CYLINDER HEAD MATERIAL	Aluminum Alloy
FUEL TYPE	Gasoline
FUEL SYSTEM	Direct Injection
CONFIGURATION	Inline 3-cylinder
STROKE BORE RATIO	0.97
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	999
COMPRESSION RATIO	10.0.1
POWER, HP-kW	123hp
TORQUE, lb-ft	148 lb-ft(200 Nm)@1,400-4,500 rpm
FIRING ORDER	1-3-2
BORE, mm	72.2
STROKE, mm	72
VALVETRAIN LAYOUT	SOHC

14.2 RENAULT TWINGO SCE

The Renault Twingo SCe 75 is a five-door, rear-engine hatchback known for its playful character, compact size, and fuel efficiency. The Renault Twingo SCe 75 is currently available in some European markets. However, its availability may vary depending on your location.

Figure 42 Renault Twingo 1.0 SCe.

Table 7 Specifications of Renault Twingo SCE 75. [34]

RENAULT TWINGO SCE 75	
TYPE OF ICE	4-Stroke Cycle, Naturally Aspirated
CYLINDER BLOCK MATERIAL	Aluminum Alloy
CYLINDER HEAD MATERIAL	Aluminum Alloy
FUEL TYPE	Gasoline
FUEL SYSTEM	Multi-point Fuel Injection
CONFIGURATION	Inline 3-Cylinder
STROKE BORE RATIO	0.997
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	999
COMPRESSION RATIO	10.0:1
POWER, HP-kW	73 hp (54 kW) @5500 rpm
TORQUE, lb-ft	70 lb-ft (95 Nm) @2750 rpm
FIRING ORDER	1-2-3
BORE, mm	72.2 mm
STROKE, mm	72.0 mm
VALVETRAIN LAYOUT	SOHC

14.3 VOLKSWAGEN UP! 1.0 TSI

The Volkswagen Up! 1.0 TSI is a small city car that offers a unique blend of fuel efficiency, affordability, and fun-to-drive performance. However, it faces stiff competition in a crowded market segment. Despite its strengths, the Up! faces an uphill battle in a market dominated by established players like the Fiat 500, Ford Fiesta, and Hyundai i10. These rivals offer similar features and performance at comparable price points, making it difficult for the Up! to stand out. However, the Up! has a few key advantages that could help it win over buyers. Its fuel efficiency is unmatched in its class, and its playful handling makes it a joy to drive. Additionally, Volkswagen's reputation for quality and reliability could sway some buyers towards the Up! Ultimately, the success of the Up! will depend on its ability to effectively communicate its unique selling points to potential customers. By highlighting its strengths and addressing its weaknesses, Volkswagen may be able to carve out a niche for the Up! in the crowded small car market.

Figure 43 2018 Volkswagen Up! (Facelift 2016) GTI 1.0 TSI.

Table 8 Specifications of Volkswagen Up! 1.0TSI. [35]

VOLKSWAGEN UP! 1.0 TSI	
TYPE OF ICE	3-Cylinder, Turbocharged Petrol
CYLINDER BLOCK MATERIAL	Aluminum
CYLINDER HEAD MATERIAL	Aluminum
FUEL TYPE	Gasoline
FUEL SYSTEM	Multi-point fuel injection
CONFIGURATION	Inline 3
STROKE BORE RATIO	0.875
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	999 cc
COMPRESSION RATIO	10.5:1
POWER, HP-kW	95 HP (70kW)
TORQUE, lb-ft	115 lb-ft (156 Nm)
FIRING ORDER	1-3-2
BORE, mm	74.5mm
STROKE, mm	65.9mm
VALVETRAIN LAYOUT	DOHC

14.4 VOLKSWAGEN AUDI 1.4 TDI EA288

The 1.4 TDI EA288 is a 3-cylinder, turbocharged diesel engine that was introduced by the Volkswagen Group in 2014. It is a modular engine that is used in various Volkswagen, Audi, Škoda, and SEAT models. A common rail fuel injection system that delivers fuel at a high pressure of up to 2,000 bar. A turbocharger with variable geometry (VGT) that helps to improve fuel efficiency and emissions. A diesel particulate filter (DPF) that helps to reduce emissions of harmful pollutants. The 1.4 TDI EA288 is available in a variety of power outputs, ranging from 75 to 90 horsepower. It is known for its fuel efficiency, torque, and relatively low emissions.

Figure 44 Volkswagen Audi 1.4 TDI.

Table 9 Specifications of Audi 1.4 TDI. [36]

AUDI 1.4TDI EA288	
TYPE OF ICE	Four-stroke, turbocharged
CYLINDER BLOCK MATERIAL	Aluminum
CYLINDER HEAD MATERIAL	Aluminum
FUEL TYPE	Diesel
FUEL SYSTEM	Common Rail
CONFIGURATION	Inline
STROKE BORE RATIO	1,2
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	1422
COMPRESSION RATIO	16.1:1
POWER, HP-kW	75/3000-3750-50 kW 90/2750-3250-66 kW 104/3500-3750- 77 kW
TORQUE, lb-ft	155/1500-2000 170/1500-2500 184/1500-2500
FIRING ORDER	1-2-3
BORE, mm	79.5
STROKE, mm	95.5
VALVETRAIN LAYOUT	DOHC

14.5 HYUNDAI KIA 1.0 MPI/T-GDI ENGINE

The Hyundai 1.0L MPi engine, a member of the Kappa family, stands out as a three-cylinder gasoline engine featuring multi-point fuel injection, aligning with Hyundai-Kia's strategy for superior fuel efficiency. Initially introduced in 2011, it remains a popular choice for the Hyundai i10 and KIA Picanto.

Constructed with an aluminum cylinder block utilizing an open-deck design and cast-iron liner, the engine incorporates a cast iron crankshaft. Noteworthy is the optimization of counterweights to minimize vibrations in a three-cylinder engine, eliminating the need for a balance shaft. The crankshaft's offset of 11 mm against the cylinder line enhances performance. Friction reduction is achieved through the application of lightweight pistons with a compression height of 24.7 mm and short skirt length, featuring Physical Vapor Deposition (PVD)-coated piston rings and MoS2-coated piston skirts.

The 1.0L Kappa engine boasts an aluminum cylinder head with four valves per cylinder and dual overhead camshafts. The design includes pent-roof combustion chambers and tumble intake ports. Unique to its class, the valvetrain incorporates a Dual Continuously Variable Valve Timing (Dual-CVVT) system, reducing inertial mass and friction with mechanical lash adjusters (MLA tappets) and taper valve springs.

The G3LC introduces a split-cooling concept, incorporating separate cooling channels for the cylinder head and engine block, each with an individual thermostat. This design optimizes temperatures for efficient operation, enhancing fuel consumption and reducing CO2 emissions. Hyundai's approach caters to the demand for smaller engines with varied fuel efficiency requirements, offering both a straightforward version and a more advanced variant at an affordable price.

Figure 45 Hyundai KIA 1.0 MPi/T-GDI Engine (Kappa G3LA/G3LC). [37]

Table 10 Specifications of Hyundai KIA 1.0 MPI/T-GDI Engine

HYUNDAI KIA 1.0MPI/T-GDI	
TYPE OF ICE	Four-Stroke, naturally aspirated/turbocharged
CYLINDER BLOCK MATERIAL	Aluminum
CYLINDER HEAD MATERIAL	Aluminum
FUEL TYPE	Gasoline
FUEL SYSTEM	Multi-point fuel injection; Direct injection
CONFIGURATION	Inline
STROKE BORE RATIO	1,18
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	998 cc
COMPRESSION RATIO	10.5:1-Mpi 10.0:1-T-Gdi
POWER, HP-kW	66 hp (48 kW) /5,500- Mpi 68 hp (49 kW) /6,200- MPi LPG version 100 hp (74 kW) /4,500- T-Gdi
TORQUE, lb-ft	70 lb-ft (95 Nm) / 3,500 - Mpi 120 hp (88 kW) / 6,000 - T-GDi 66 ft-lb (90 Nm) / 3,500 - MPi LPG version 127 ft-lb (172 Nm) / 1,500-4,500 - T-Gdi
FIRING ORDER	1-3-2
BORE, mm	71.0 mm
STROKE, mm	84.0 mm
VALVETRAIN LAYOUT	DOHC

14.6 MERCEDES-BENZ OM639

The OM639 is a 1,493 cc in-line 3-cylinder diesel engine. and water cooled. The power is 68-95 hp. Power Index: 39 HP for 1 liter of volume. Developed the engine Mercedes Benz and Mitsubishi Motors. The OM639 engine was co-developed by Mercedes-Benz and Mitsubishi Motors. It was used in the Smart Forfour and Mitsubishi Colt models from 2004 to 2014. The OM639 was a reliable and fuel-efficient engine that was well-suited for small cars. It was replaced by the OM607 engine in 2018.

Figure 46 Engine Mercedes OM639.

Table 11 Specifications of Mercedes-Benz OM639. [38]

MERCEDES-BENZ OM639	
TYPE OF ICE	Four-Stroke, Turbocharged Diesel
CYLINDER BLOCK MATERIAL	Aluminum
CYLINDER HEAD MATERIAL	Aluminum
FUEL TYPE	Diesel
FUEL SYSTEM	Common rail direct injection
CONFIGURATION	Inline 3
STROKE BORE RATIO	1.11:1
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	1493
COMPRESSION RATIO	19,5:1
POWER, HP-kW	50 kW (68 hp)- 70 kW (95 hp)
TORQUE, lb-ft	118 lb-ft (160 Nm)- 155 lb-ft (210 Nm)
FIRING ORDER	1-3-2
BORE, mm	74.5 mm
STROKE, mm	83.0 mm
VALVETRAIN LAYOUT	SOHC

14.7 BMW 1 SERIES 114I

The BMW 1 Series 114i is the entry-level model in the 1 Series lineup. It boasts a unique position in the market due to its combination of features. The 3-cylinder engine delivers impressive fuel economy, making it a good choice for eco-conscious drivers. The 114i comes with a decent number of standard features, including automatic climate control, a sunroof, and a leather-wrapped steering wheel. The BMW 1 Series 114i is a niche vehicle that offers a unique blend of affordability, fuel efficiency, and driving dynamics. However, it is important to consider its limitations in terms of power, practicality, and futureproofing before making a purchase decision.

Figure 47 BMW 114i with 1.6L Turbo.

Table 12 Specifications of BMW 1 Series 114i. [39]

BMW 1 SERIES 114I	
TYPE OF ICE	Four-Stroke, Turbocharged Gasoline
CYLINDER BLOCK MATERIAL	Aluminum
CYLINDER HEAD MATERIAL	Aluminum
FUEL TYPE	Gasoline
FUEL SYSTEM	Direct Injection
CONFIGURATION	Inline 3
STROKE BORE RATIO	1.33:1
NUMBER OF CYLINDERS	3
VALVES PER CYLINDER	4
DISPLACEMENT, cc	1499
COMPRESSION RATIO	11.0:1
POWER, HP-kW	102 hp (75 kW) at 5000-6250 rpm
TORQUE, lb-ft	147 lb-ft (200 Nm) at 1400-4300 rpm
FIRING ORDER	1-3-2
BORE, mm	82.0 mm
STROKE, mm	107,8 mm
VALVETRAIN LAYOUT	DOHC

15. 3-CYLINDER DIESEL ENGINE DESIGNS MADE IN THE LAST 3 YEARS AT MARMARA UNIVERSITY

Figure 48 Volkswagen EA189 Engine.

The engine used as a reference in 3-cylinder diesel engine designs in the past years is Volkswagen EA189 engine. Designs such as block, injection system, cylinder head base and valve have been made for years based on the engine's bore and stroke values.

The EA189 is a TDI (Turbocharged Direct Injection) engine, a diesel engine type designed by Volkswagen. Known for its efficient energy conversion from fuel to motion, TDI engines utilize the Turbocharged Direct Injection system, where fuel is directly sprayed into the engine. Ranging from two to twelve cylinders, TDI engines are employed in various automobile segments, not only by Volkswagen but also by other brands within the group. It is crucial to use high-quality fuel for TDI engines to maintain optimal performance. These engines, equipped with a turbocharger system, exhibit durability and effectively optimize fuel consumption across a broad range of diesel vehicles.

Table 13 Volkswagen EA189 Engine parameters. [40]

Manufacturer	Volkswagen
Production years	2009-2015
Cylinder Block Material	Cast Iron
Cylinder Head Material	Aluminum
Fuel Type	Diesel
Fuel System	Common Rail
Configuration	Inline
Number of Cylinders	3
Valves per Cylinder	4
Valvetrain layout	DOHC
Bore, mm	79.5
Stroke, mm	80.5
Stroke Bore Ratio	1.01
Displacement, cc	1199
Type of Fuel Intake	Turbocharged
Stroke	Four-Stroke
Compression Ratio	16.5:1
Power, hp-kW	75hp (55kW) @4200 rpm
Torque, lb-ft	132 lb-ft. (180Nm) @2000 rpm
Firing Order	1-2-3

15.1 HAKAN SÖKMEN- EMİR TALHA ŞAHİN (2021)

Among the designs made in the last three years, we first examined the design made in 2021. While designing this engine, they use the Volkswagen EA 189 engine as a reference and design accordingly. In this design, they make the lubrication channels with the crankshaft. These crankshafts relate to the connecting rod. They also added a cylinder block and piston.

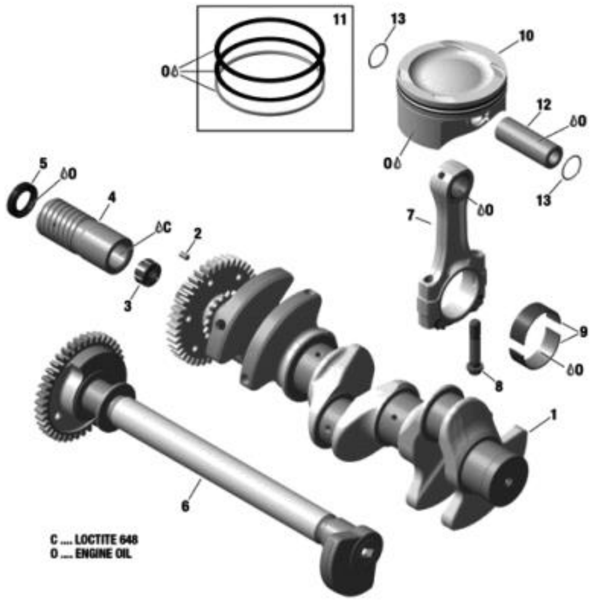

Figure 49 Crank Mechanism for 3-cylinder engine with balance shaft.

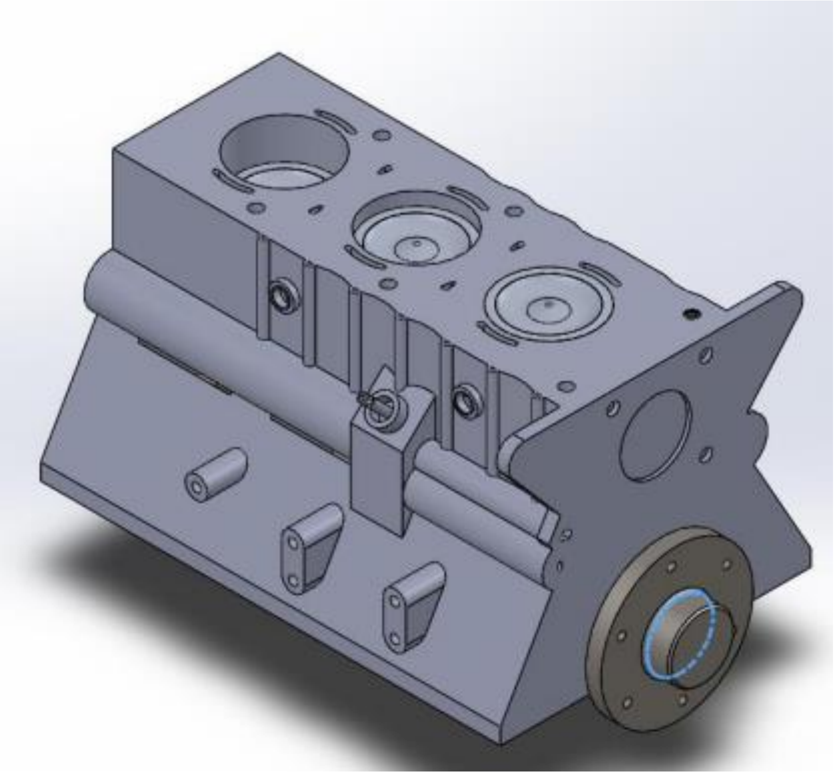

Figure 50 Assemble of crank mechanism and cylinder rack.

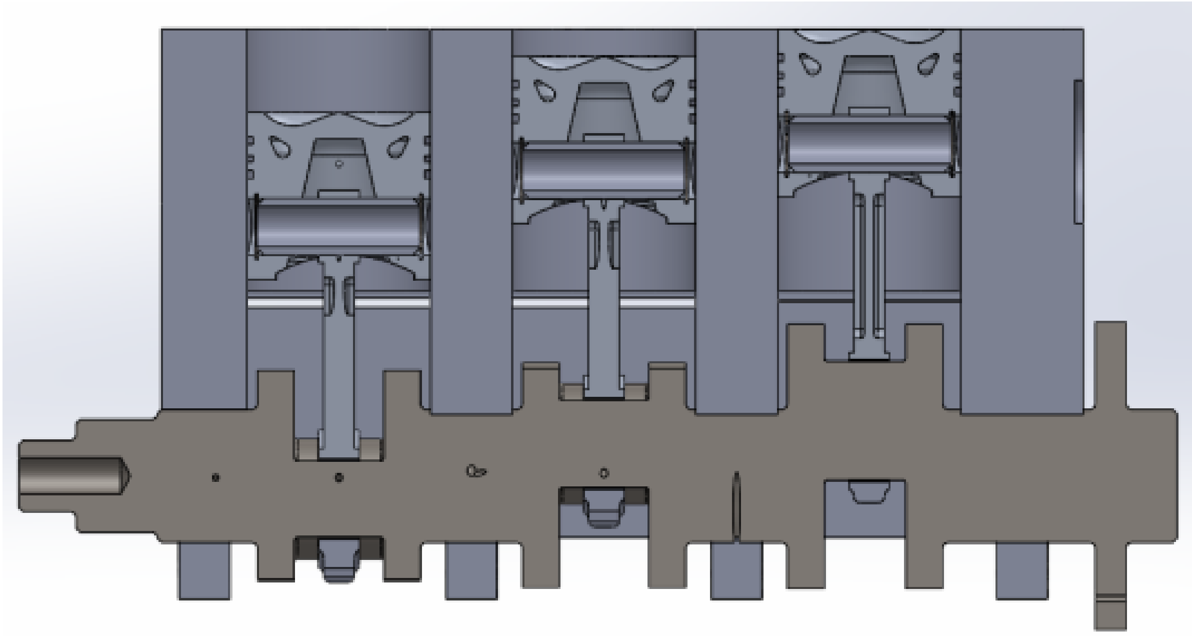

Figure 51 Section view of assemble of crank mechanism and cylinder block.

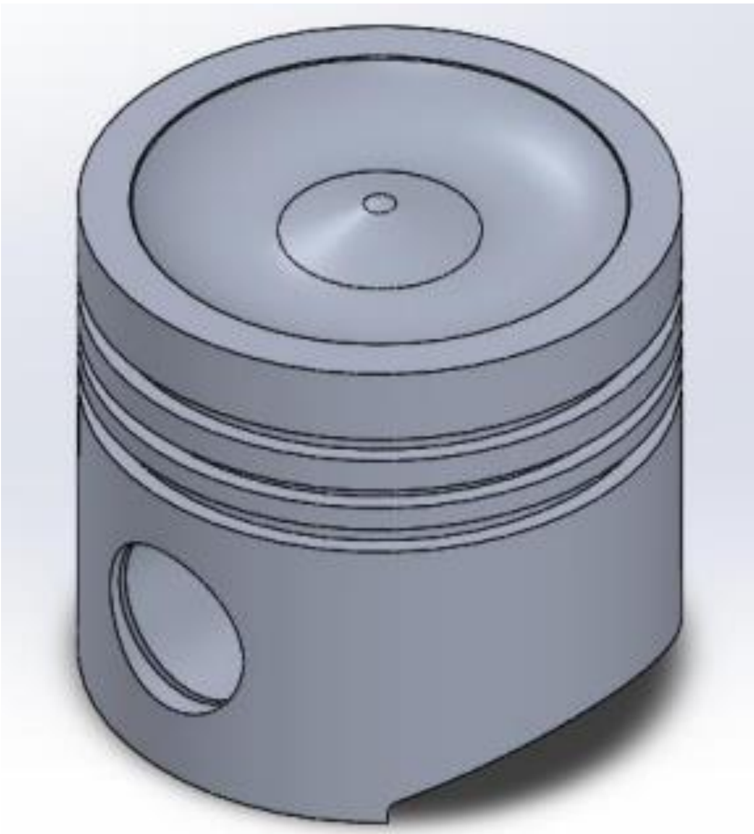

Figure 52 CAD design of piston.

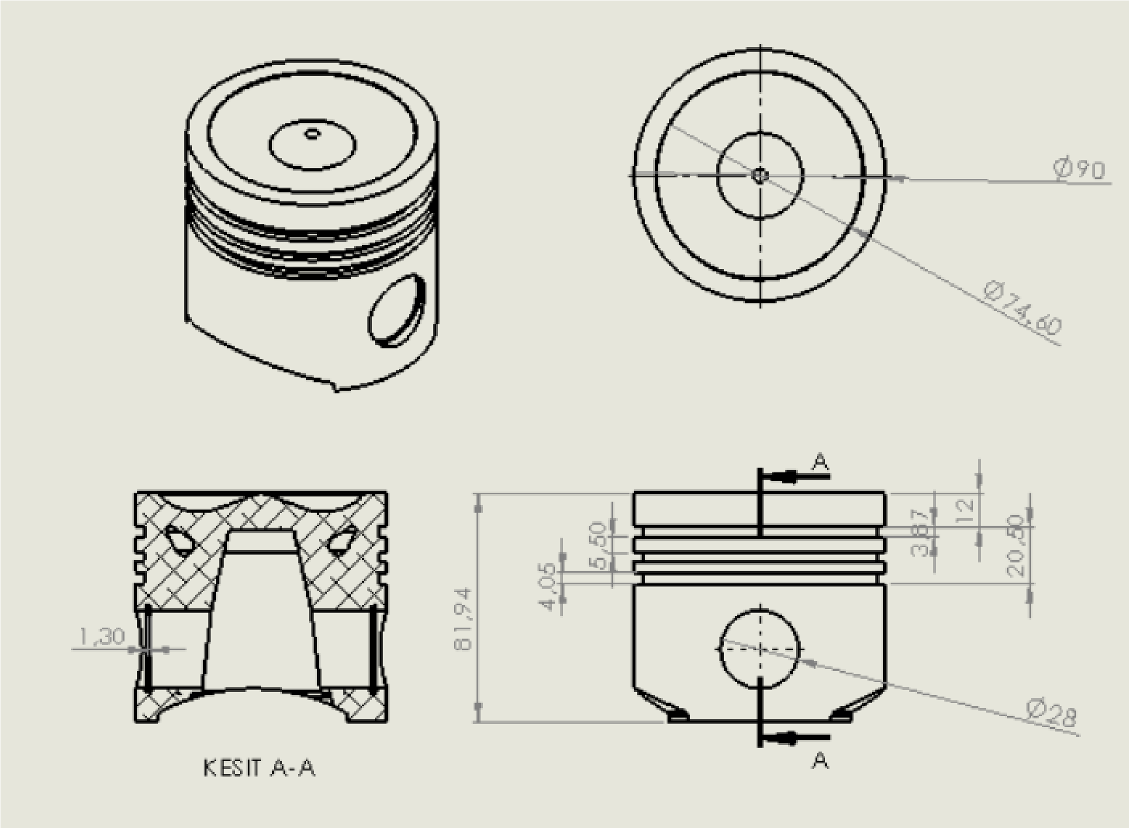

Figure 53 Technical drawing of piston.

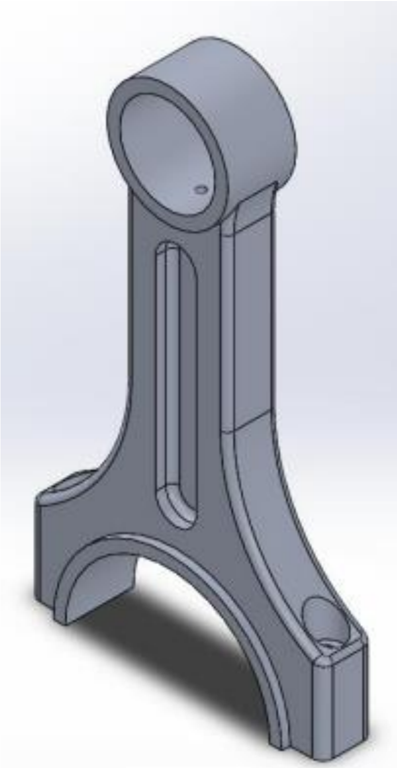

Figure 54 CAD design of connecting rod body.

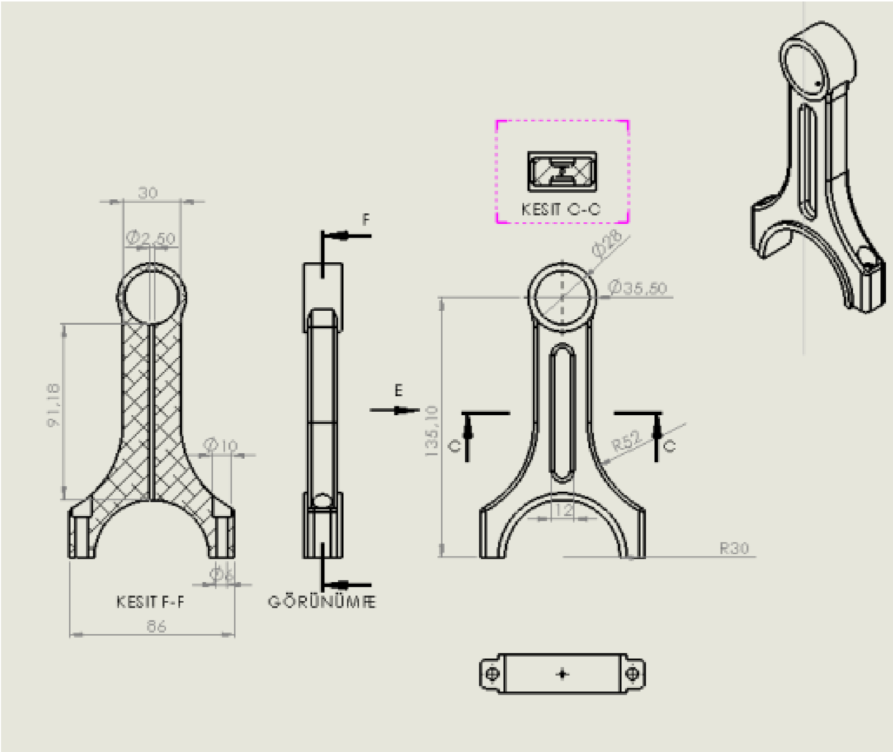

Figure 55 Technical drawing of body.

15.2 EZGİ ALTAY- UFUK MAMİKOĞLU (2021)

In the second design, changes were made compared to the first design. They designed the cylinder with 4 valves in each cylinder, that is, 2 intake valves and 2 exhaust valves. The reason why it does this is because it has more space and provides more power. In this design, Camshaft is used instead of crankshaft and fuel injector is added. And finally, they finish the design by adding a cylinder head.

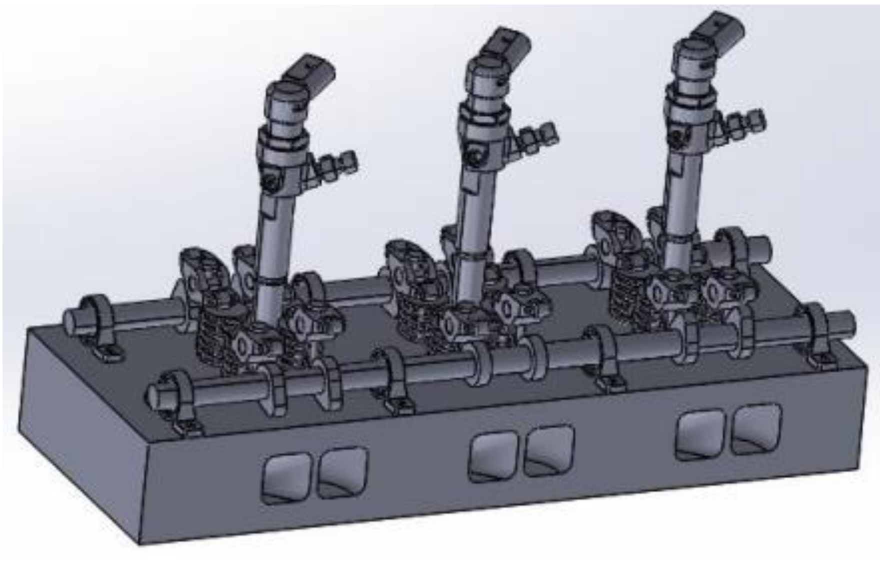

Figure 56 Assembly of the engine.

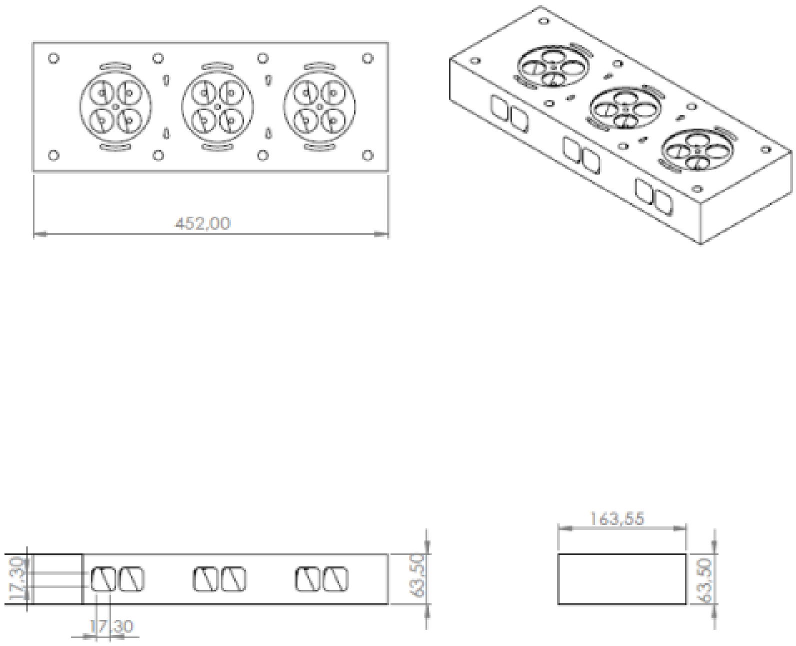

Figure 57 Technical drawing of cylinder head base.

15.3 FERHAT ÇETREZ- BURAK AYDIN (2022)

Since there was no cooling system in the engine block in last year's project, they added a cooling system to this project. They solved alignment issues and dimension issues.

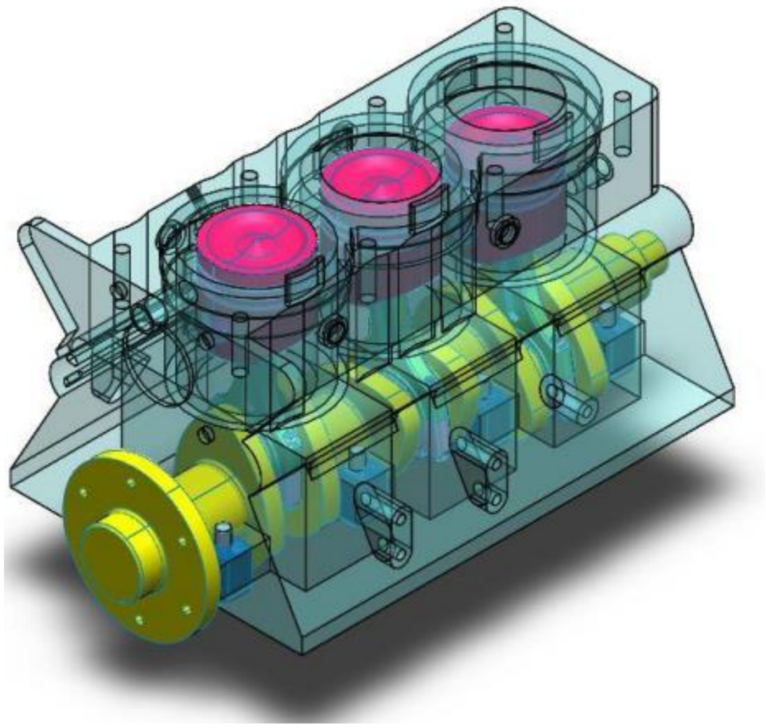

Figure 58 Motor block assembly.

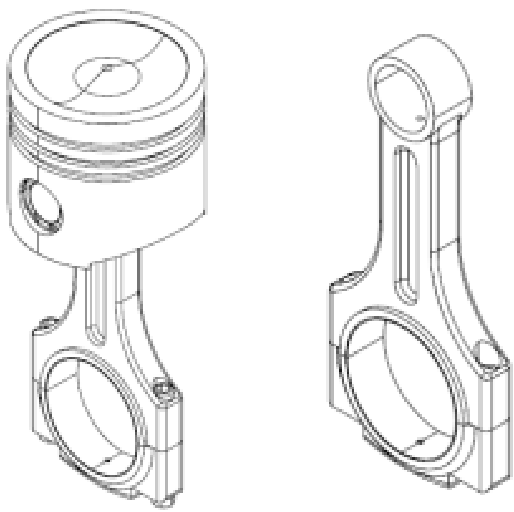

Figure 59 Piston-rod assembly.

15.4 AHMET YASIN BAS- ARDAN NURALP PAKYUREK (2023)

In the last design, they changed the position of the camshaft because it was wrong. That's why they made a belt chain system, thanks to which they established a connection between the crankshaft and the camshaft. Finally, they added an oil pan to the design.

Figure 60 Assembly of the engine.

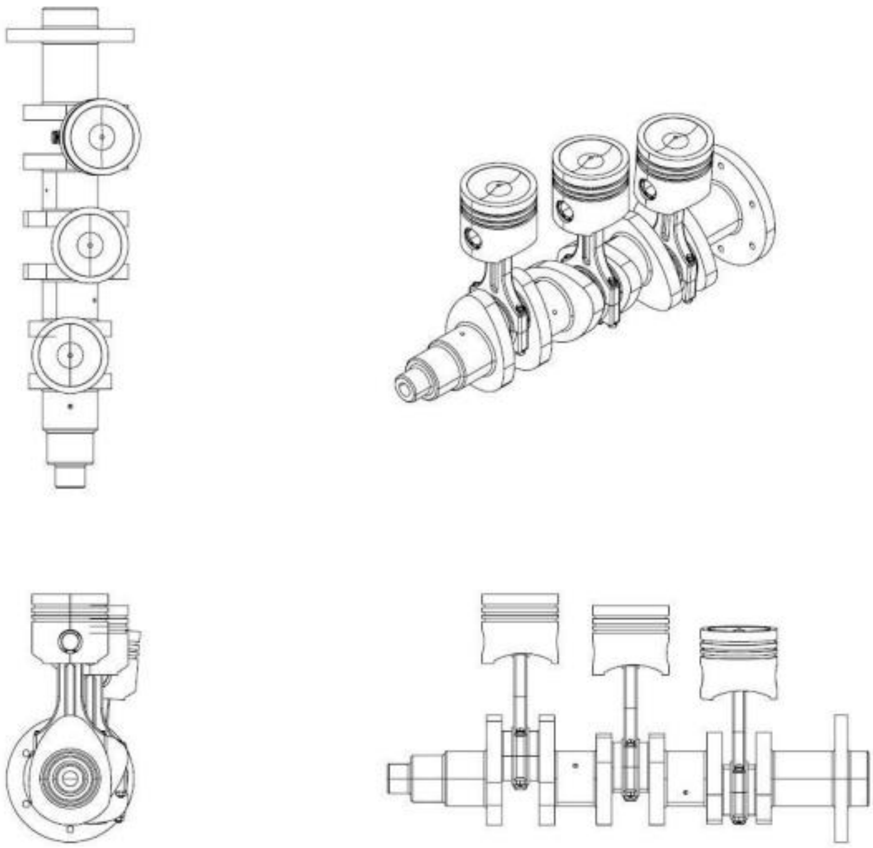

Figure 61 Crank- Piston Subassembly.

16. DEVELOPING A REFERANCE ENGINE

We chose the Antor branded engine produced by Anadolu Motor as a reference. We used the engines with the lowest cylinder volume as a reference to produce them in cooperation with the company. We chose the DieselAD400 engine as a reference. This engine is normally produced as a single cylinder, but we will design and produce this engine as a 3-cylinder.

Table 14 Features Table of Diesel AD320, AD400 and AD510 single-cylinder diesel engines produced by Anadolu Motor. [41], [42]

Tip	**DIESEL AD320**	**DIESEL 6LD400**	**DIESEL AD510 BS**
Cylinders	1	1	1
Displacement (cm^3)	315	395	510
Bore (mm)	78	86	85
Stroke (mm)	66	68	90
Compression Ratio	17,5:1	18:1	17,5:1
Rotation (rpm)	3600	3600	3000
Rating N (DIN70020) (hp)	6,5	8,5	12
Max. Torque (kgm)	1,8@2200 rpm	2@2200 rpm	32,8@1800 rpm
Fuel Tank Capacity (lt)	5	4,5	5,3
Specific Fuel Consumption (g/Hph)	220	220	
Oil Consumption (gr/h)	5	11,5	8
Oil Sump Capacity (lt)	0,30	1,2	1,75

Figure 62 The Diesel AD320 single-cylinder engine of Anadolu Motor.

Figure 63 The Diesel AD400 single-cylinder engine of Anadolu Motor.

Figure 64 The Diesel AD510 single-cylinder engine of Anadolu Motor.

16.1 CHOOSING NUMBER OF CYLINDER

Table 15 Specification table if the Diesel AD360, AD400 and AD510 single cylinders motor produced by Anadolu motor are increased from single cylinder to 3-cylinder. (The single cylinder engine whose piston dimensions we will use as reference is marked in yellow.)

Tip	**DIESEL AD320**	**DIESEL 6LD400**	**DIESEL AD510 BS**
Cylinders	3	3	3
Displacement (cm^3)	945	1185	1530
Bore (mm)	78	86	85
Stroke (mm)	66	68	90
Compression Ratio	17,5:1	18:1	17,5:1
Rotation (rpm)	3600	3600	3000

According to the current design, the piston diameter is 90 mm, and we have noticed that it is larger compared to the single-cylinder engines of the Anadolu Motor company. Following discussions with the company and the suggestion of Prof. Dr. Mehmet Zafer Gul, we have decided to revise the piston diameter to 85 mm. We will adopt this measurement from Anadolu Motor's single-cylinder Diesel 6LD400 engine and redesign it as a 3-cylinder engine.

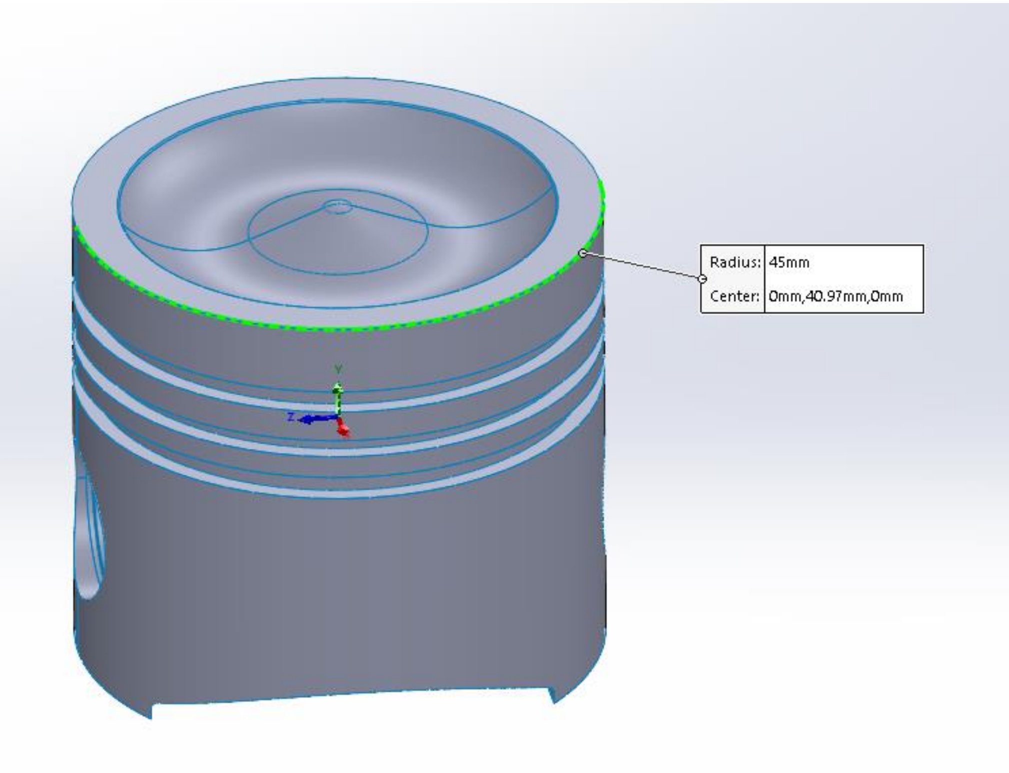

Figure 65 CAD and dimension of the piston designed and to be optimized in previous years.

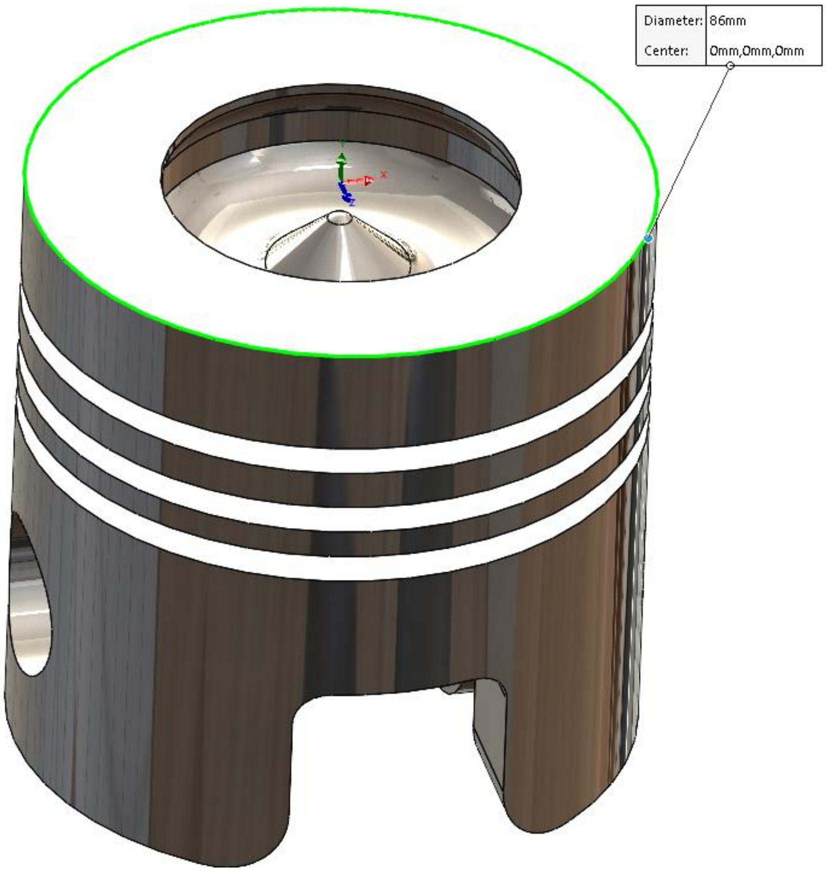

Figure 66 CAD and dimensions of the piston designed and to be optimized in 2024 year.

16.2 DETERMINING NUMBER OF VALVES

In line with the contemporary design approach in recent years, we will decrease the bore diameter of the engine. Transforming the four-valve engine into a three-valve structure, considering optimizations developed over the years, will be our goal. By reducing the valve count to a total of 2 intake and 1 exhaust, we aim to optimize the design.

To evaluate the results of this optimization, valve diameters and design standards will be thoroughly examined, and their appropriateness will be investigated.

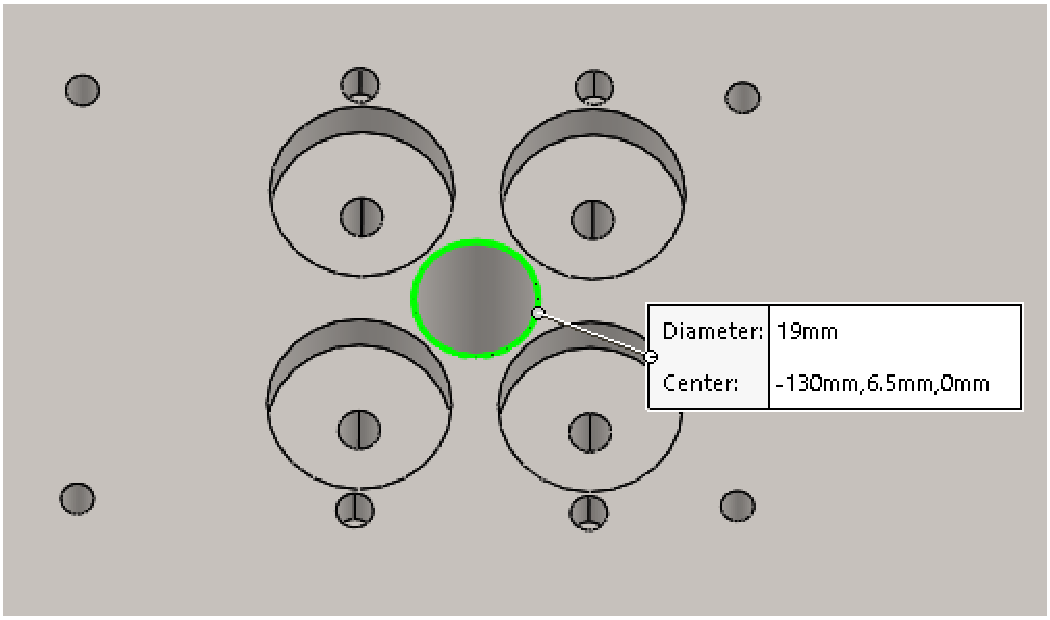

Figure 67 CAD and dimension of the direct injection designed and to be optimized in previous years.

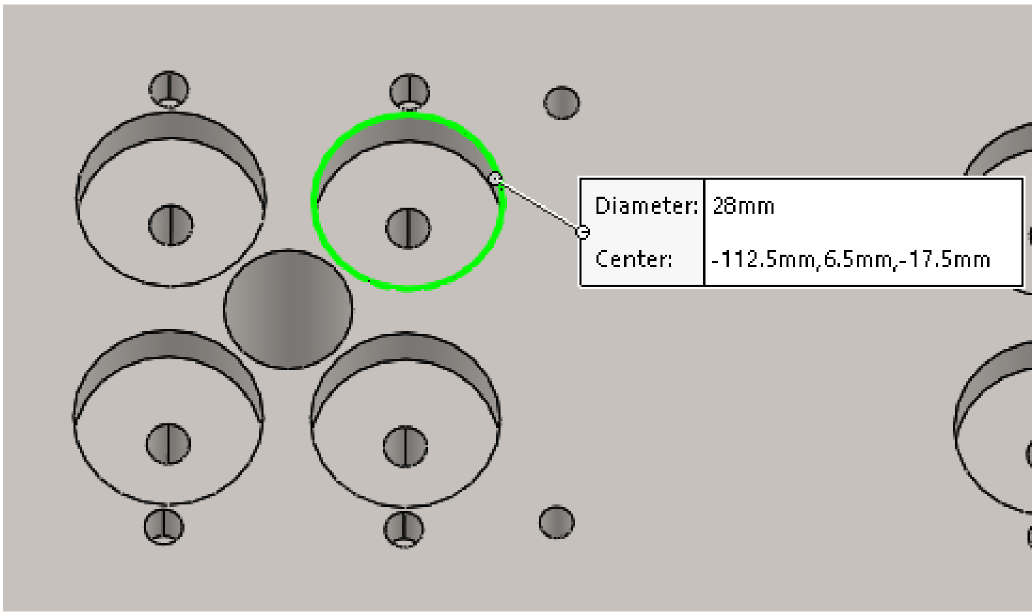

Figure 68 CAD and dimension of the valves designed and to be optimized in previous years.

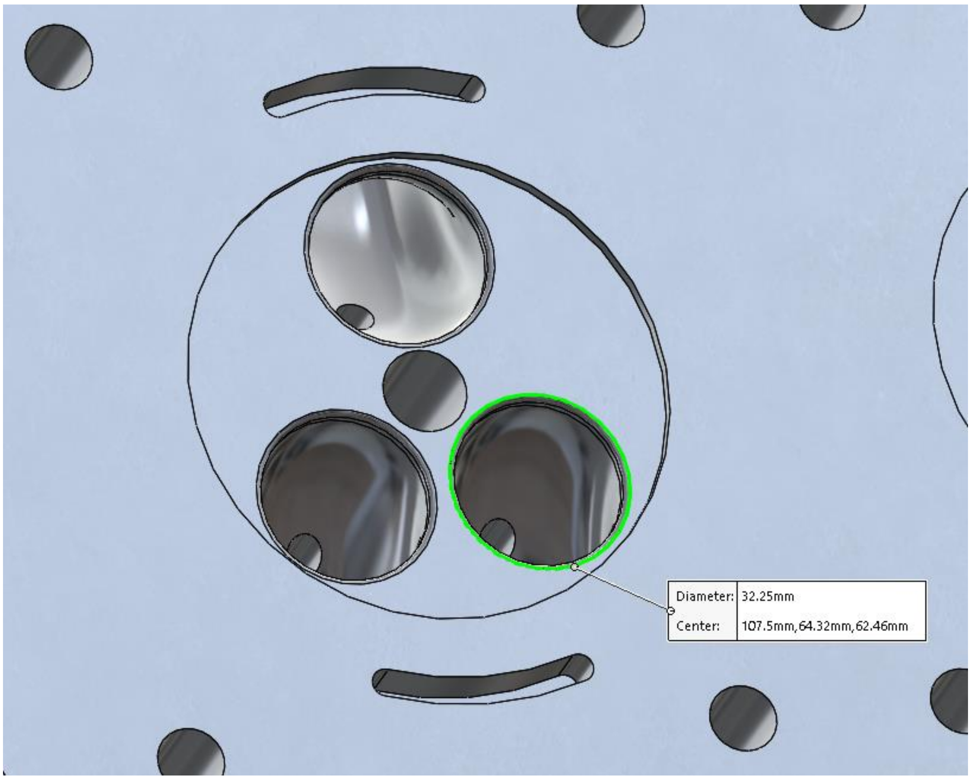

Figure 69 CAD and dimensions of the intake valves designed and to be optimized in 2024 year.

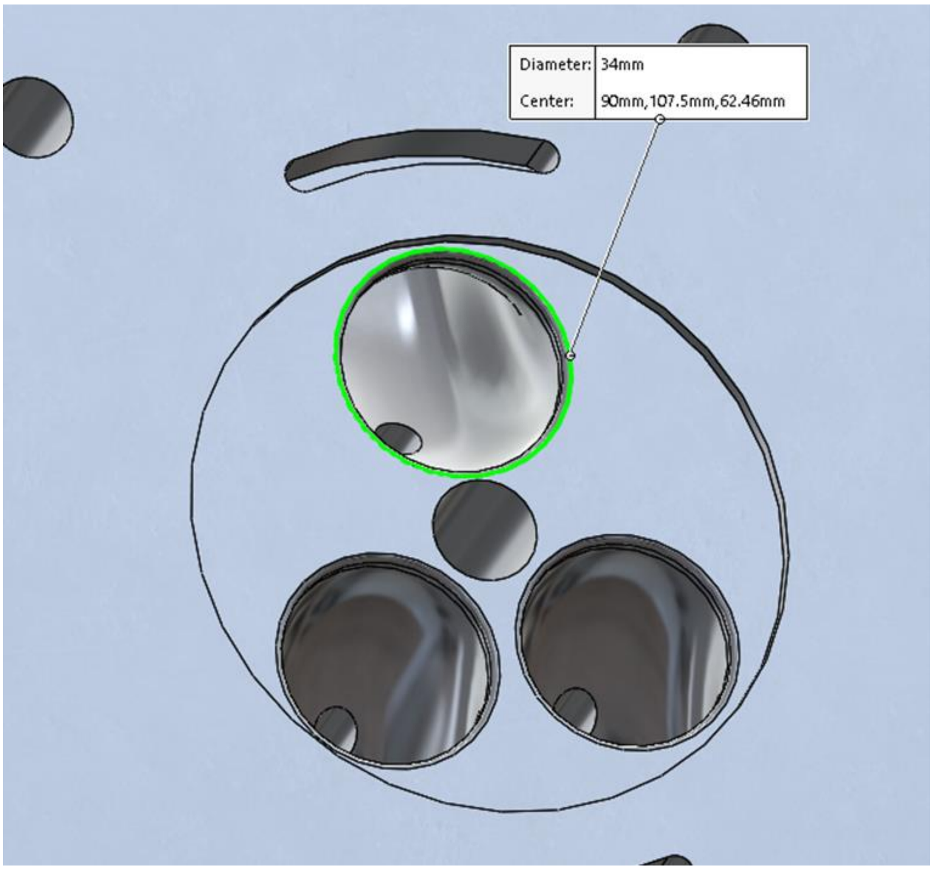

Figure 70 CAD and dimension of the exhaust valve designed and to be optimized in 2024 year.

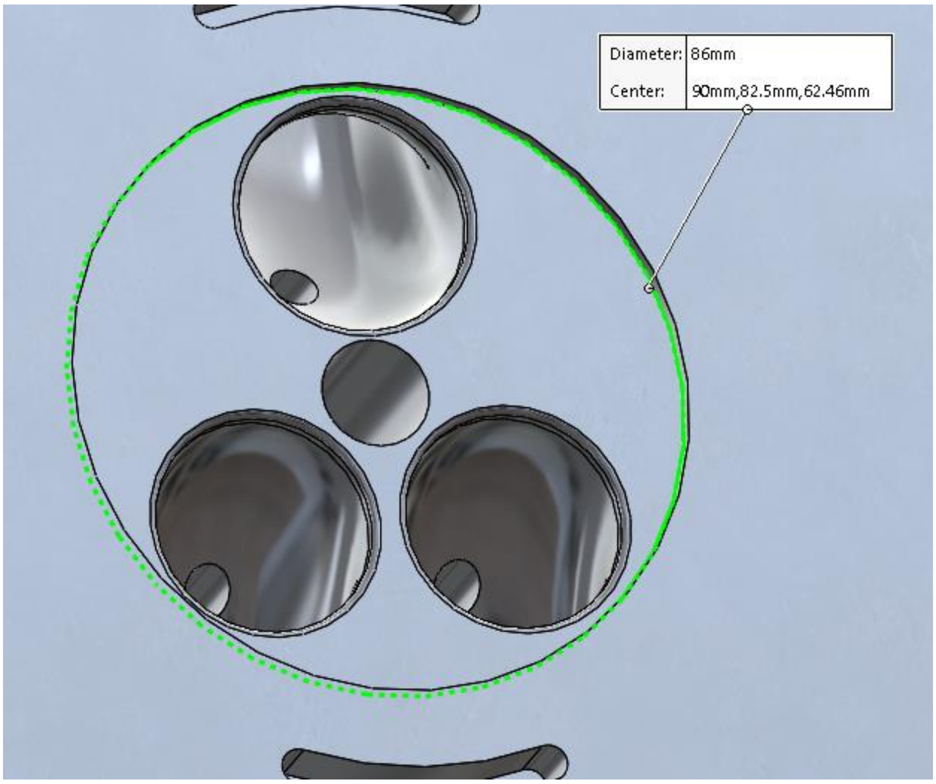

Figure 71 CAD and dimension of the piston designed and to be optimized in 2024 year.

In addition, according to the documents we examined, it was preferred that the valves be made of steel because it is a material resistant to high temperatures, as we saw maximum temperatures of 800 degrees on the piston. [44]

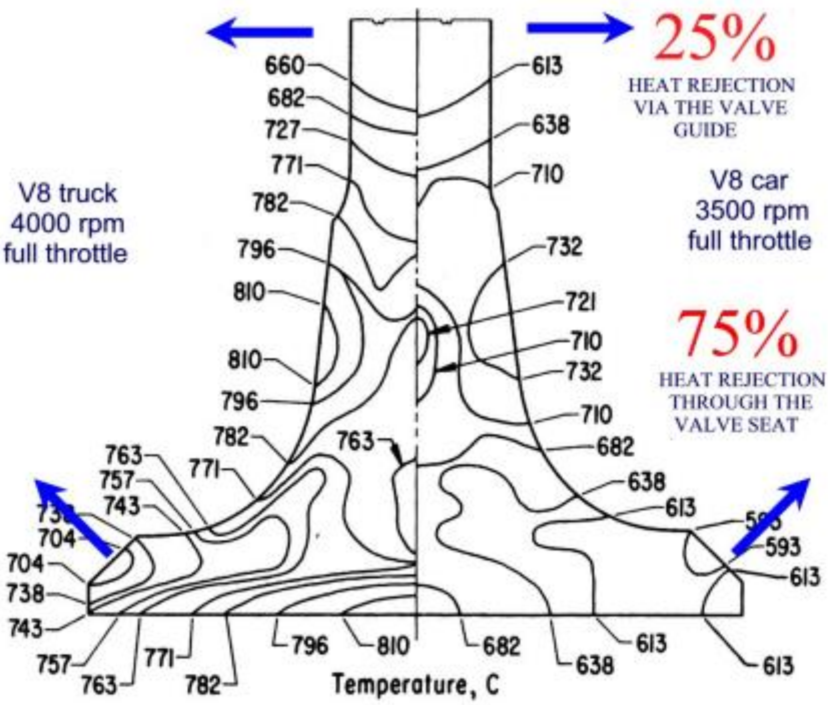

Figure 72 Examples of heat distribution in valve heads.

16.3 DESIGN OF PISTON BOWL GEOMETRY

The combustion of air and fuel mixture and emission formation in diesel engine show very close relationship with piston bowl geometry Experimental studies on the effects of different bowl geometries of diesel engines were represented by Jaichandar and Annamalai. In their study, three bowl geometries, namely hemispherical combustion chamber (HCC), toroidal combustion chamber (TCC) and shallow-depth combustion chamber (SCC), were tested with diesel and biodiesel fuels. These three piston bowl geometries were compared and observed. [43]

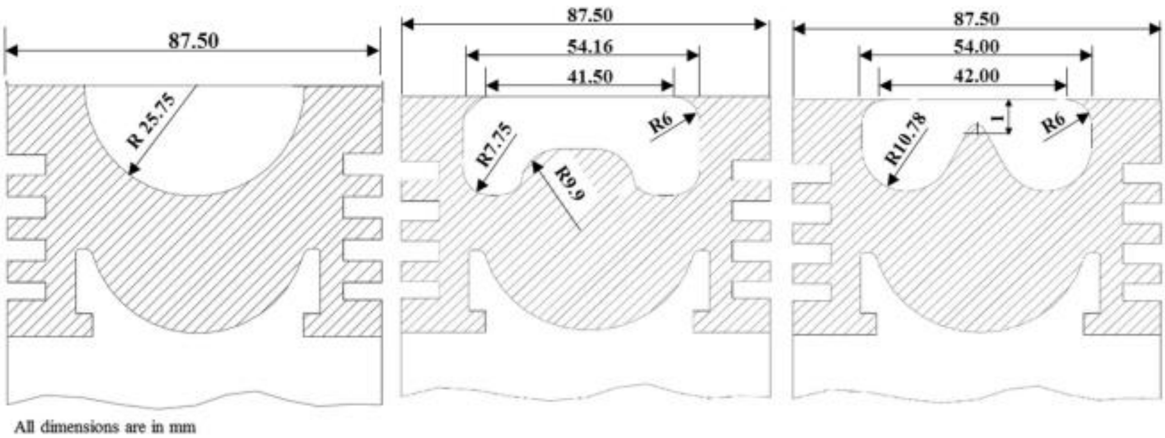

Figure 73 Geometry of the three basic designs HCC, SCC and TCC.

The 3 reason why we chose TCC over other designs:

- Improved ISFC and soot emissions.
- Enhanced mixture homogeneity with a high swirl ratio.
- Significantly reduced NOx and soot emissions compared to the TCC baseline in some cases.

Additionally, during the manufacturing process, we anticipated potential difficulties with the TCC design. To mitigate these issues, we opted to flatten the edges, simplifying the manufacturing process and ensuring consistent quality and reliability in the produced components.

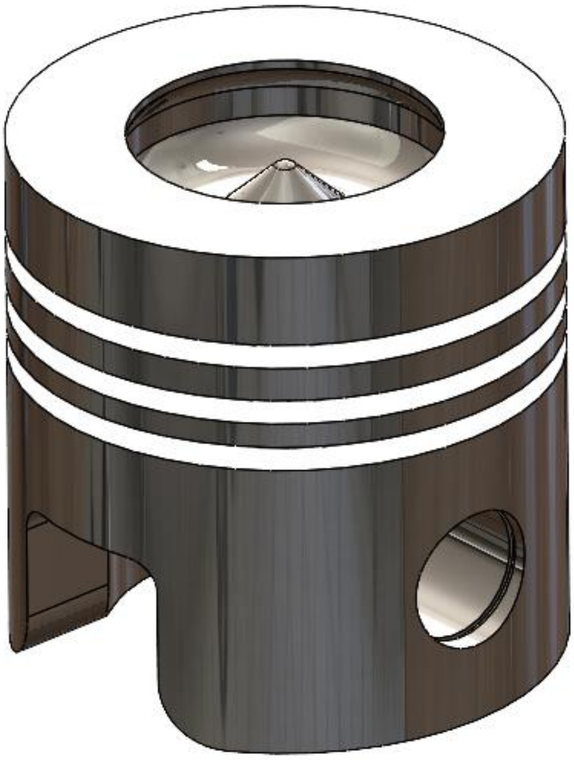

Figure 74 CAD of Piston design.

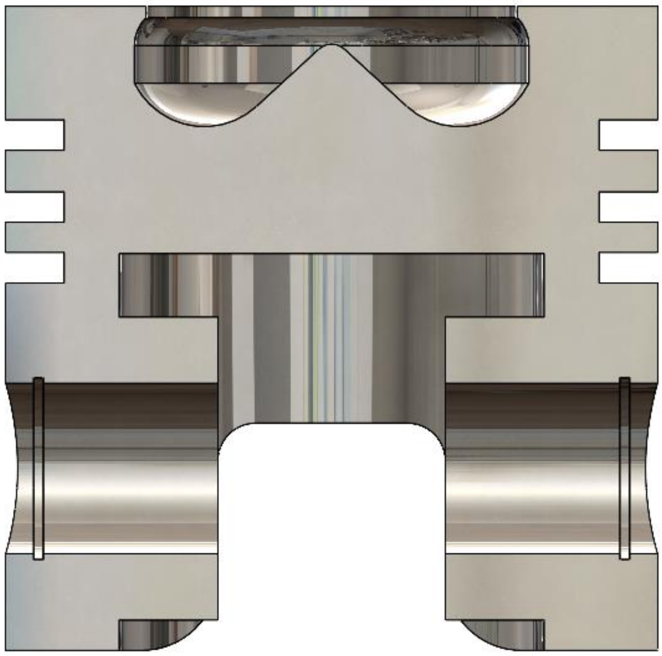

Figure 75 CAD of section of piston design.

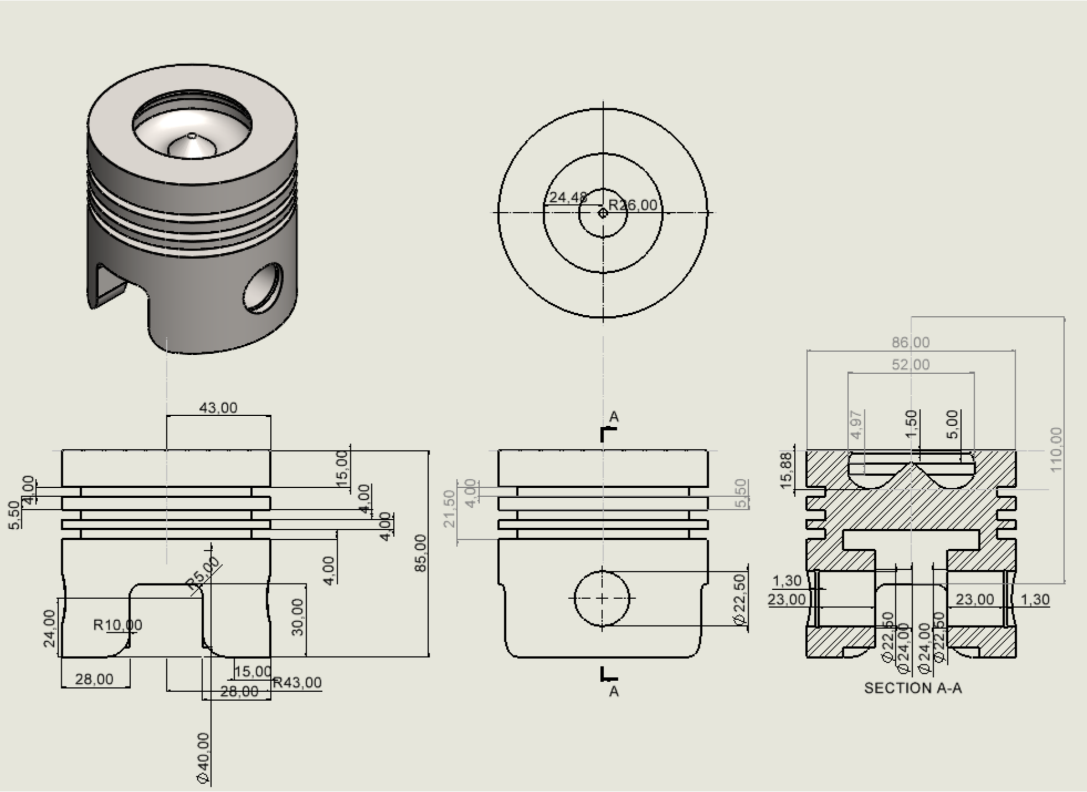

Figure 76 Technical Drawing of Piston.

16.4 DESIGN OF CRANKSHAFT AND CAMSHAFT

In general, the rotation angle of crankshafts is 120 degrees for 3-cylinder engines, but in Turkey, the standard rotation angle of crankshafts is 180 degrees. Therefore, it is reasonable to design the production process of crankshafts according to this 180-degree rotation standard.

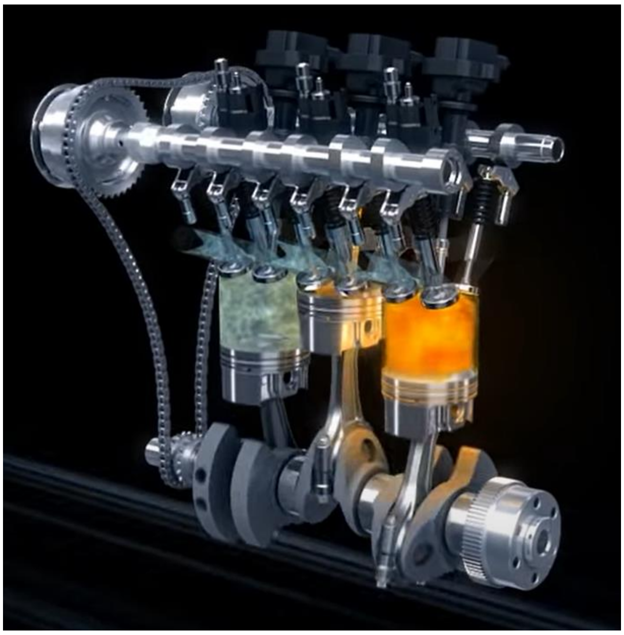

Figure 77 60 degree of crankshaft by Mahle. [45]

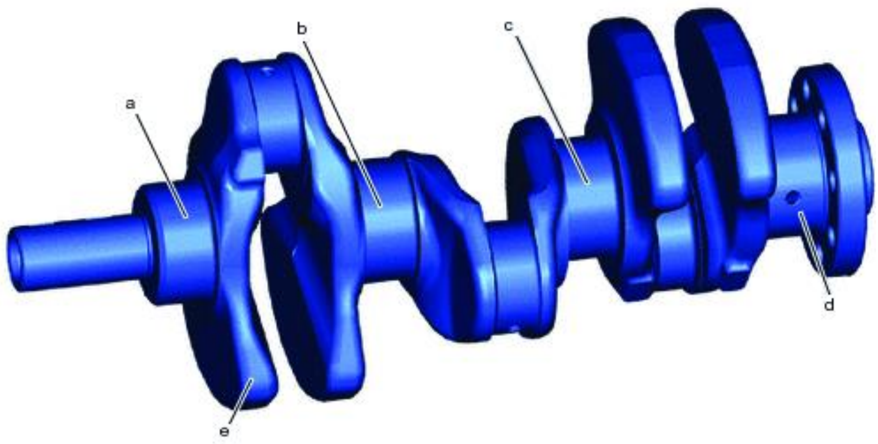

Figure 78 Example of crankshaft by Toyota (a-d= journal, e= balance weight). [46]

The manufacturing process will involve hot pressing followed by CNC machining to ensure precision and adherence to the specified design parameters. This approach will help in maintaining the required tolerances and achieving the desired mechanical properties for optimal engine performance.

Here's a detailed breakdown of the process:

1. **Hot Pressing:**

The initial step in manufacturing the crankshafts will involve hot pressing. This technique is selected due to its ability to shape metal at elevated temperatures, which makes the metal more malleable and easier to form into complex shapes.

During hot pressing, a blank (a piece of metal) will be heated to a high temperature to make it more pliable. Once heated, the blank will be placed in a die and subjected to high pressure using a hydraulic press. This combination of heat and pressure will form the metal into the rough shape of the crankshaft. The high temperature ensures that the metal can be shaped without cracking or breaking, and the hydraulic press ensures uniform shaping and density.

2. **CNC Machining:**

After cold pressing, the rough-shaped crankshaft will undergo CNC (Computer Numerical Control) machining. CNC machining is chosen for its precision and efficiency in producing complex shapes and fine details required in crankshafts.

In this step, the crankshaft will be clamped onto a CNC machine where it will be machined to the final dimensions. This includes drilling, milling, and turning operations to achieve the precise tolerances and surface finishes needed for optimal engine performance.

The CNC process will ensure that all critical features such as journals, oil passages, and keyways are accurately machined to the specified design.

By following this manufacturing process, we can produce high-quality crankshafts that meet the specific rotational angle requirements and performance standards for 3-cylinder engines in Turkey.

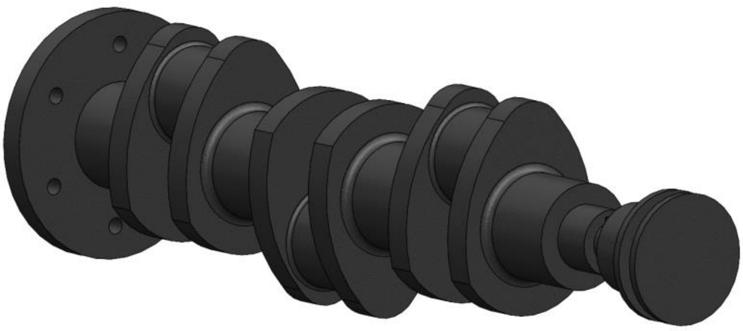

Figure 79 Crankshaft CAD design with 180 degree of piston movement.

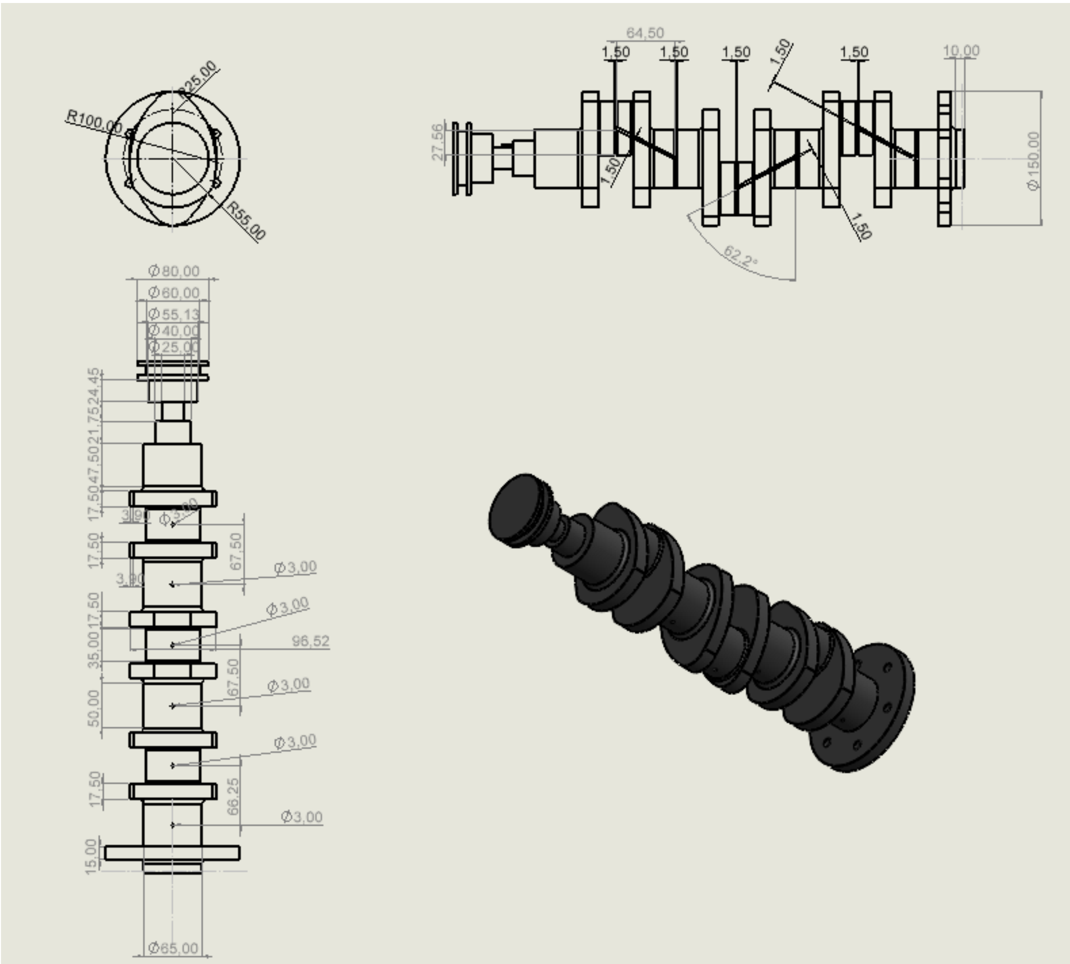

Figure 80 Technical Drawing of Crankshaft.

Figure 81 Camshaft CAD design with 180 degree of exhaust valves open- closed movement.

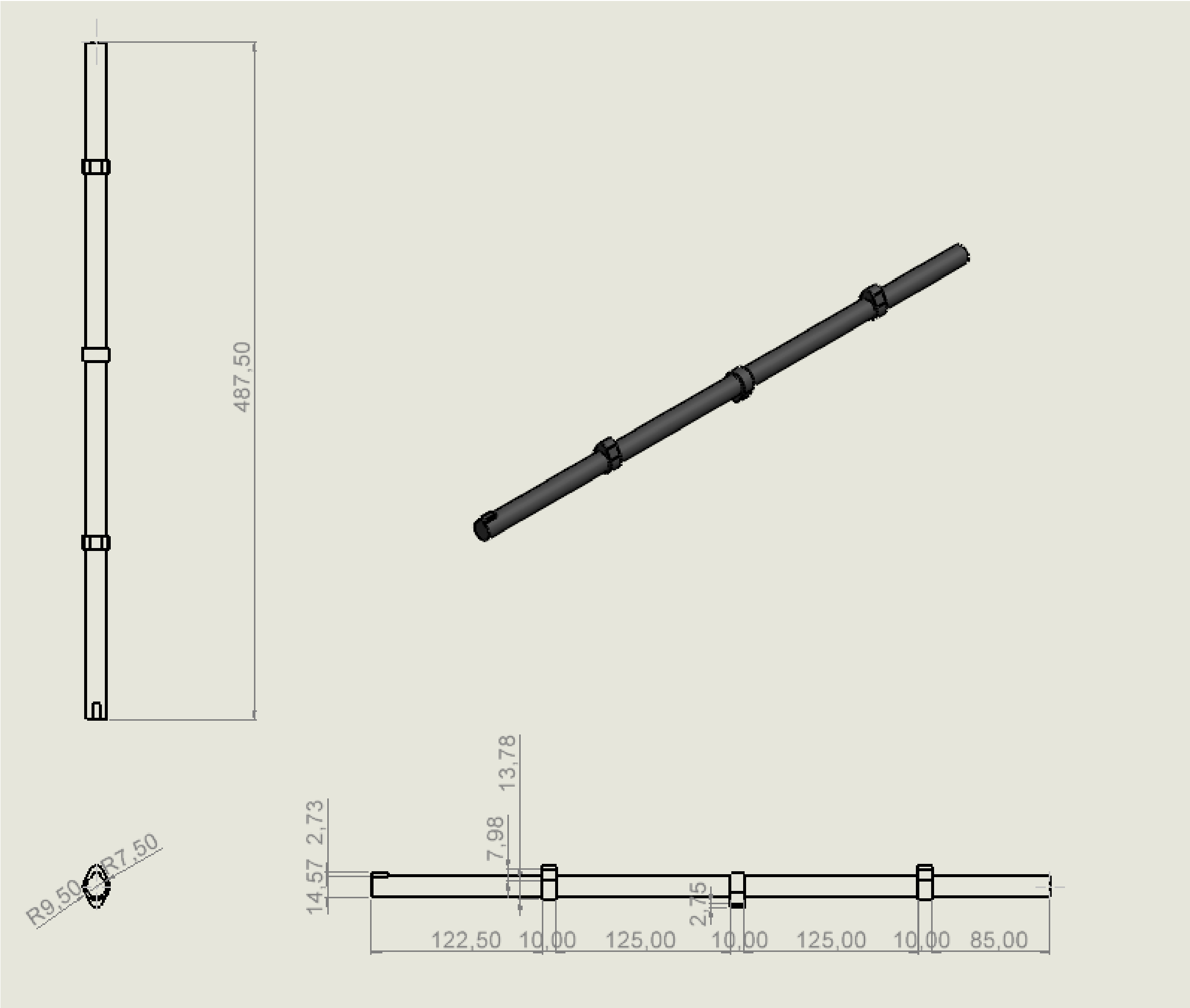

Figure 82 Technical Drawing of Exhaust Valves Camshaft.

Figure 83 Camshaft CAD design with 180 degree of intake valves open- closed movement.

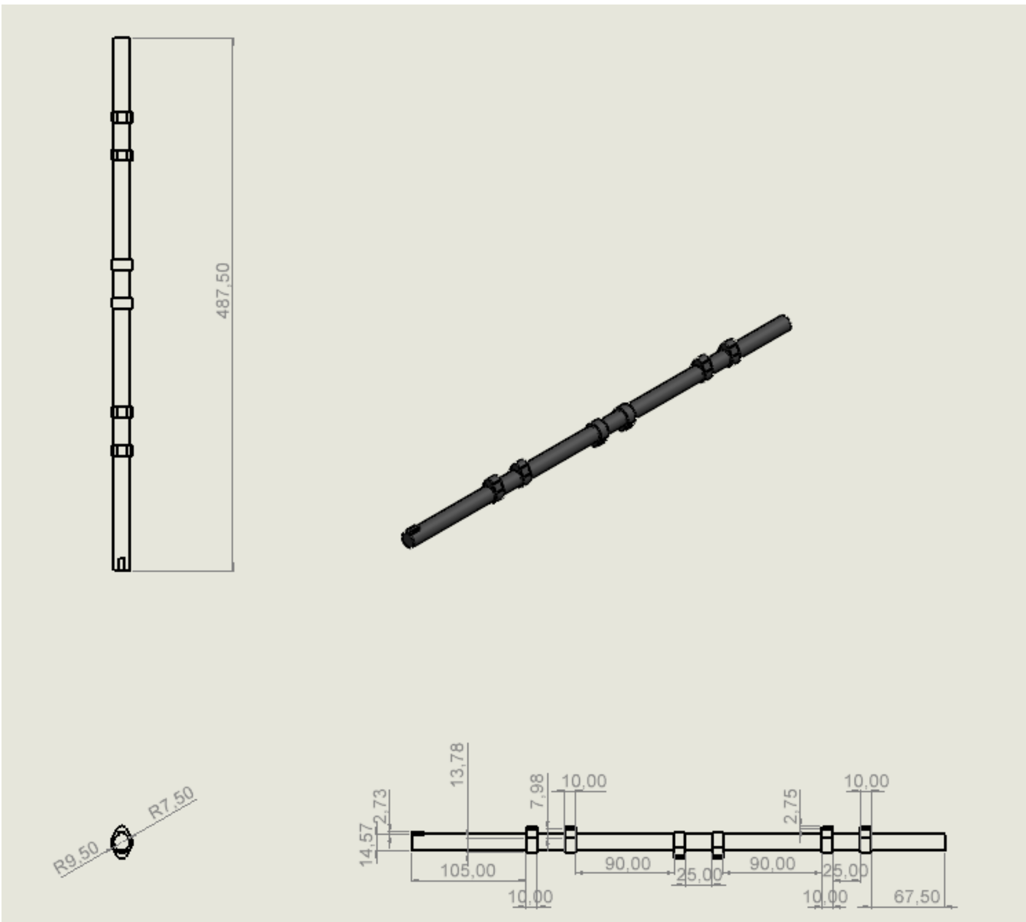

Figure 84 Technical Drawing of Intake Valves Camshaft.

16.5 ELECTRONICS UNIT PUMP (UNIT INJECTION & PUMP SYSTEM- UPS)

With emission standard increased from EURO II to EURO III, unit pump and common rail pump are the two primary technological approaches. Both achieve high combustion efficiency through electronically controlled injection. Unlike the common rail system, which has seen substantial investment and development by leading manufacturers like BOSCH, the unit pump technology has not benefited from similar levels of capital and research. We will compare these two systems, focusing on the differences and underlying reasons, starting with the control of injection pressure.

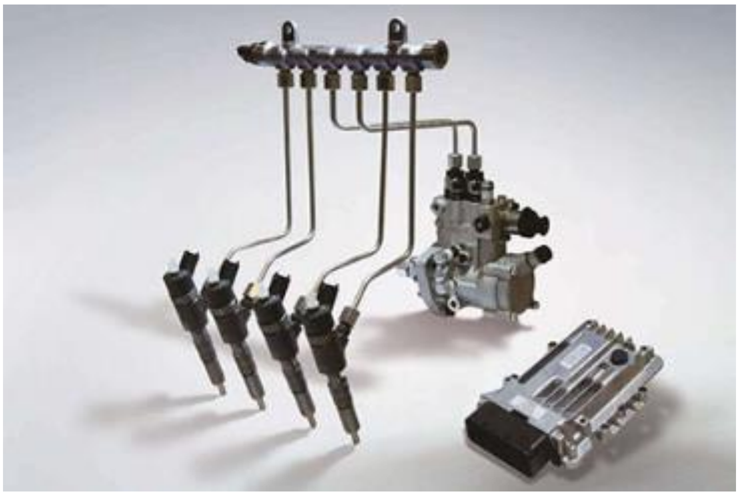

Figure 85 Common rail fuel injection system.

16.5.1 CONTROL OF INJECTION PRESSURE

The injection pressure in an electric unit pump is determined by the pump CAM profile design and is influenced by the injector's bore diameter and the engine speed. Specifically, a smaller nozzle bore diameter results in a higher maximum injection pressure, while lower engine speeds result in lower injection pressures. This system currently achieves a maximum injection pressure of 180 MPa.

In contrast, the injection pressure in a common rail system is entirely independent of engine speed, enhancing engine performance at low speeds. It is regulated by an electromagnetic valve on the high-pressure pump and is flexibly controlled by the corresponding MAP. Additionally, the injection pressure is not dependent on the nozzle bore diameter. Currently, this system can reach a maximum injection pressure of 160 MPa.

Thus, in terms of fuel injection pressure control, the common rail system outperforms the electronic unit pump, making it more effective in meeting stricter emission standards.

Figure 86 Electronic Unit Pump (EUP) System. [47]

16.5.2 CONTROL AMOUNT OF FUEL INJECTION

Both systems can flexibly and accurately adjust the fuel injection quantity for each engine operating condition. The electronic unit pump can achieve a minimum fuel injection amount of 3 mm^3/st, but it does not support pre-injection. In contrast, the common rail system can achieve a minimum fuel injection amount of 2 mm^3/st and supports both pre-injection and post-injection. Pre-injection aids in cold starts and reduces noise, while post-injection is beneficial for post-treatment processes, offering a technical advantage to meet future stricter emission regulations like EURO IV.

16.5.3 INJECTION TIMING

Both the unit pump and the common rail system can flexibly adjust the fuel injection timing based on the engine's requirements in various operating conditions. This capability is highly beneficial for optimizing fuel consumption and reducing NOX emissions and smoke from the engine.

16.5.4 FUEL-INJECTION LAWS

The injection law of the electronic unit pump (EUP) closely resembles that of the mechanical in-line pump, which is advantageous for reducing nitrogen oxides (NOx). In contrast, the common rail system employs a rectangular injection pattern characterized by high combustion pressure and turbulent combustion, which is less effective in NOx reduction. Therefore, the injection strategy employed by the EUP is considered superior to that of the common rail system in terms of minimizing NOx emissions.

16.5.5 QUICK OIL CUTTING CAPABILITY

The electronic unit pump (EUP) relies on the injector's needle valve spring to control fuel cutoff. Due to the long high-pressure pipe between the pump and injector, pressure waves in this pipe can hinder the injector's ability to quickly cut off fuel. This can negatively impact engine fuel consumption and increase smoke emissions.

In contrast, the common rail system uses an electromagnetic valve to control the pressure difference between the upper and lower chambers of the injector plunger. This, combined with the action of the needle valve spring, facilitates rapid fuel cutoff immediately after injection. This capability is beneficial for reducing particle emissions and smoke from the engine, contributing to improved environmental performance.

16.5.6 THE ABSORPTION POWER OF THE PUMP

In a configuration where each unit pump is associated with one injector and six of these unit pumps are integrated into a pump box, the resulting assembly occupies more space, has a bulkier drive mechanism, and requires higher power absorption by the pump due to the individual nature of each pump-injector unit.

Conversely, the high-pressure pump (HPO) in a common rail system is driven by two triangular cams, each featuring three protrusions. This design is compact, lightweight, and easy to install. Moreover, the HPO in a common rail system typically has lower oil pump power absorption compared to the integrated unit pump setup.

16.5.7 FUEL CLEANLINESS REQUIREMENTS

The electric unit pump (EUP) has relatively modest requirements for fuel cleanliness, similar to that of mechanical in-line pumps. This means the filter precision needed for the fuel is comparable between EUP and mechanical systems.

In contrast, the common rail system imposes stricter demands on fuel quality. It requires the fuel to be filtered to a high standard, often denoted as "Su," which is significantly finer than what mechanical in-line pumps typically require. The reason for this stringent requirement is that impurities in the fuel can lead to serious issues and failures within the common rail system, compromising its performance and reliability. Therefore, maintaining high fuel purity is crucial for the proper functioning and longevity of common rail systems.

16.5.8 LOCALIZATION LEVEL

In China, several components essential for fuel injection systems can be manufactured cost-effectively. This includes the high-pressure pump, electromagnetic valve, injector, and ECU used in unit pumps, making these parts accessible at lower prices locally.

However, certain critical components of common rail systems still require costly imports from overseas. Fortunately, there are exceptions like BASCOLIN's CB18 pumps, common rail injectors, nozzles, and valve sets, which are produced domestically in China. BASCOLIN products are renowned for their competitive pricing and exceptional performance, making them a preferred choice for importers and manufacturers both within China and internationally.

This availability of high-quality, competitively priced components from BASCOLIN contributes significantly to the popularity and adoption of their products in the global market.

16.5.9 WHY WE ARE SELECT ELECTRONIC UNIT PUMP

In collaboration with Anadolu Motor, we are pleased to announce a significant advancement in our fuel injection technology. After extensive discussions and careful consideration, we have chosen to integrate Electronic Unit Pumps (EUPs) into our systems. This decision underscores our commitment to innovation, efficiency, reliability, and overall performance enhancement.

Enhanced Precision and Control: UPs represent a leap forward in fuel injection technology, offering unparalleled precision and control over injection parameters. This capability allows us to optimize engine performance with precise timing and metering of fuel delivery. The electronic control unit (ECU) ensures dynamic adjustments, accommodating various operating conditions seamlessly.

Flexibility in Design and Integration: The modular design of EUPs provides us with greater flexibility in engine layout and packaging. By consolidating the pump and injector into a single unit, we streamline installation and reduce system complexity. This design versatility enables us to adapt EUPs across a range of vehicle platforms, from light-duty vehicles to heavy-duty applications.

Reliability and Durability: With Anadolu Motor's expertise and engineering excellence, we are confident in the durability and reliability of our EUP systems. The robust construction and efficient operation of EUPs minimizes wear and maintenance requirements, ensuring prolonged service life and maximum uptime for our vehicles.

Meeting Environmental Standards: As environmental regulations become increasingly stringent, EUPs play a crucial role in reducing emissions such as nitrogen oxides (NOx) and particulate matter (PM). By optimizing combustion efficiency, EUP-equipped vehicles contribute to a cleaner environment while meeting global emission standards effectively.

Commitment to Quality and Performance: Our partnership with Anadolu Motor exemplifies our dedication to delivering superior quality and performance to our customers. Through continuous innovation and collaboration, we strive to set new benchmarks in fuel efficiency, emissions control, and overall vehicle performance.

Integrating Electronic Unit Pumps (EUPs) into our systems marks a significant milestone in our quest for automotive excellence. With Anadolu Motor's support, we are poised to elevate our capabilities and set new standards in efficiency, reliability, and environmental stewardship. This strategic decision not only enhances our product offerings but also reinforces our commitment to driving innovation in the automotive industry. [48]

17. CAD MODELS AND TECHNICAL DRAWINGS

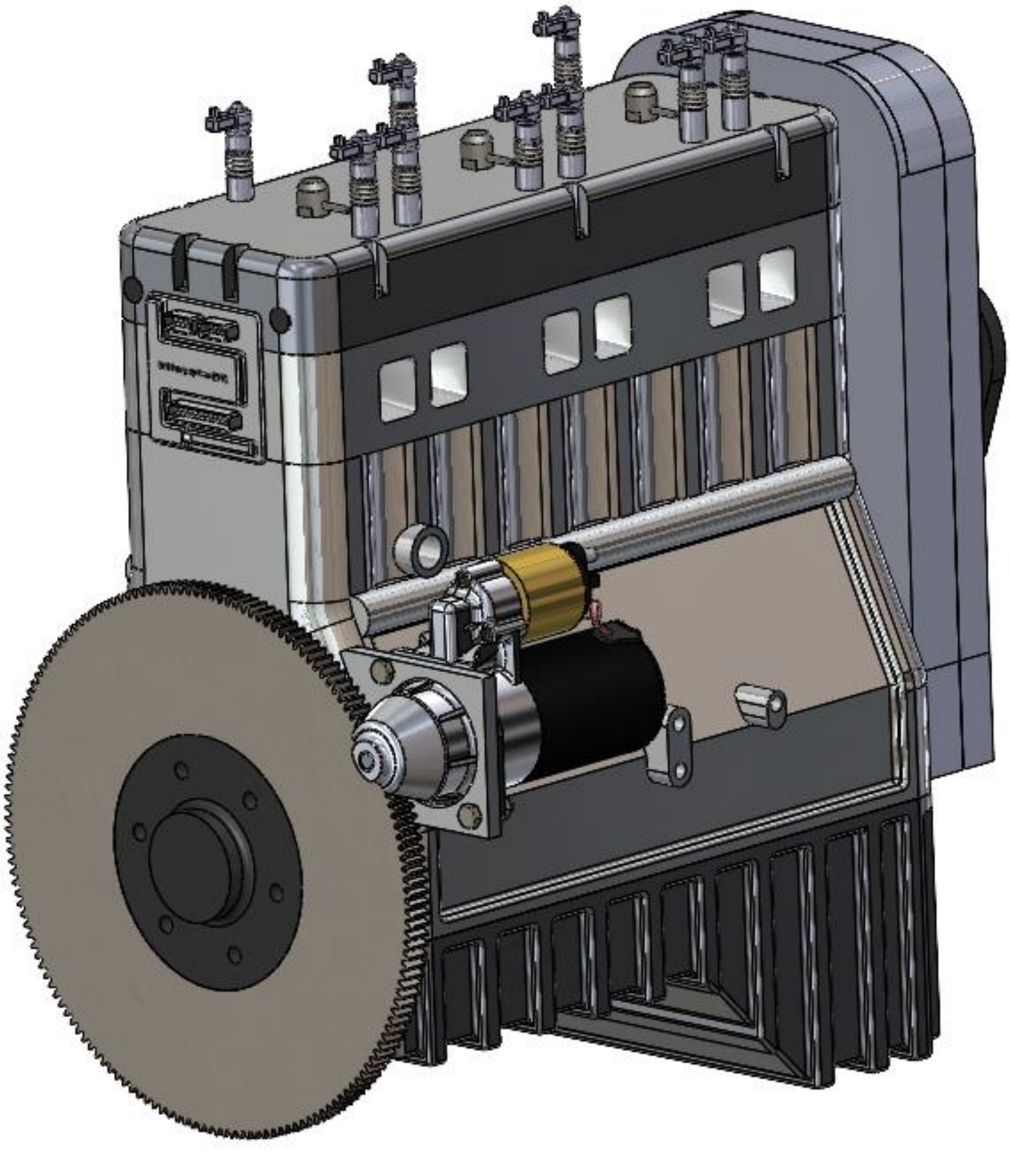

Figure 87 CAD of Assembly of the Engine We Designed.

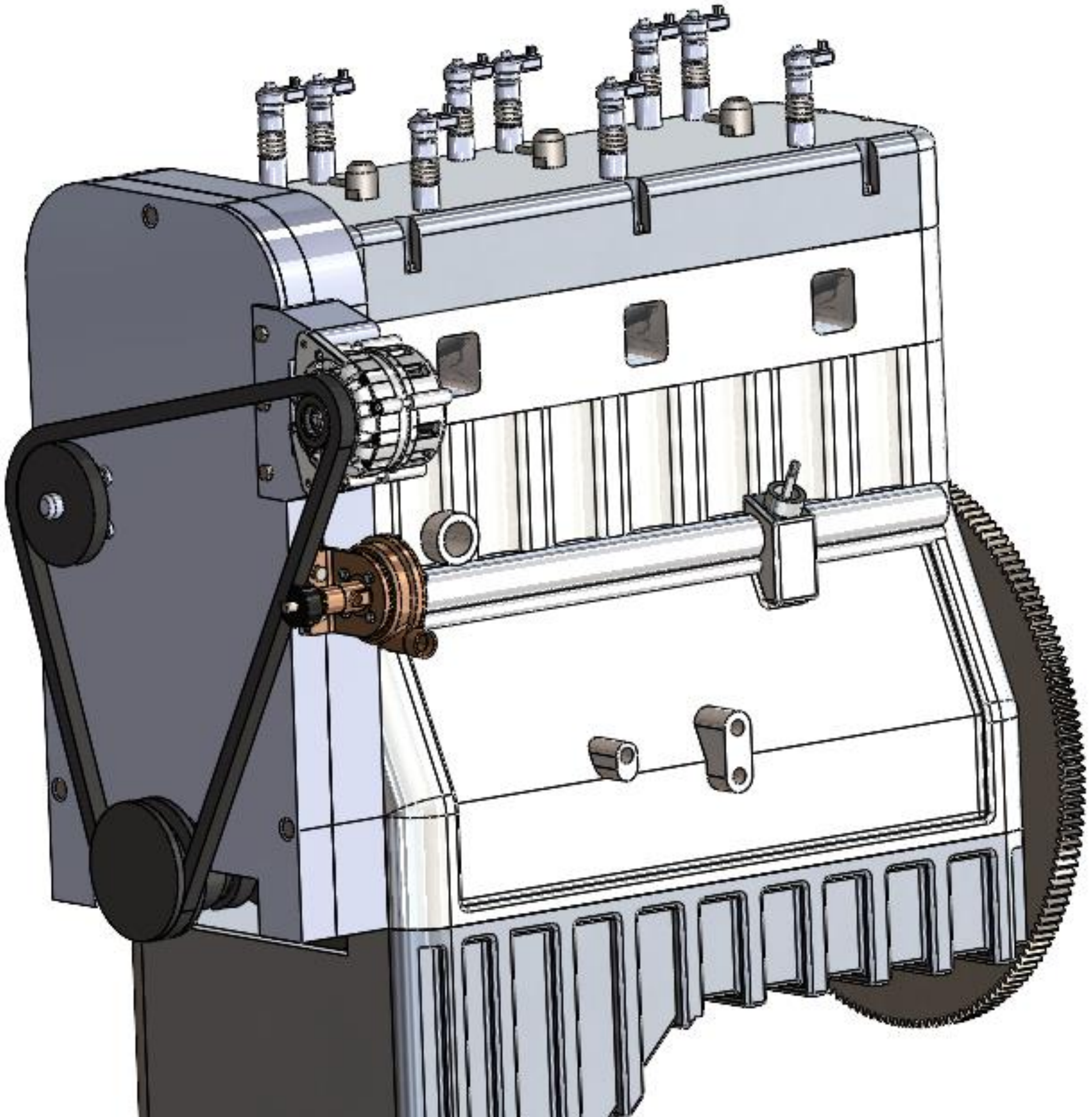

Figure 88 CAD of Assembly of the Engine We Designed.

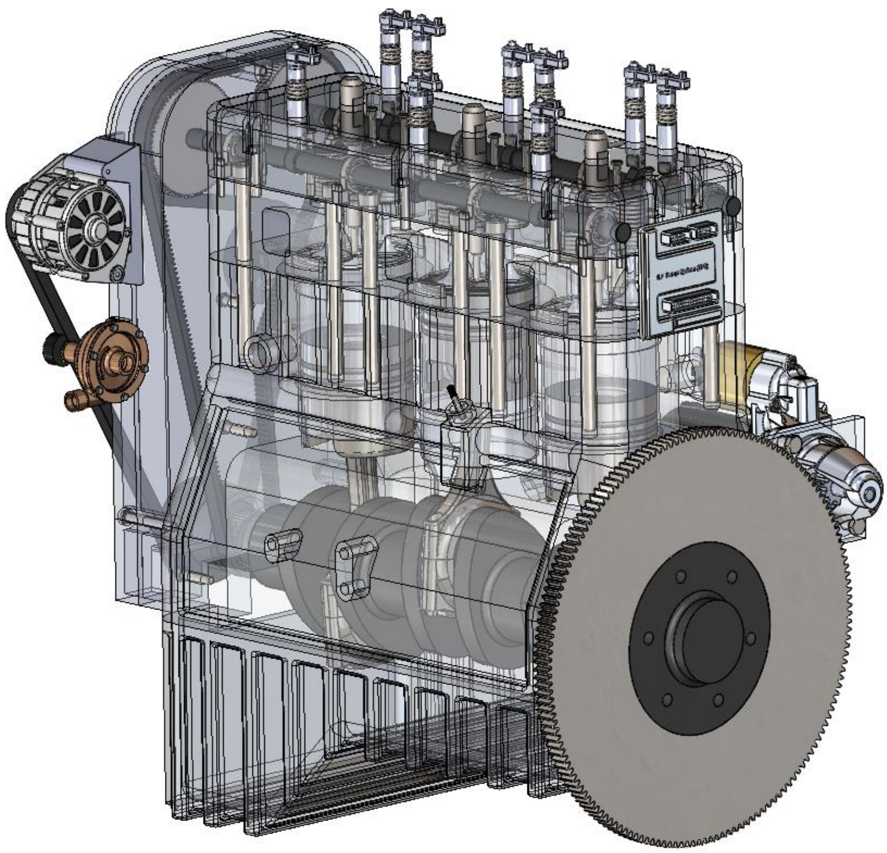

Figure 89 Transparency View of CAD of The Engine Assembly.

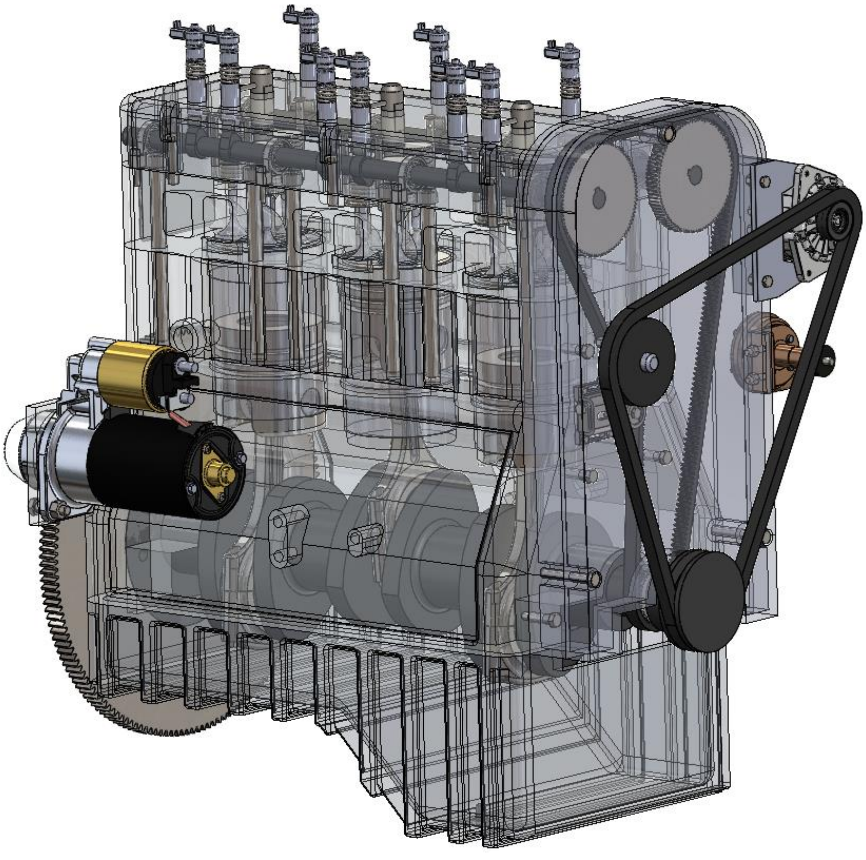

Figure 90 Transparency View of CAD of The Engine Assembly.

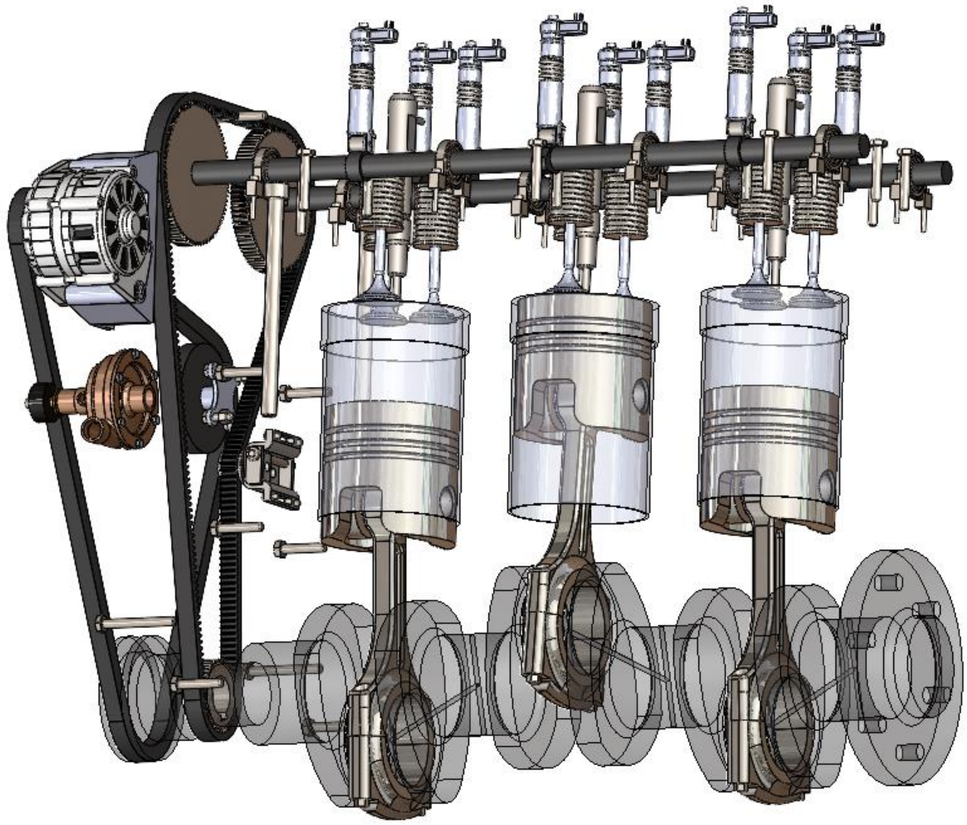

Figure 91 CAD of Crankshaft and Pistons Assembly of The Engine.

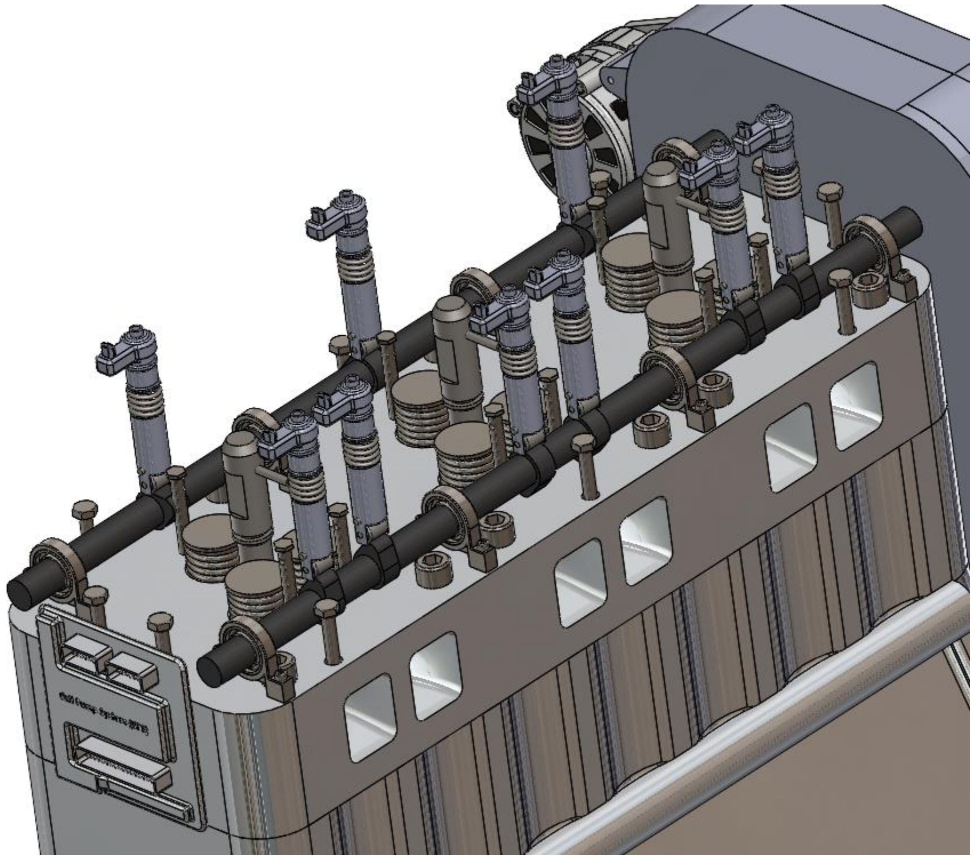

Figure 92 CAD of Assembly UPS, Valves, Valve Springs and Camshafts of The Engine.

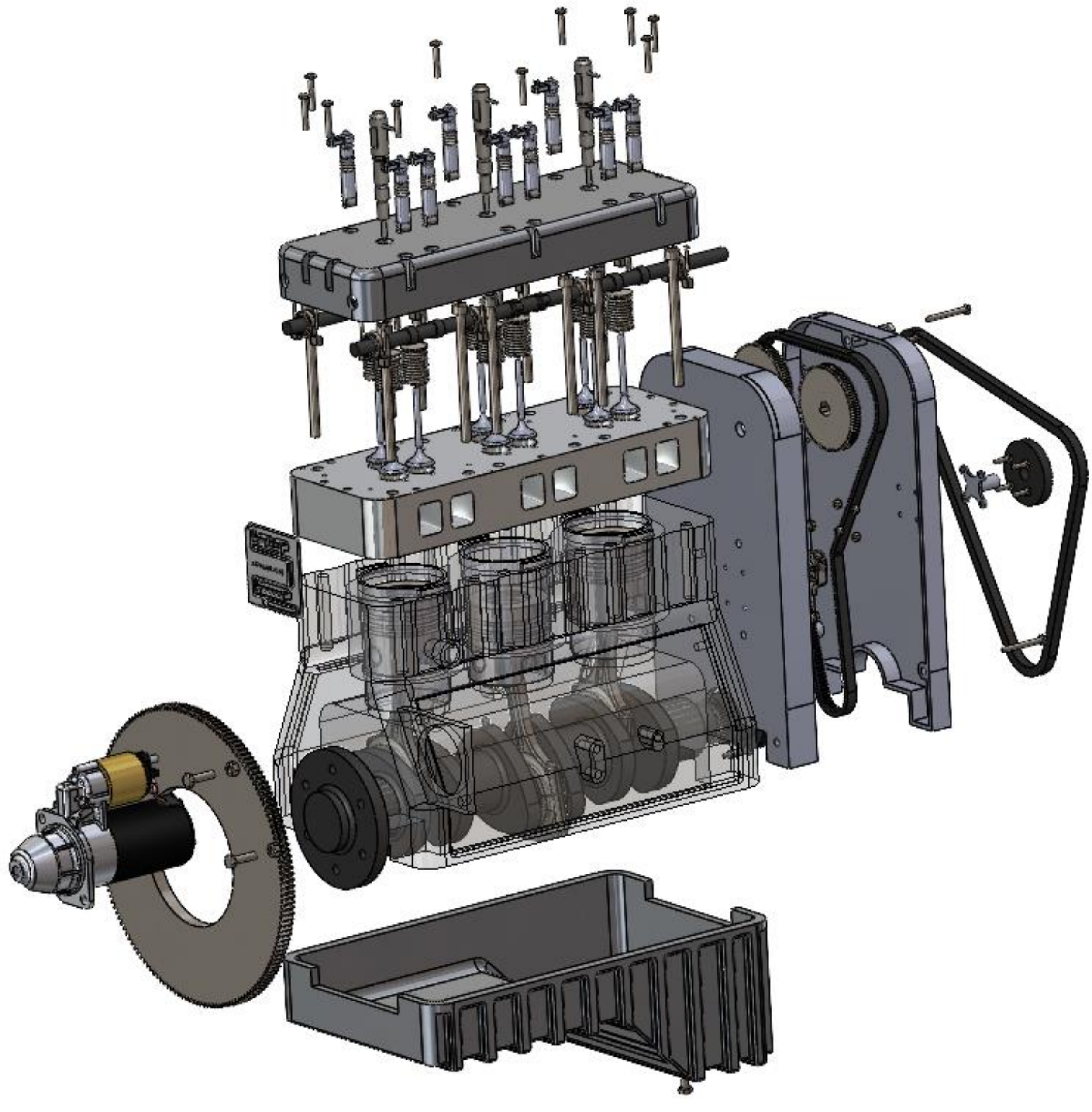

Figure 93 Exploded View of CAD of The Engine.

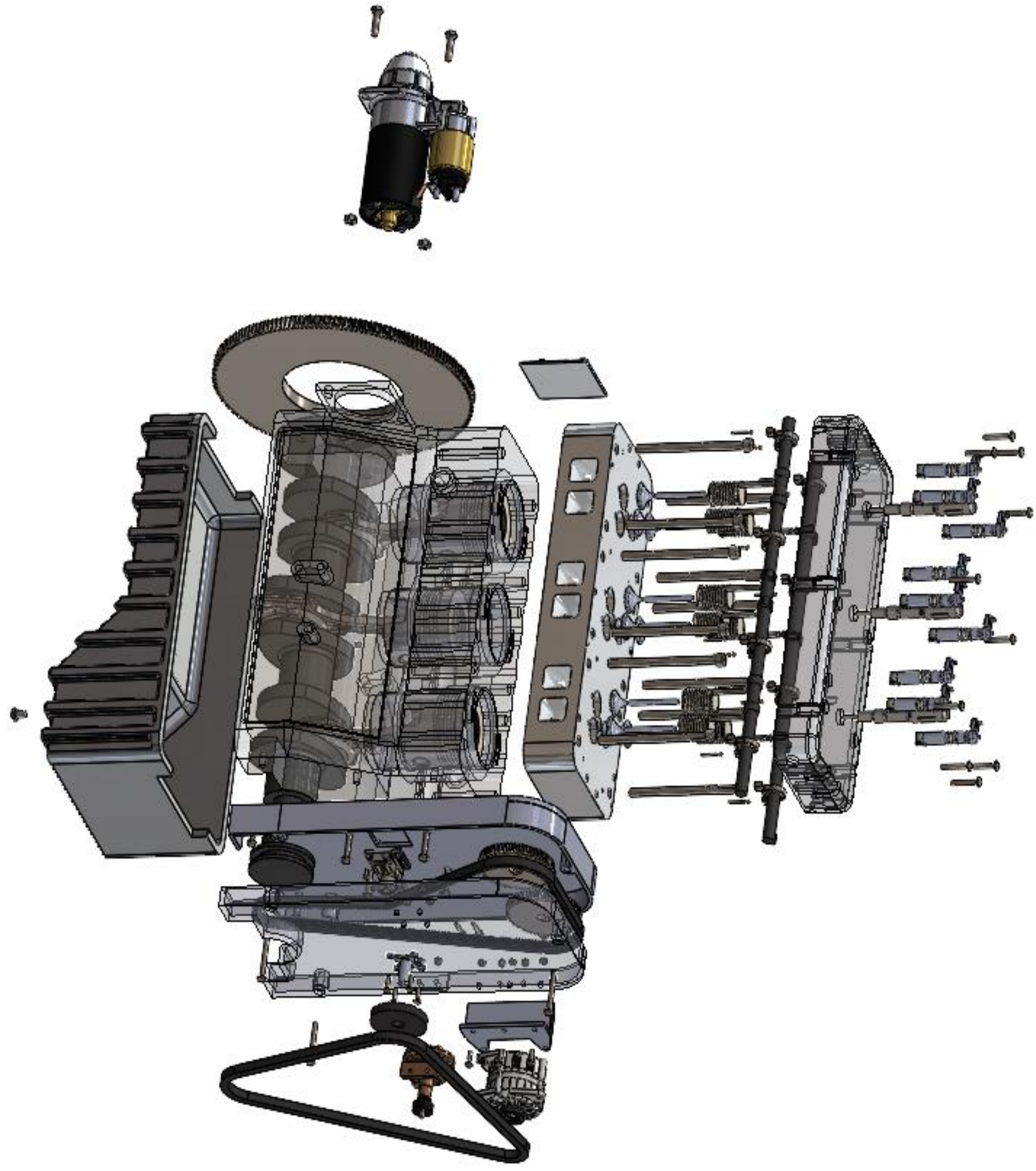

Figure 94 Exploded View of CAD of The Engine.

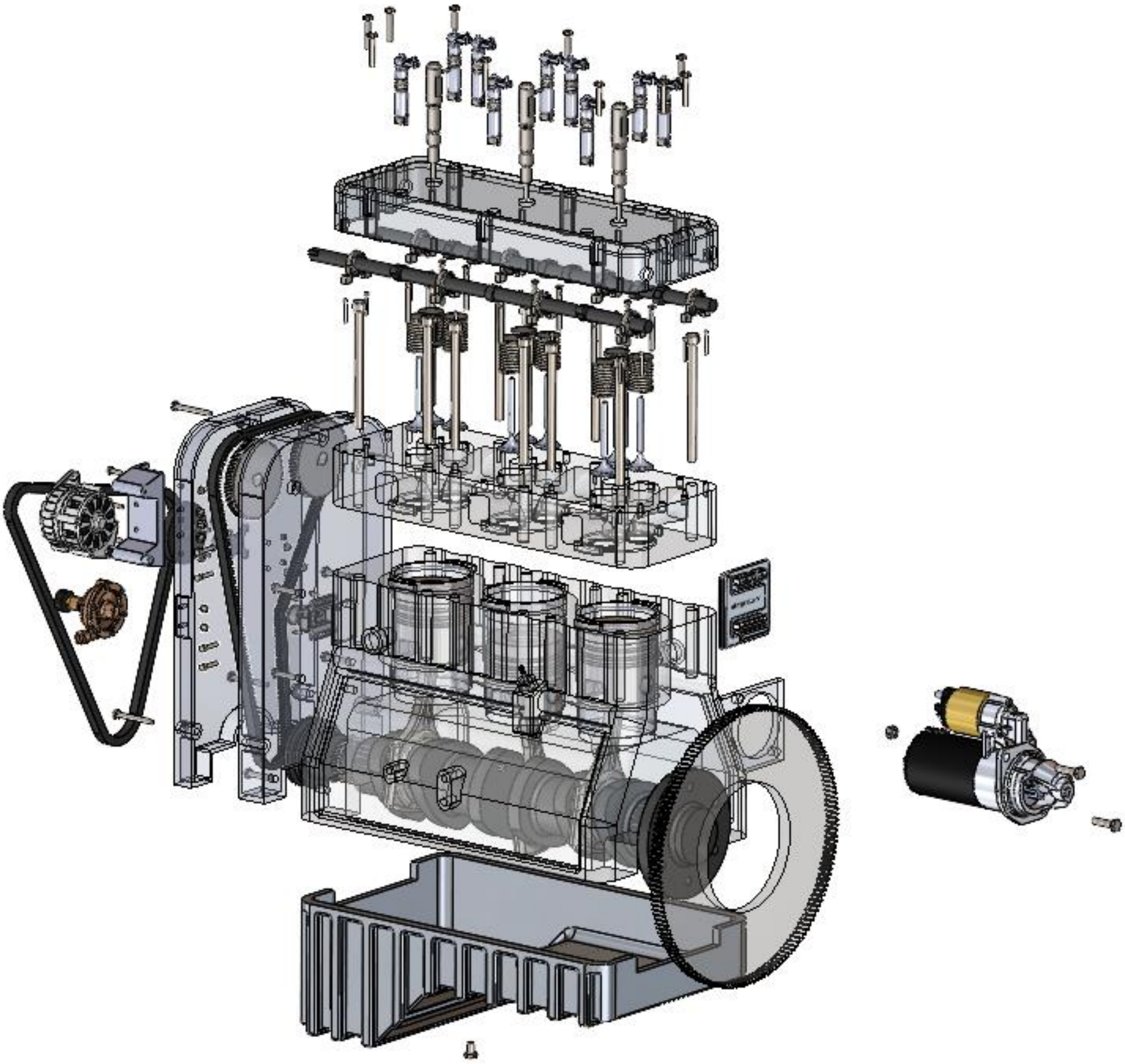

Figure 95 Exploded View of CAD of The Engine.

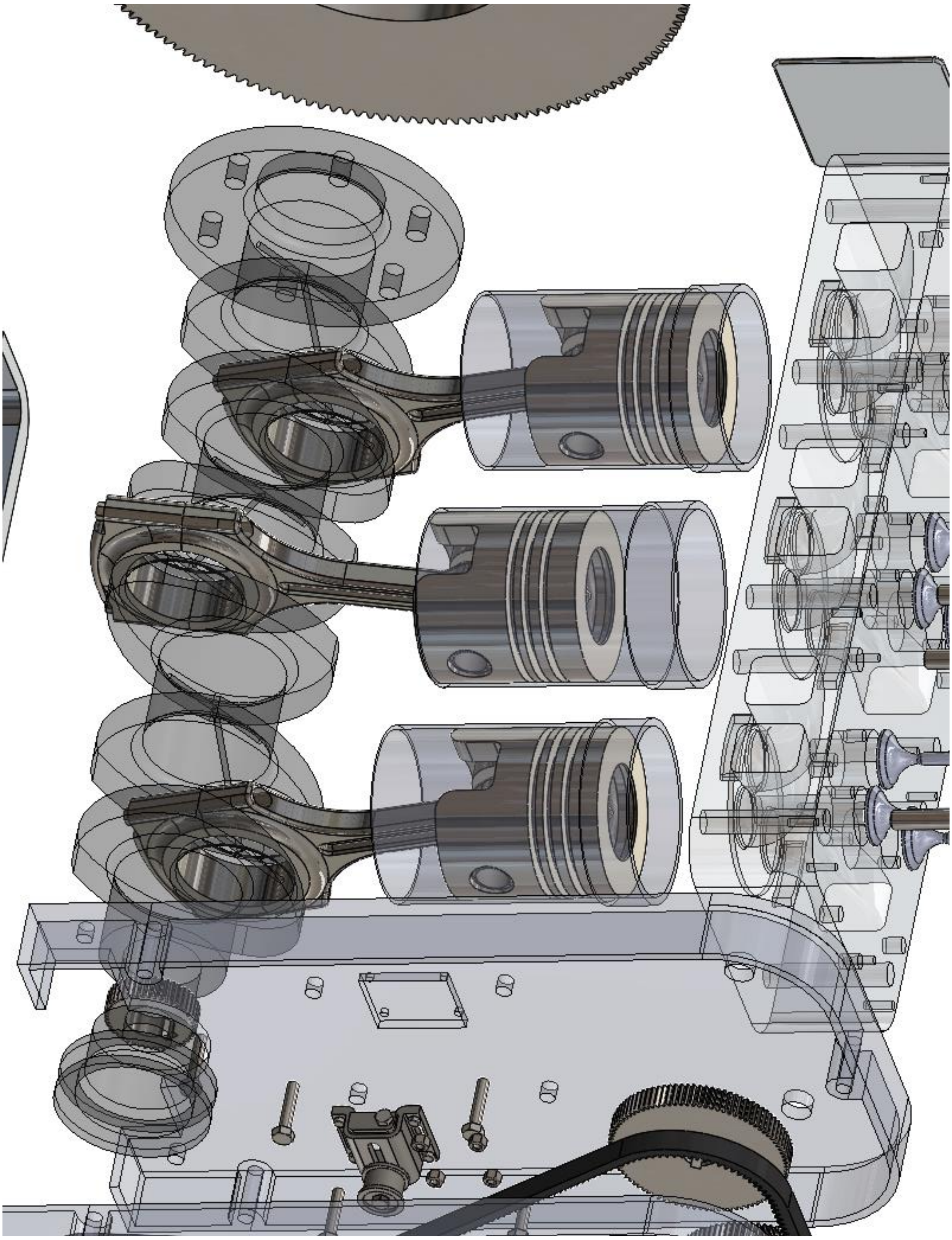

Figure 96 Detailed Exploded View of CAD of The Engine Assembly.

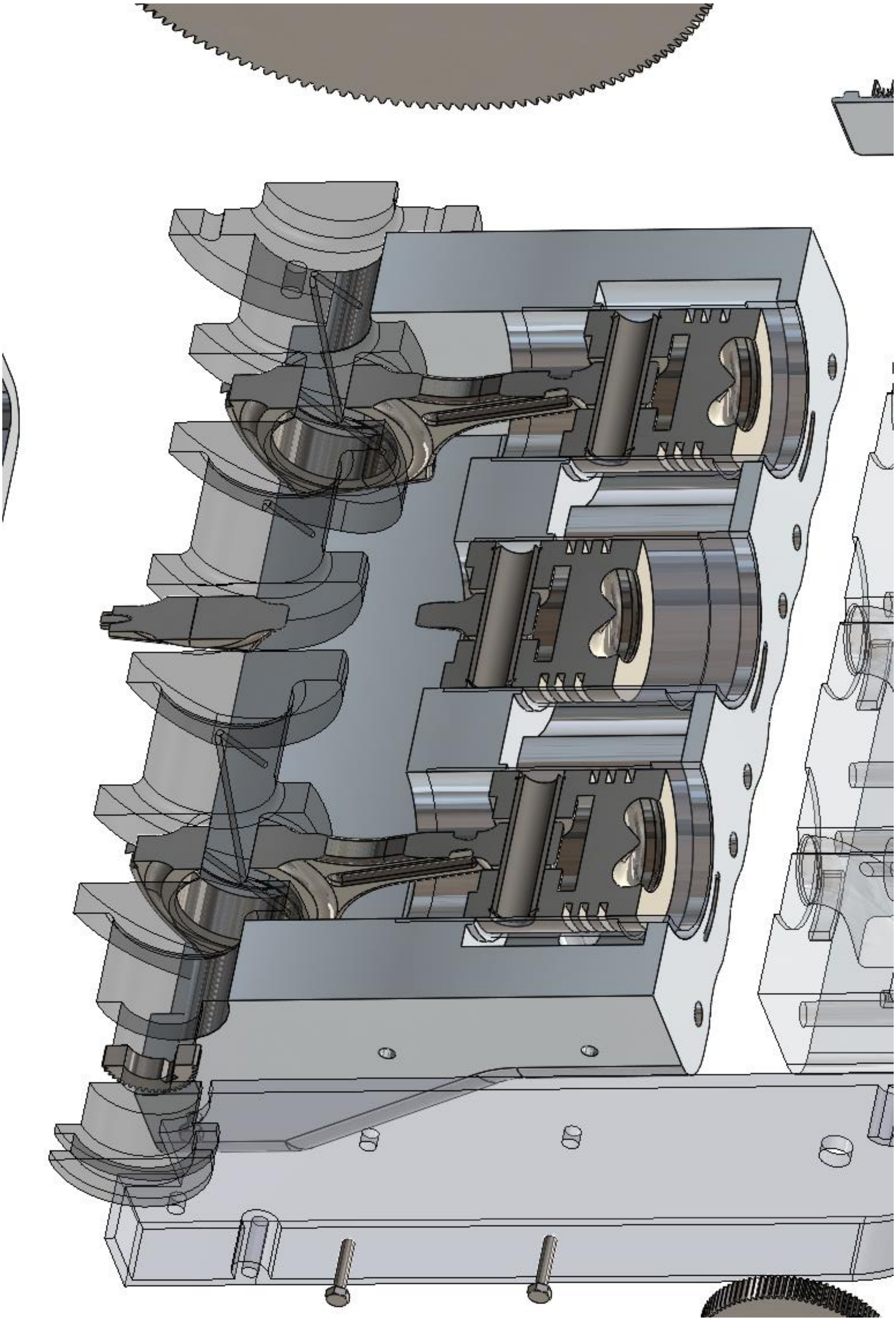

Figure 97 Section View of Detailed Exploded View of The Engine CAD Assembly.

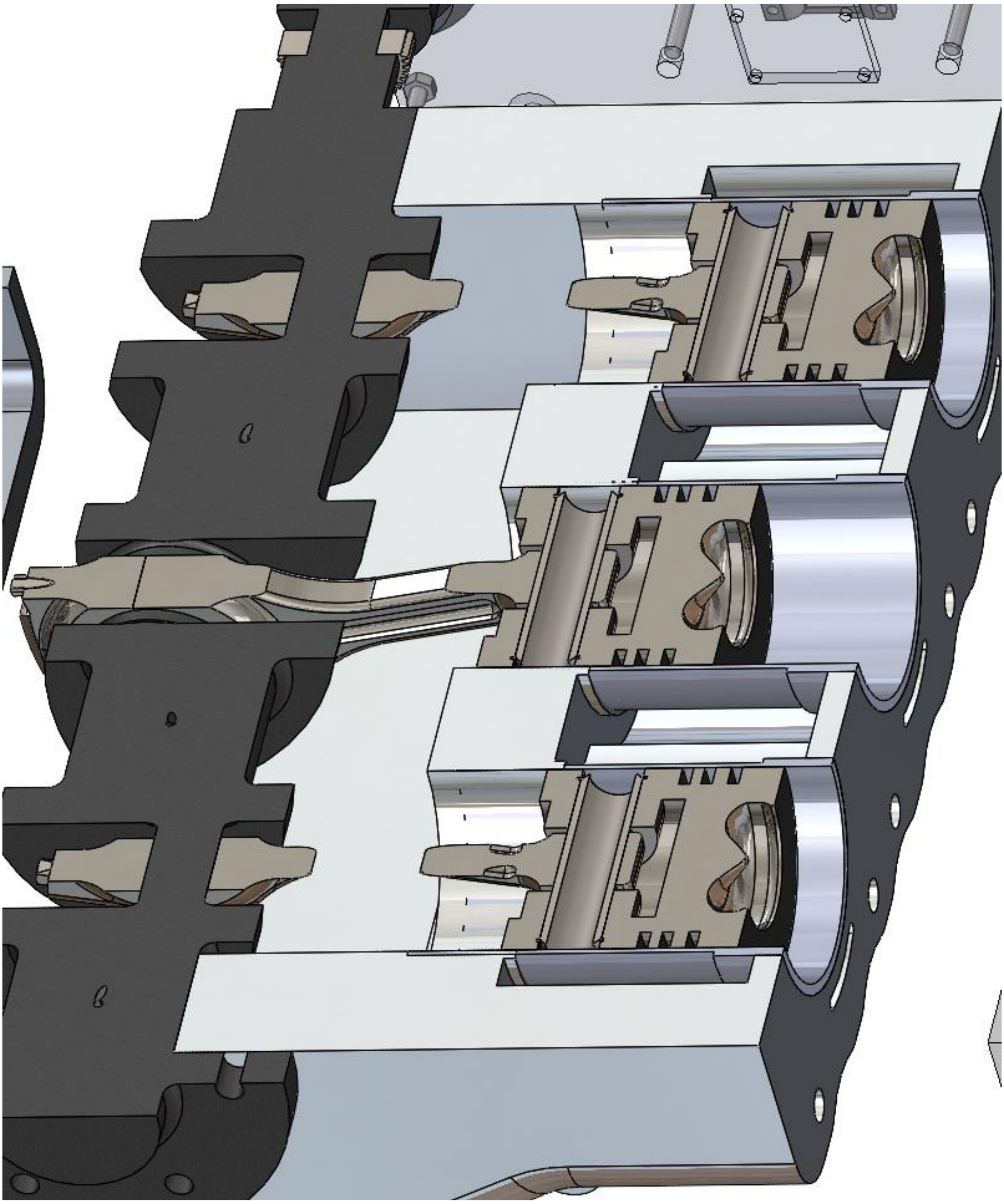

Figure 98 Section View of Detailed Exploded View of The Engine CAD Assembly.

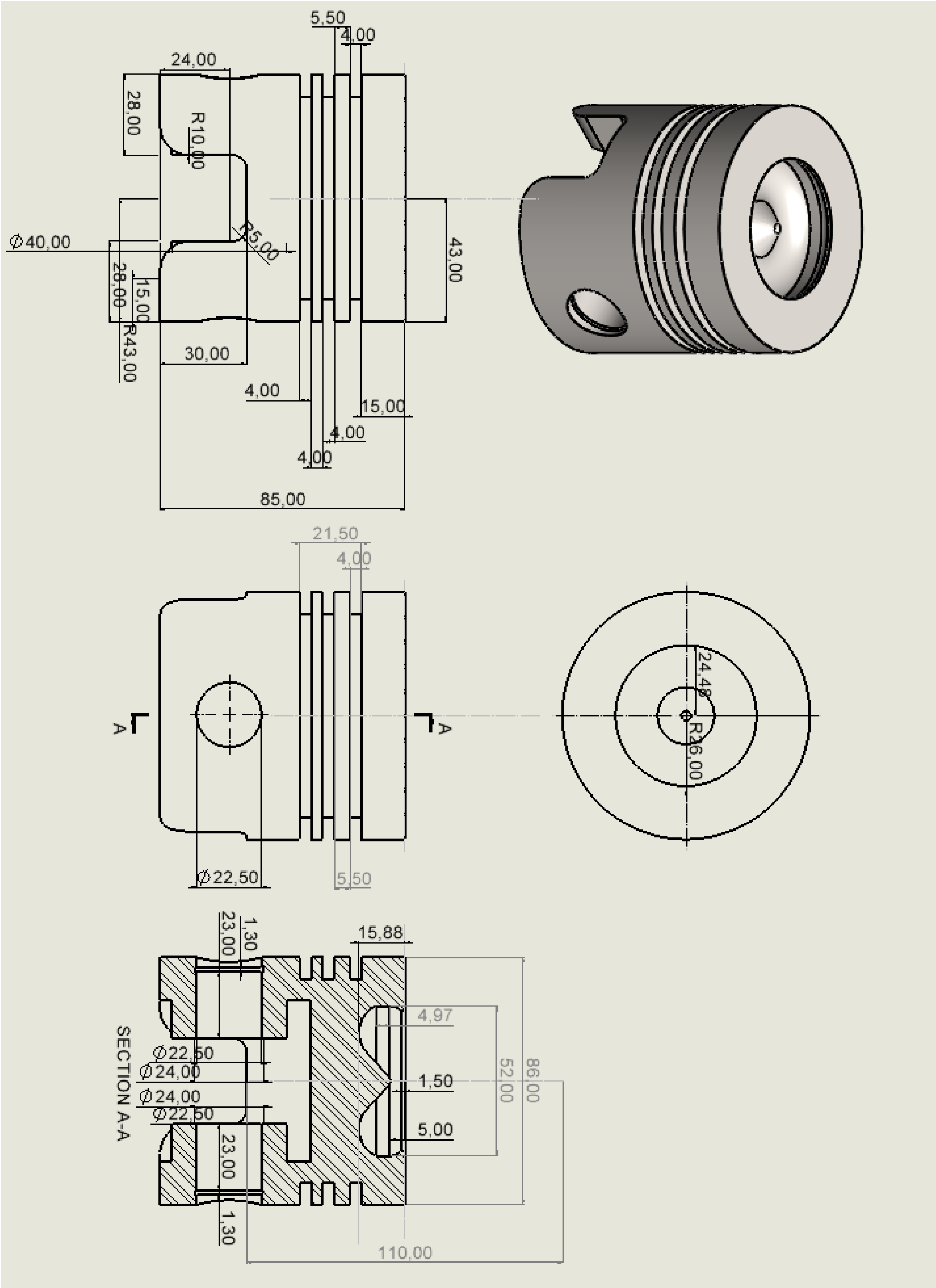

Figure 99 Technical Drawing of Piston.

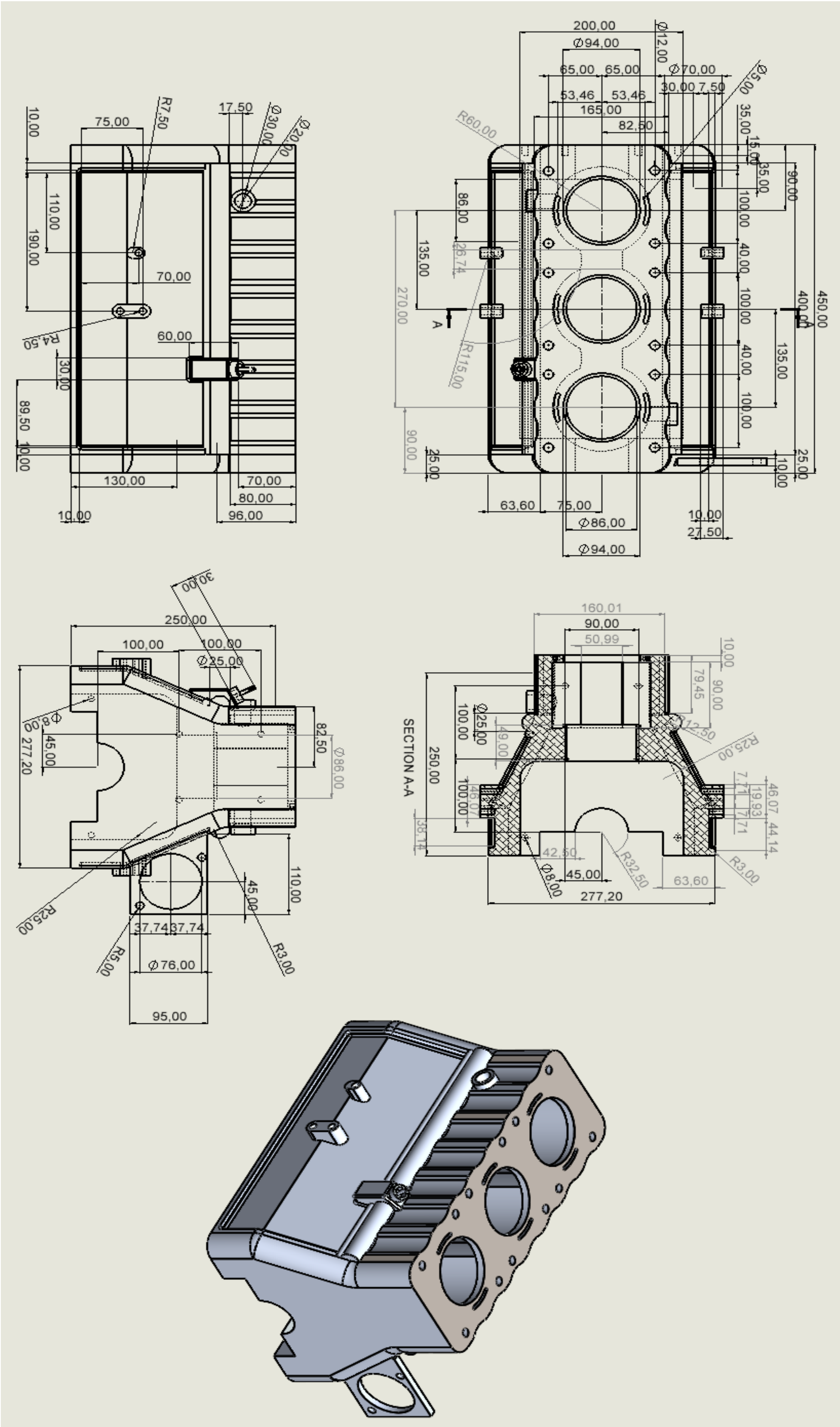

Figure 100 Technical Drawing of Engine Block.

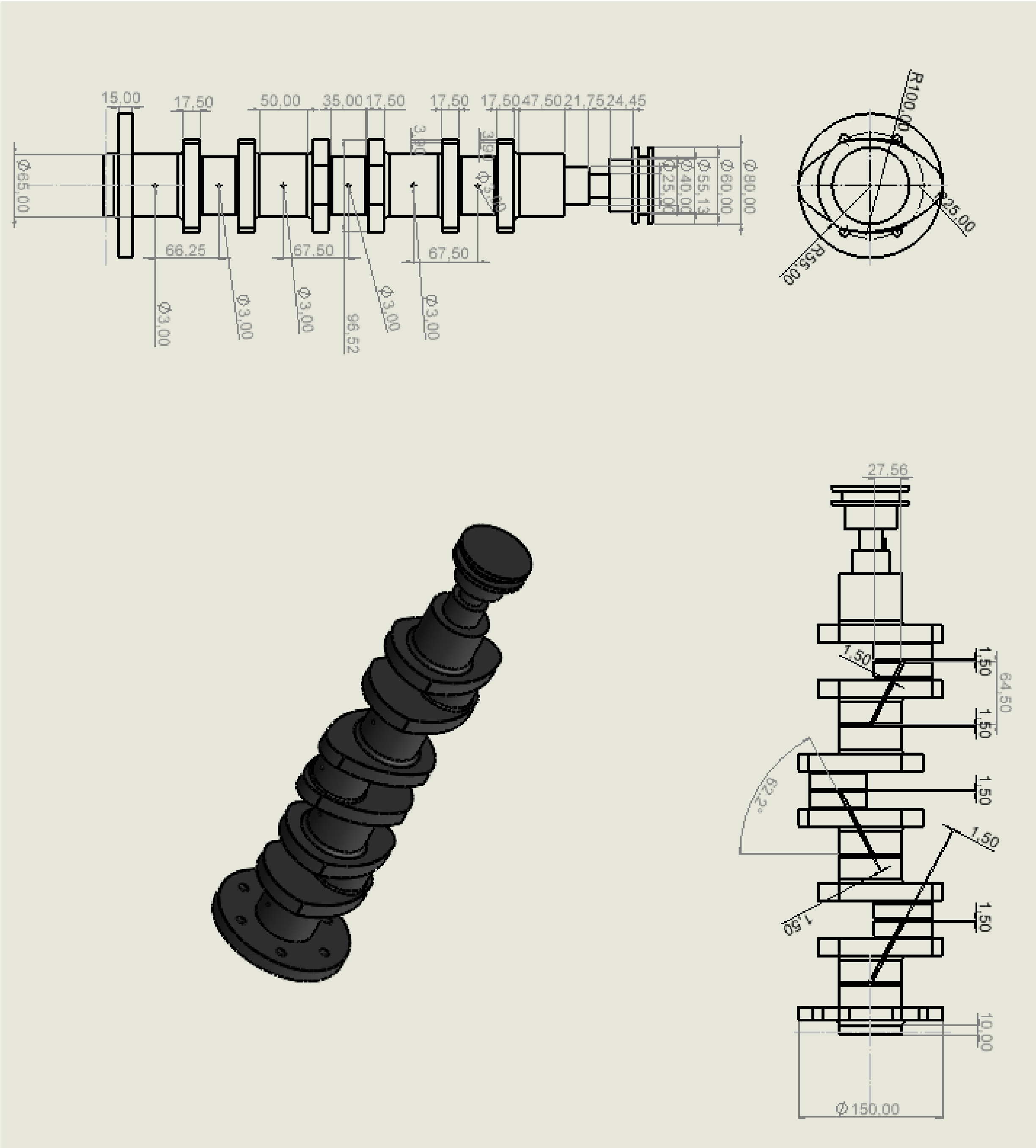

Figure 101 Technical Drawing of Crankshaft.

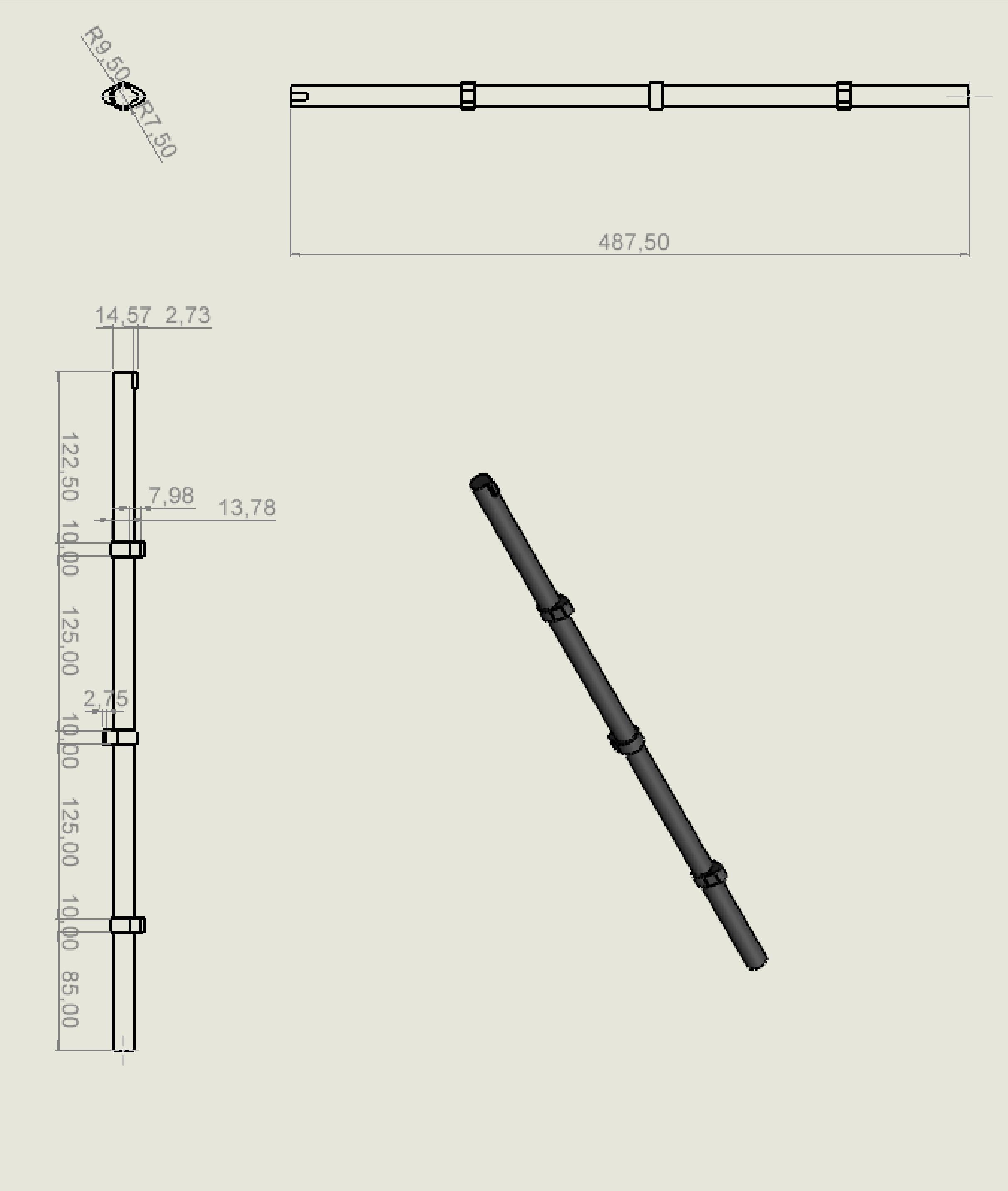

Figure 102 Technical Drawing of Exhaust Valves Camshaft.

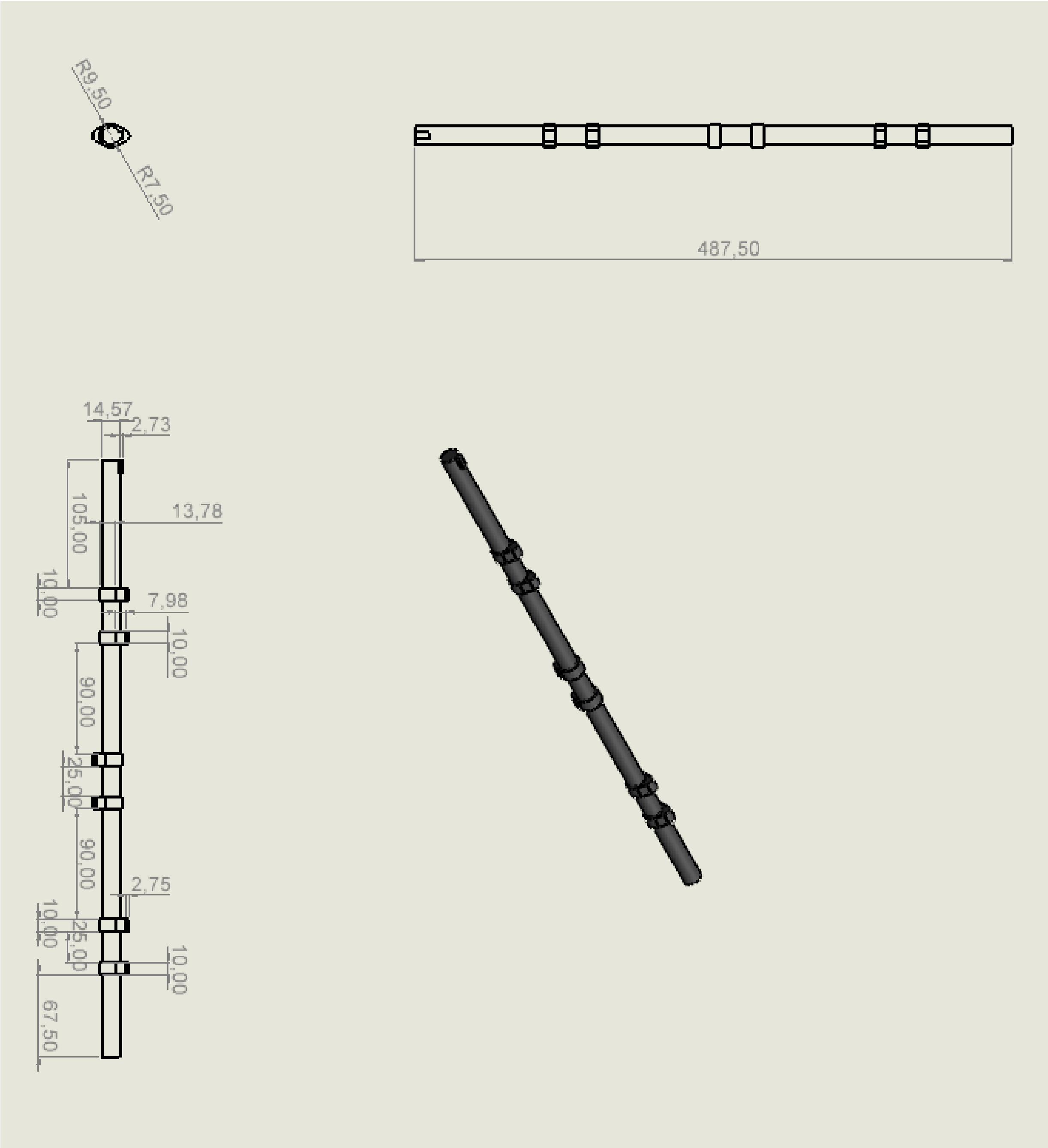

Figure 103 Technical Drawing of Intake Valves Camshaft.

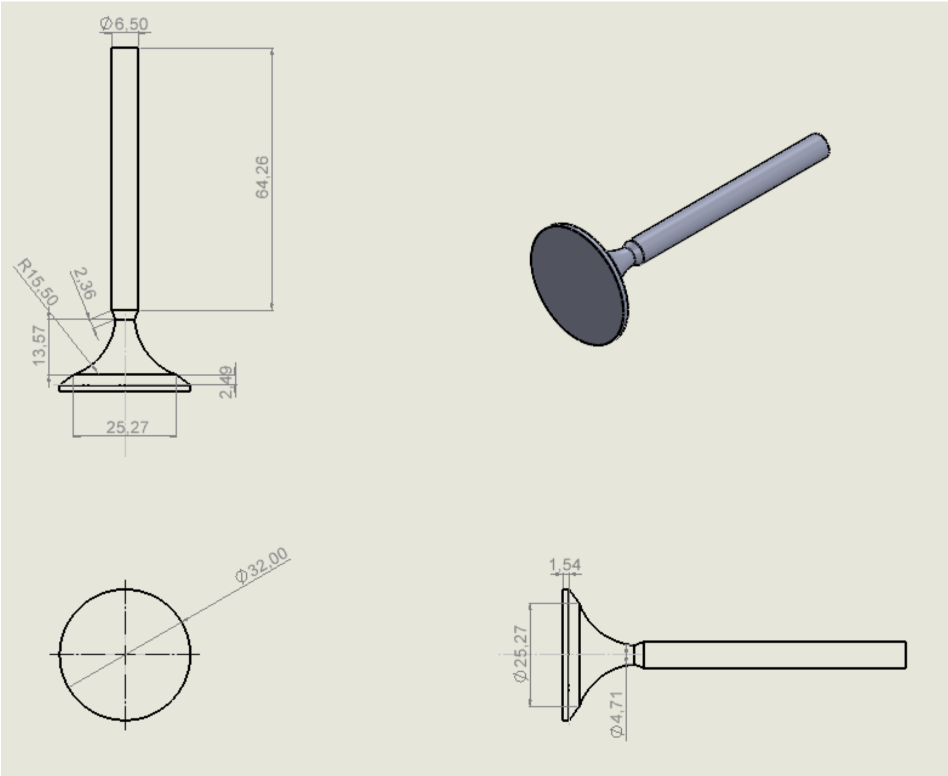

Figure 104 Technical Drawing of Exhaust Valve.

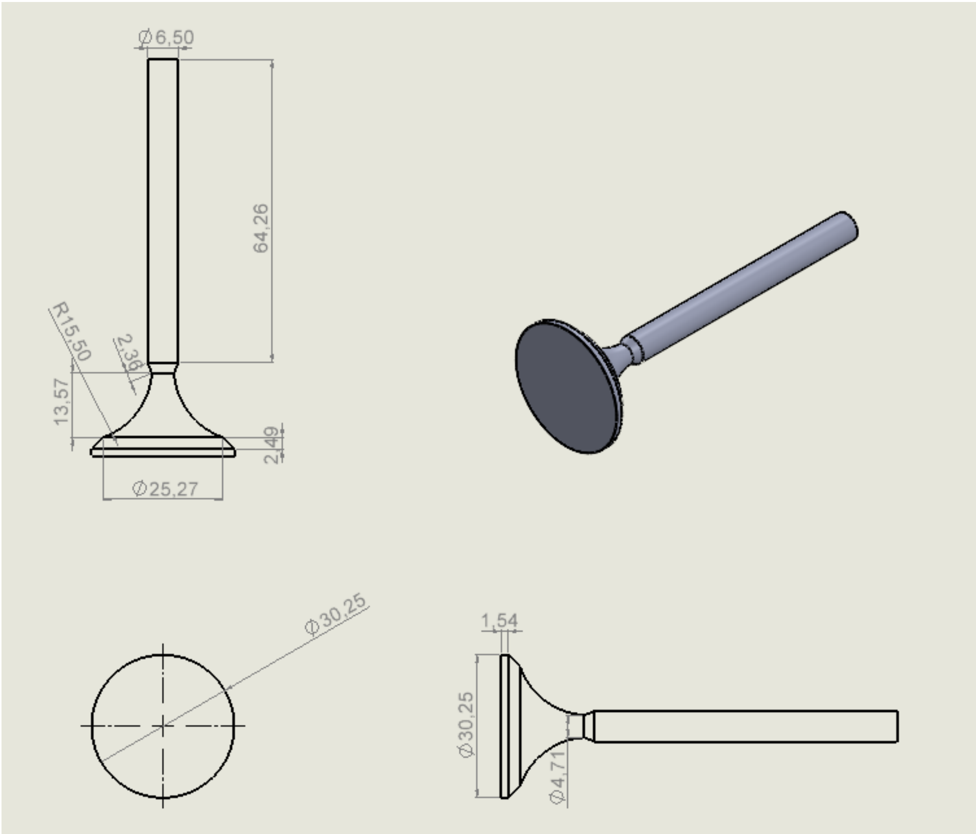

Figure 105 Technical Drawing of Intake Valve.

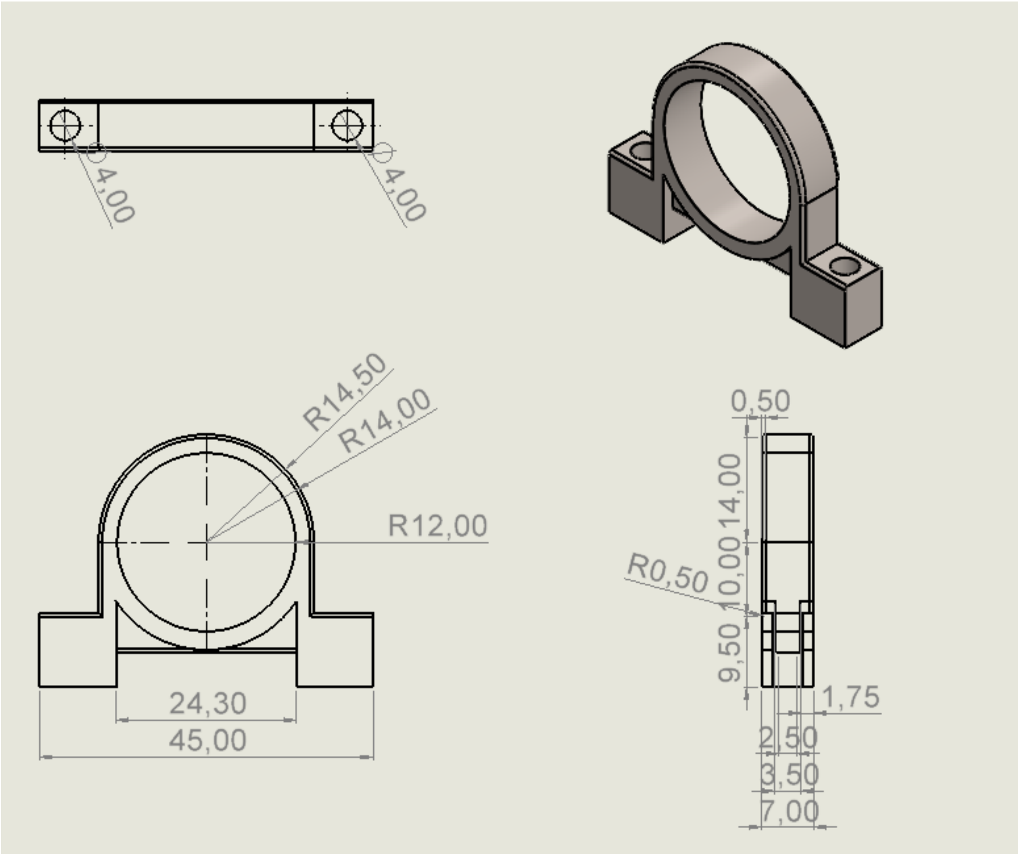

Figure 106 Technical Drawing of Bearing Seat.

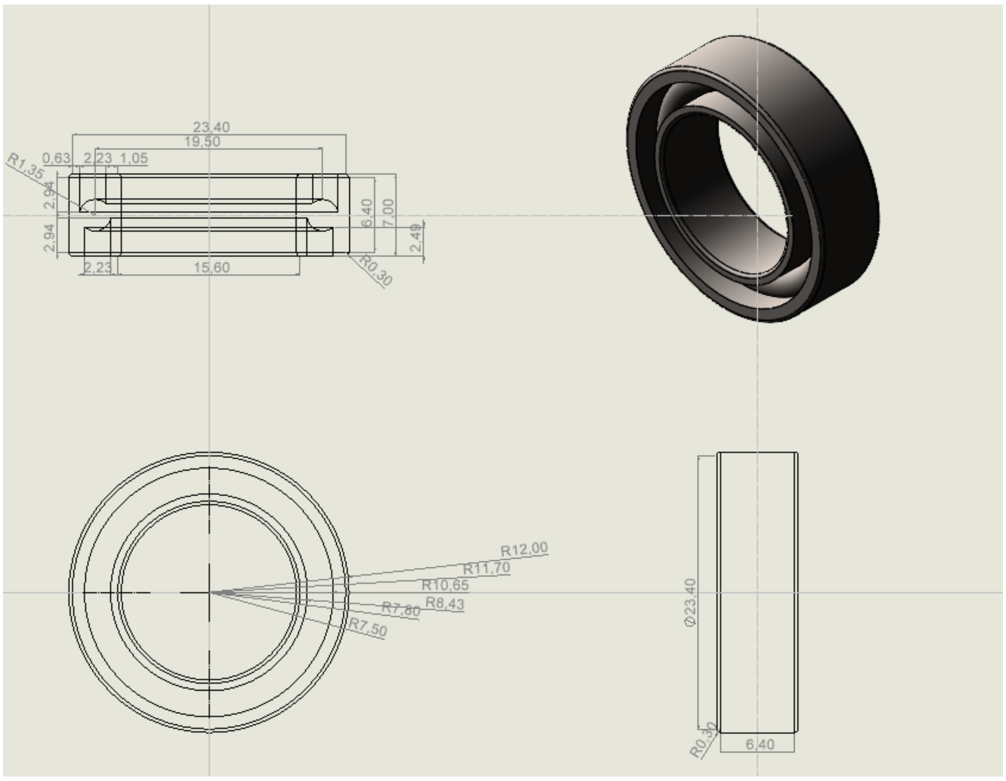

Figure 107 Technical Drawing Ball Bearing.

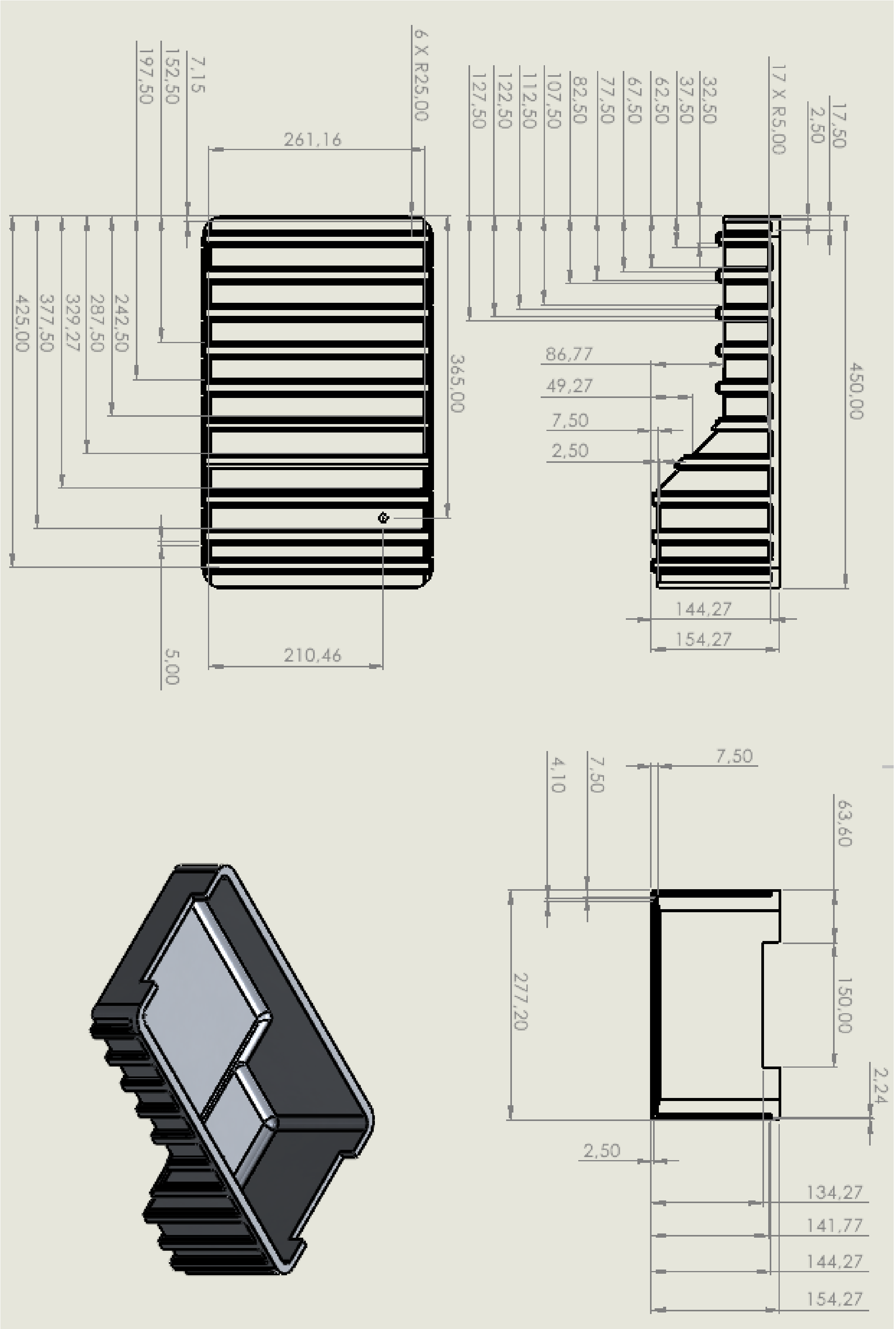

Figure 108 Technical Drawing of Crankcase.

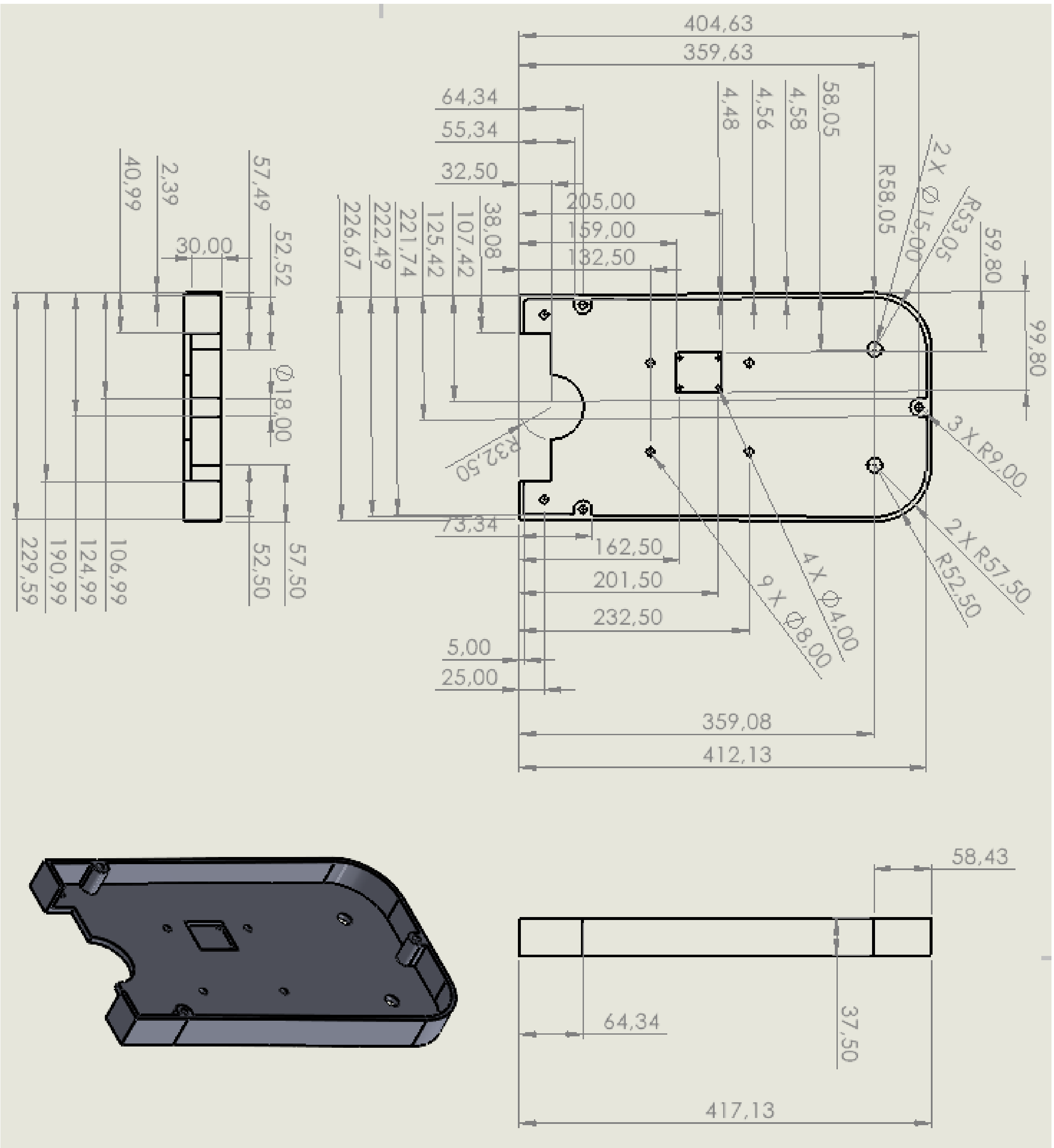

Figure 109 Technical Drawing of Gearbox.

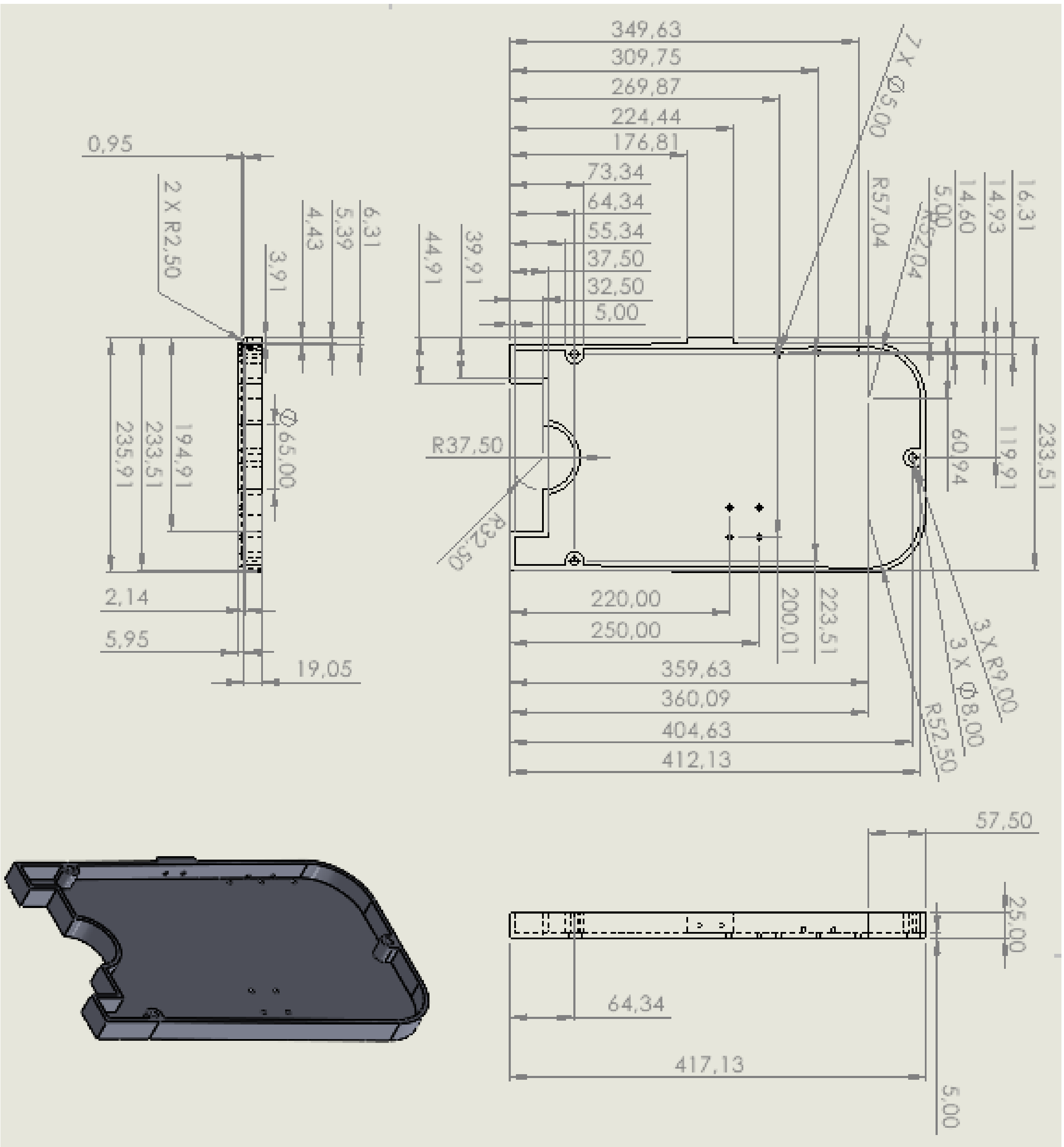

Figure 110 Technical Drawing of Gearbox Cap.

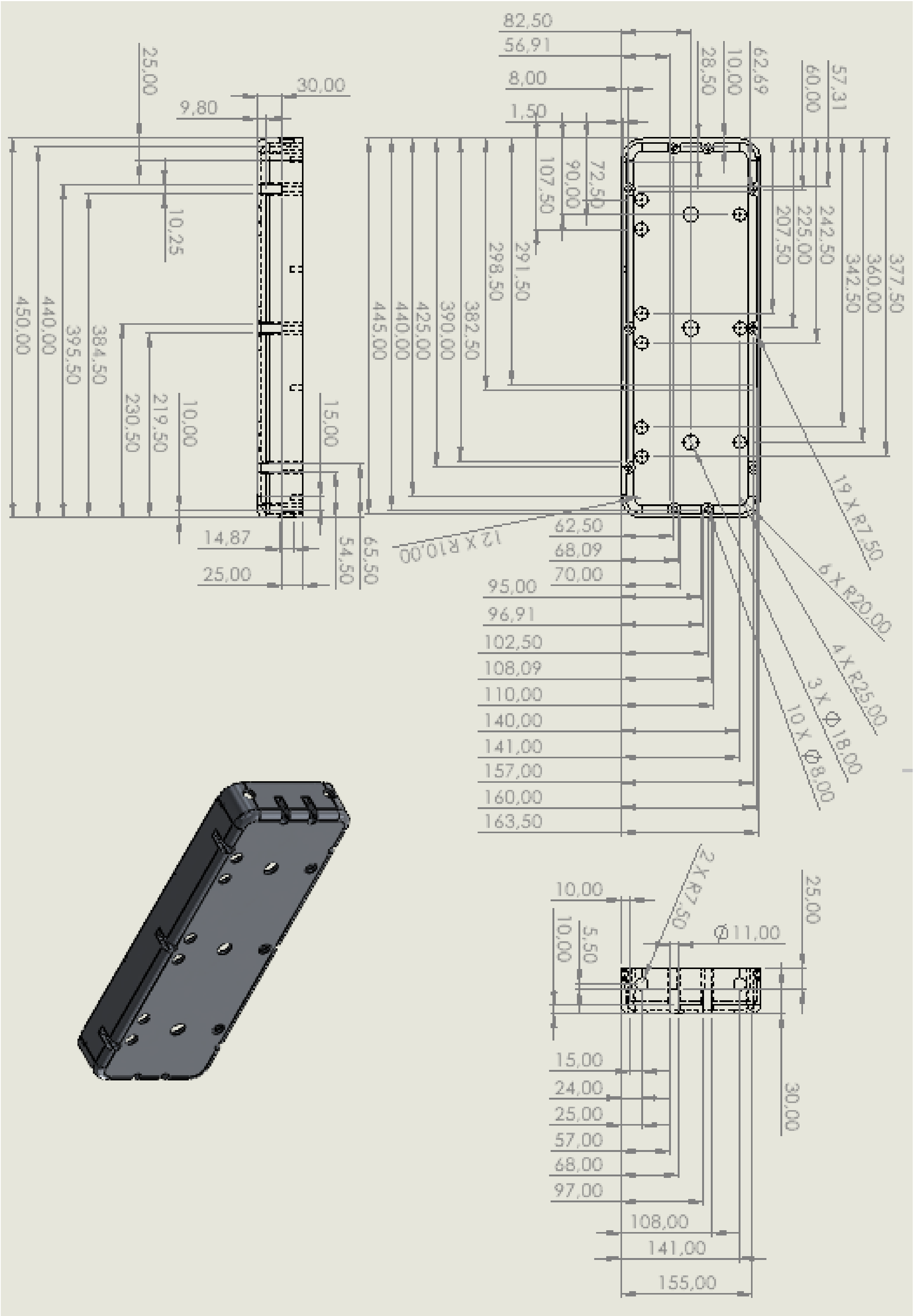

Figure 111 Technical Drawing of Rocker, Camshafts and Valves Cap.

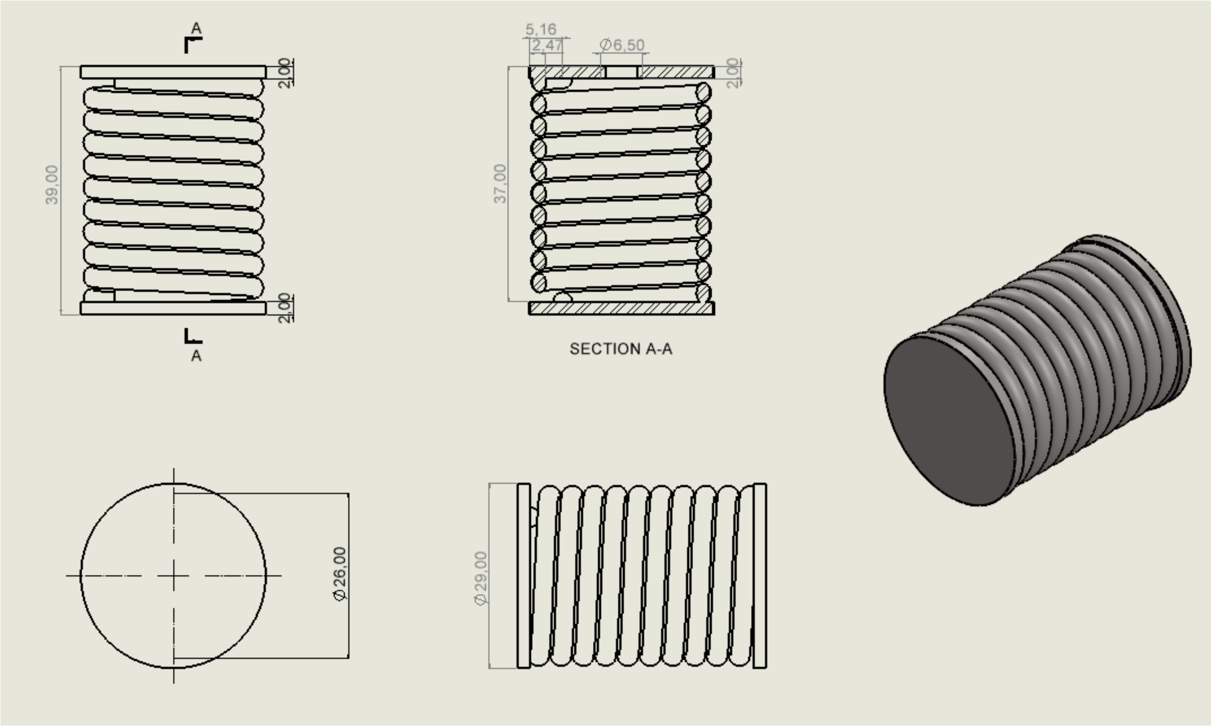

Figure 112 Technical Drawing of Intake Valve Spring.

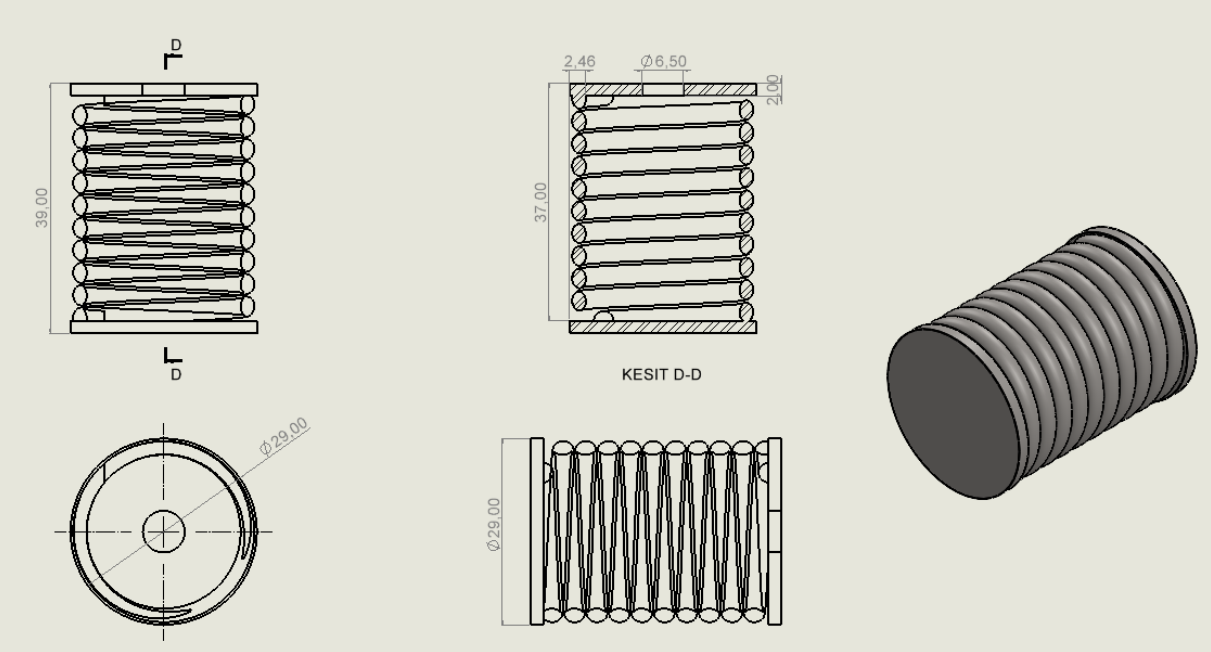

Figure 113 Technical Drawing of Exhaust Valve Spring.

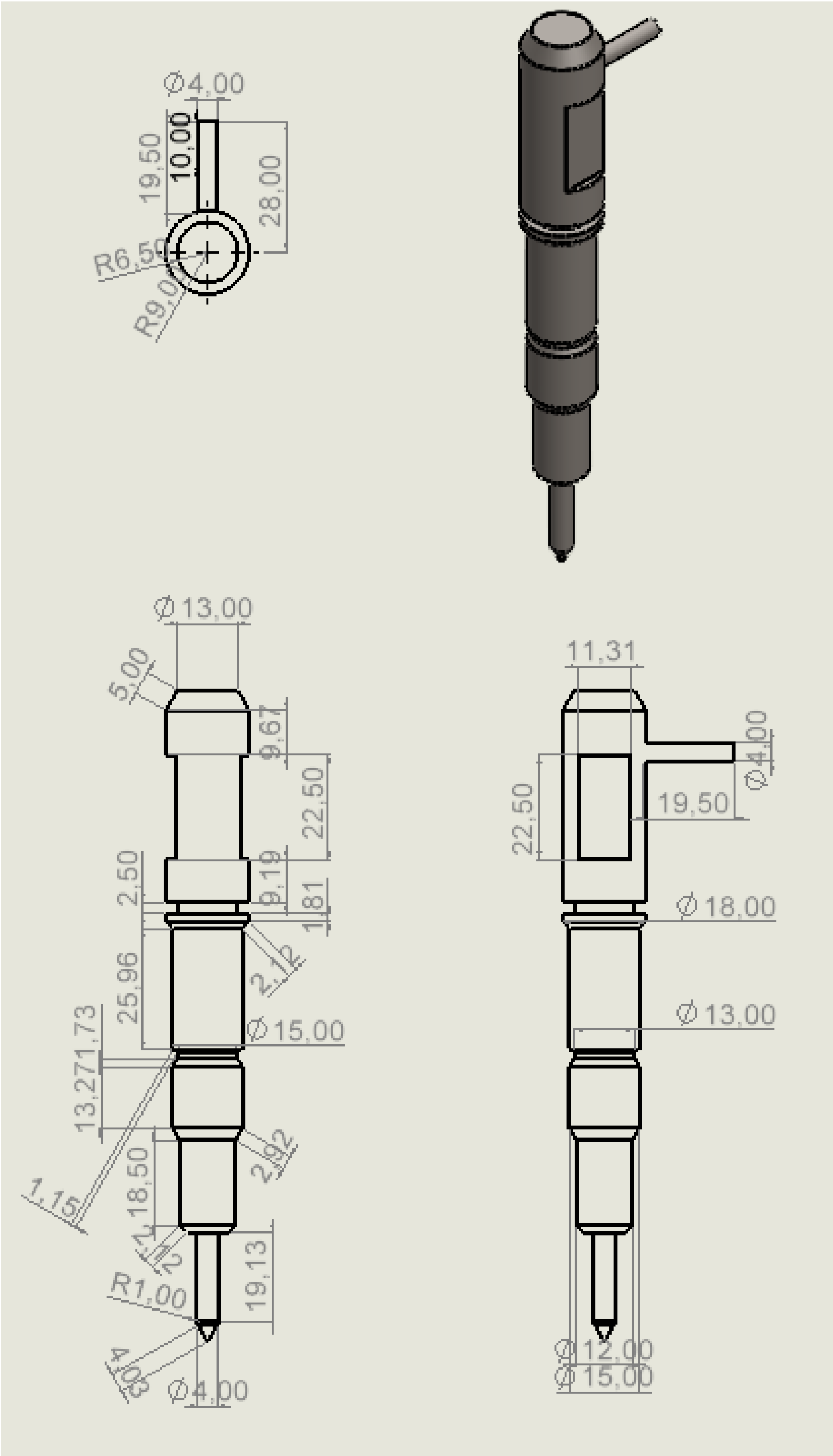

Figure 114 Technical Drawing of Injection.

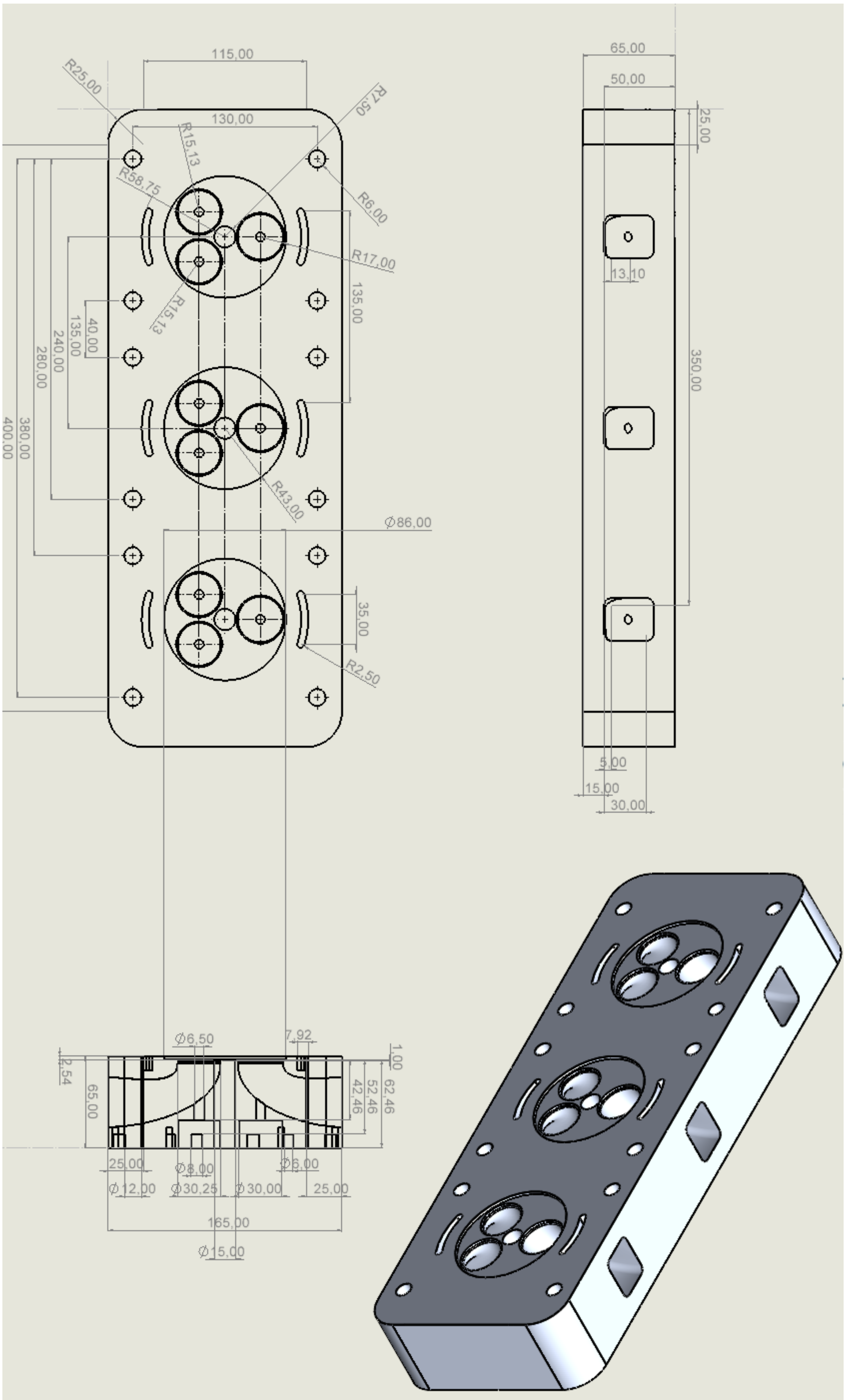

Figure 115 Technical Drawing of Engine Up Block.

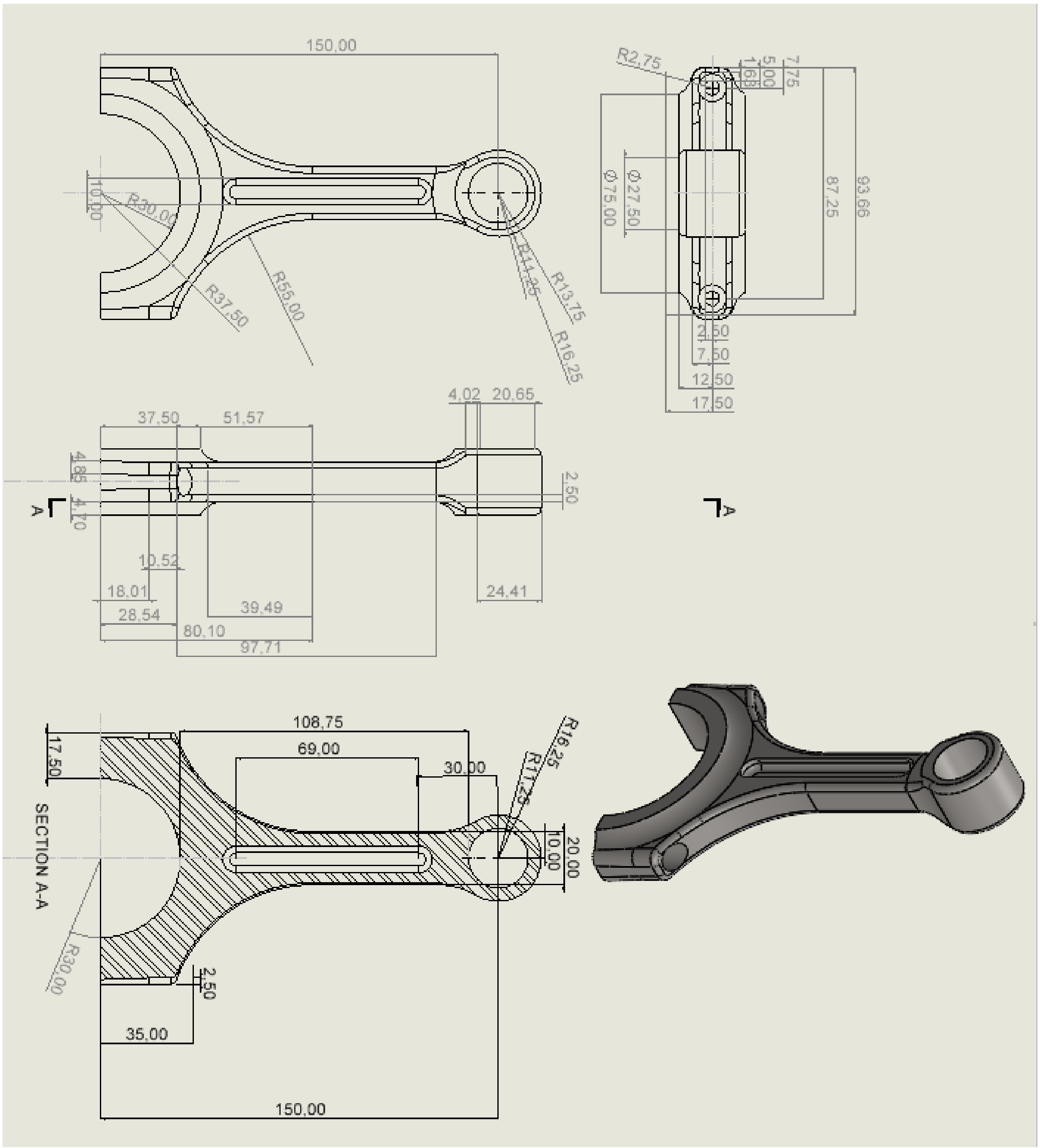

Figure 116 Technical Drawing of Piston Rod Body.

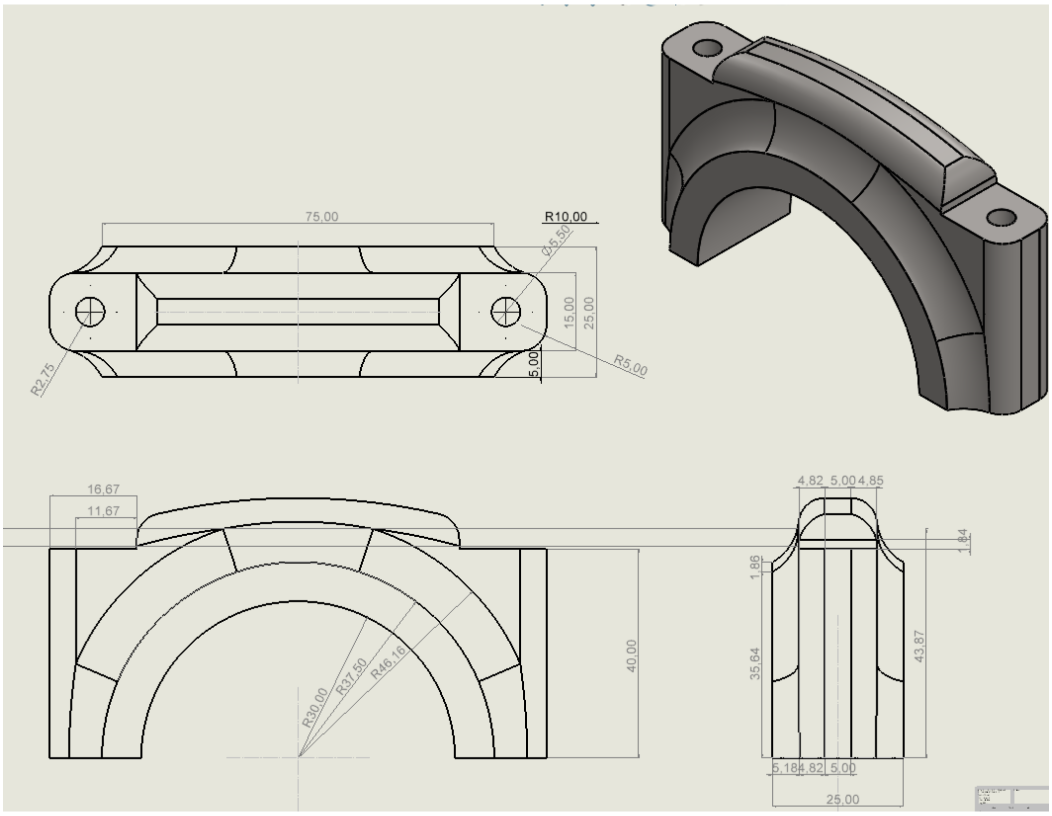

Figure 117 Technical Drawing of Piston Rod Down.

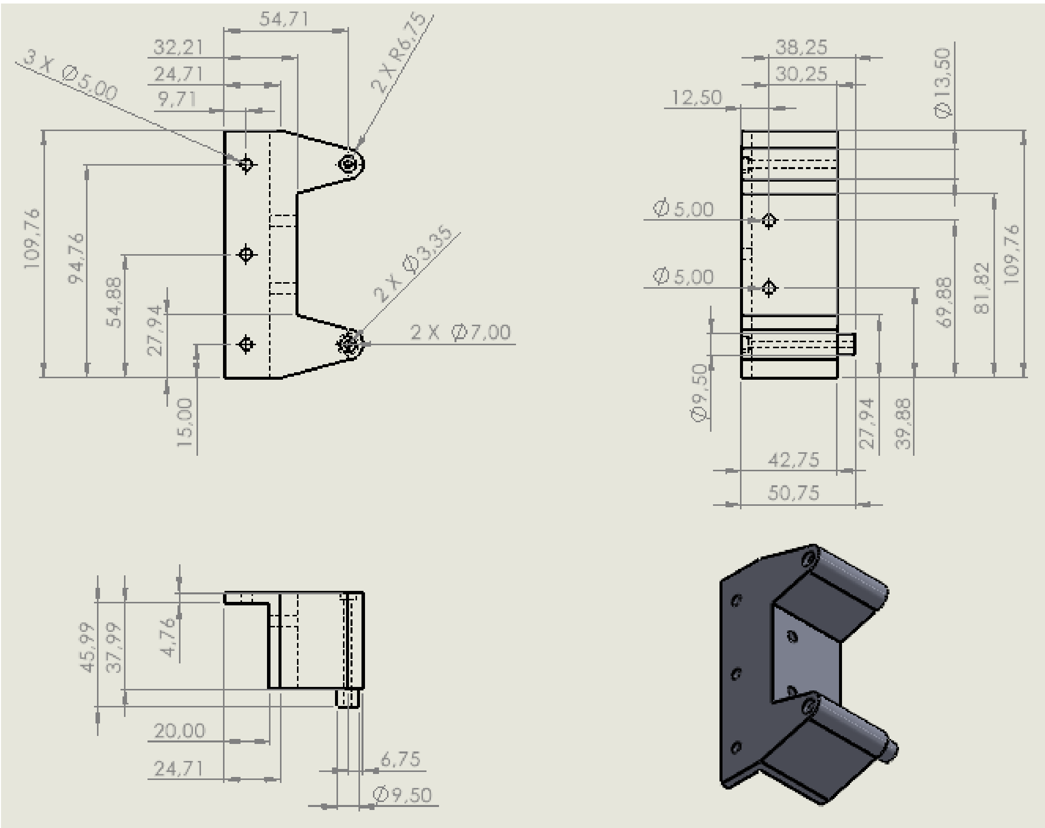

Figure 118 Technical Drawing of Alternator Connect.

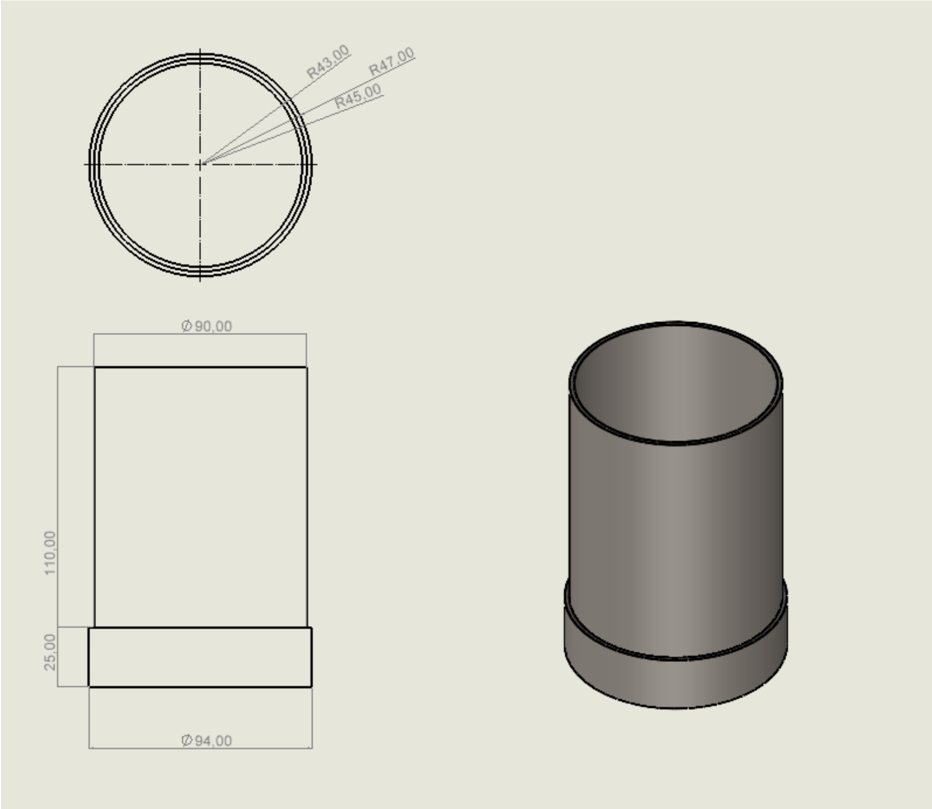

Figure 119 Technical Drawing of Cylinder Liner.

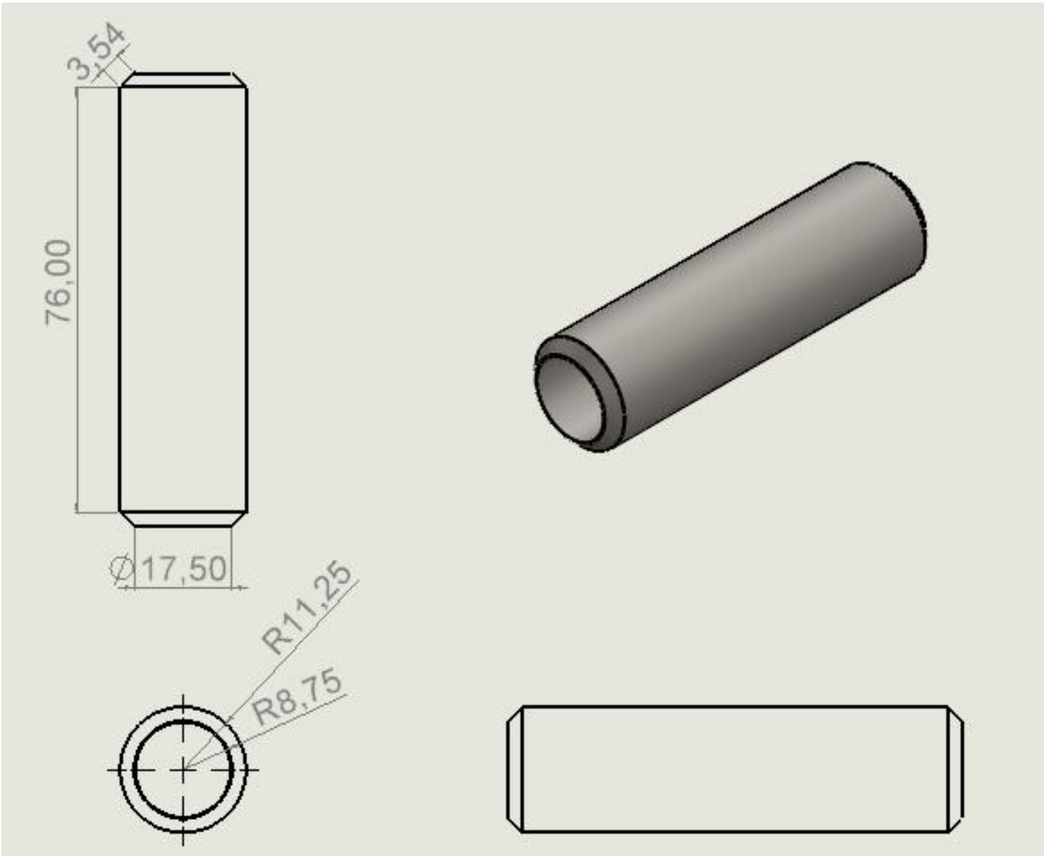

Figure 120 Technical Drawing of Piston Pin.

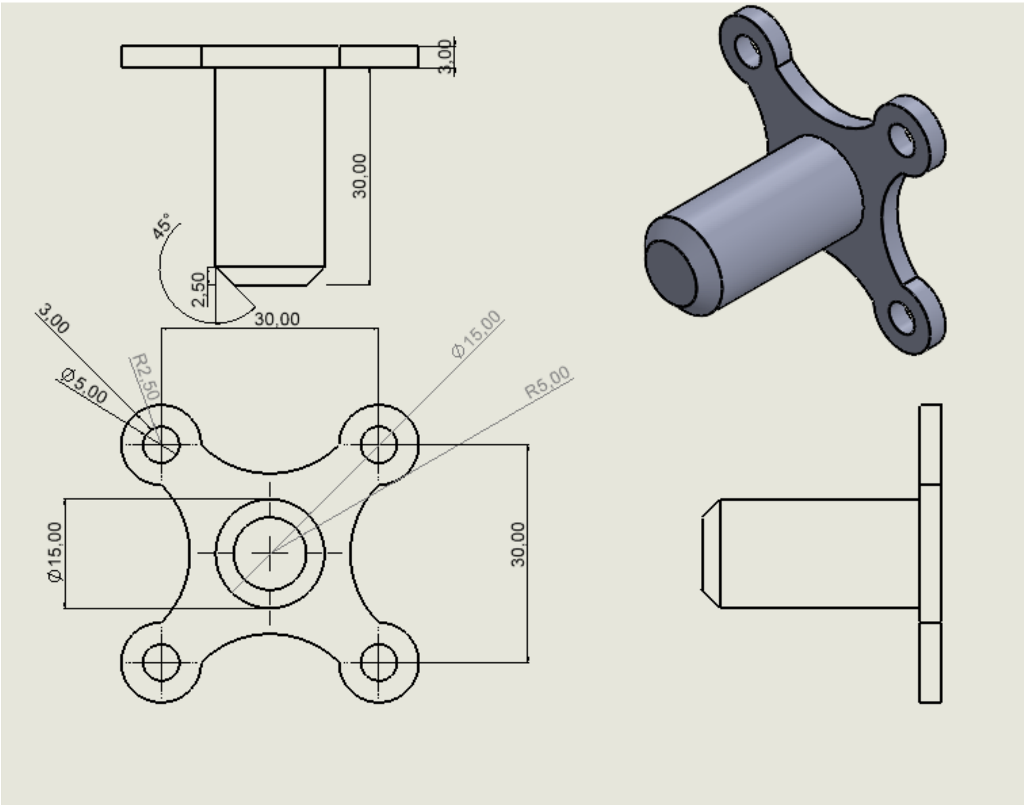

Figure 121 Technical Drawing of Pulley Bracket.

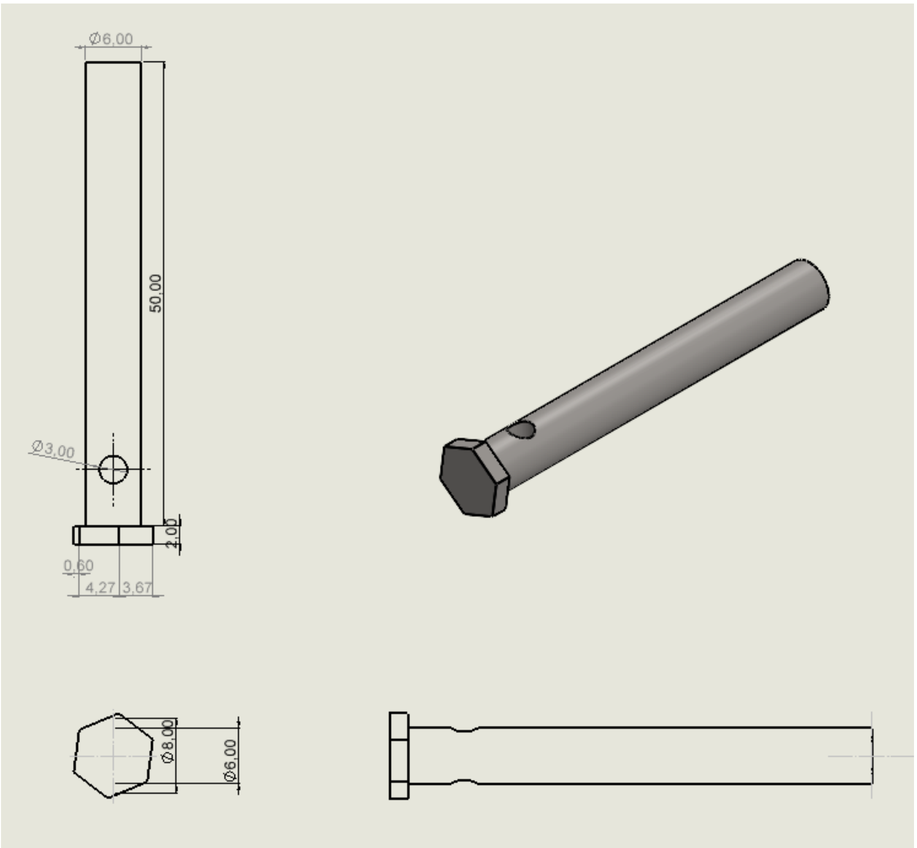

Figure 122 Technical Drawing of Rocker Screw.

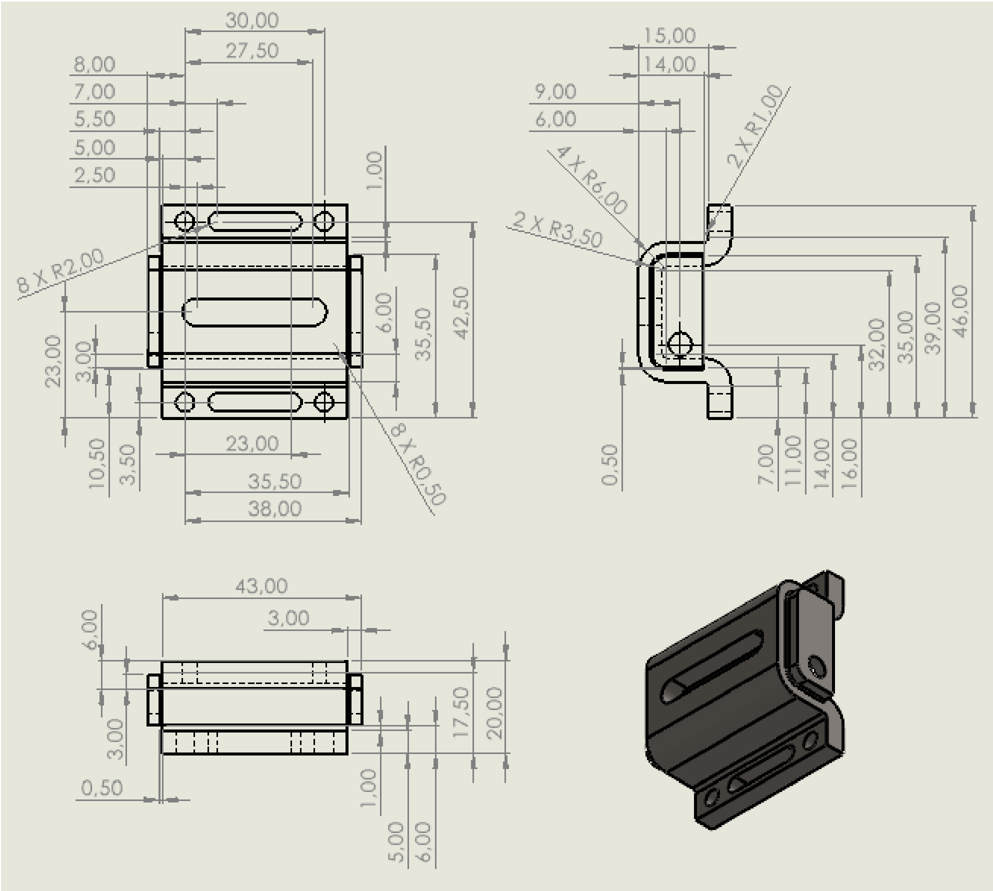

Figure 123 Technical Drawing of Tensioner Base.

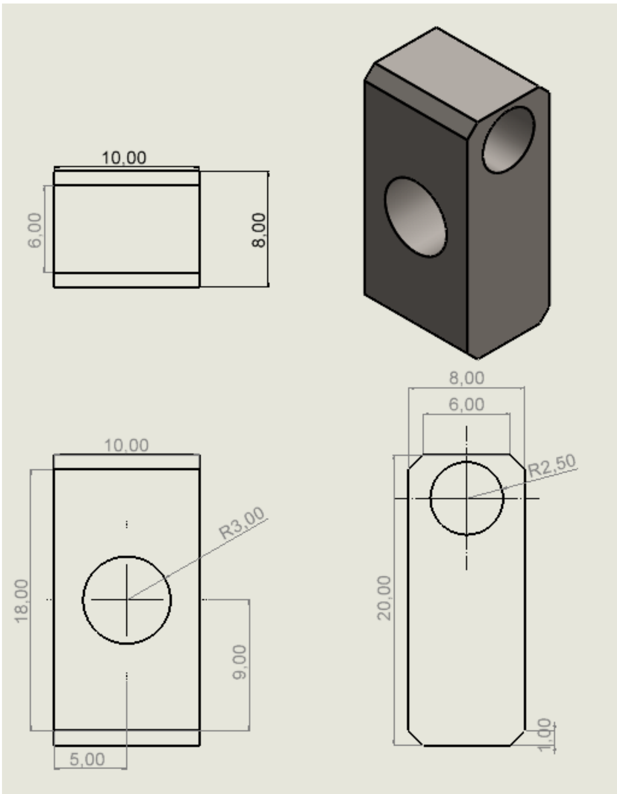

Figure 124 Technical Drawing of Tensioner Slider.

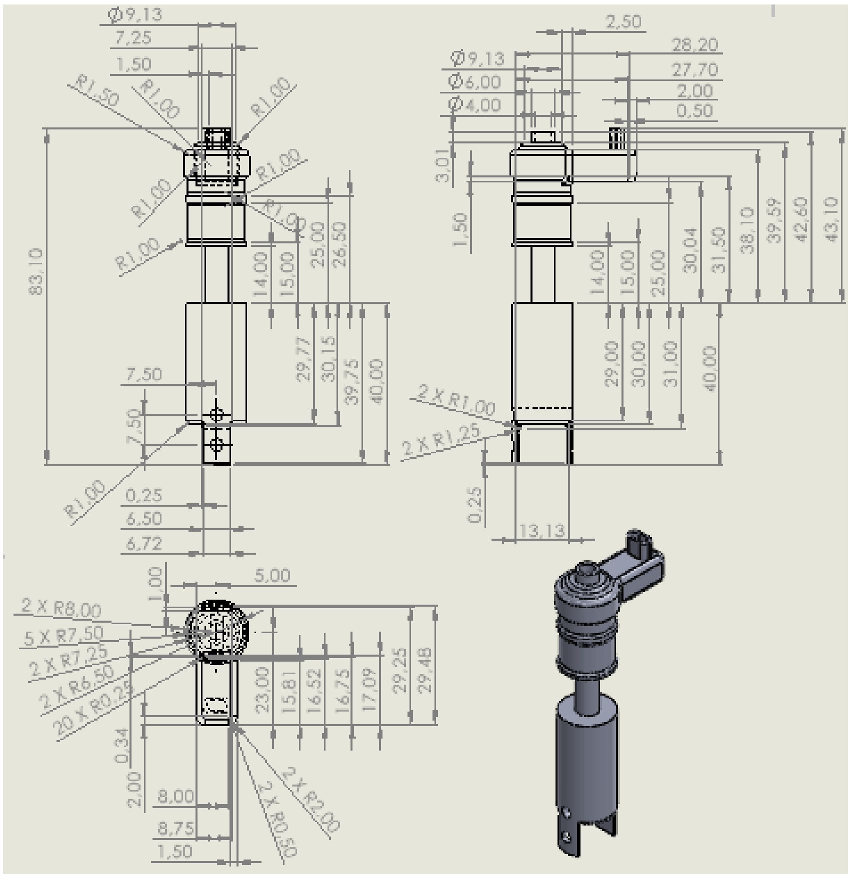

Figure 125 Technical Drawing of Unit Pump System (UPS).

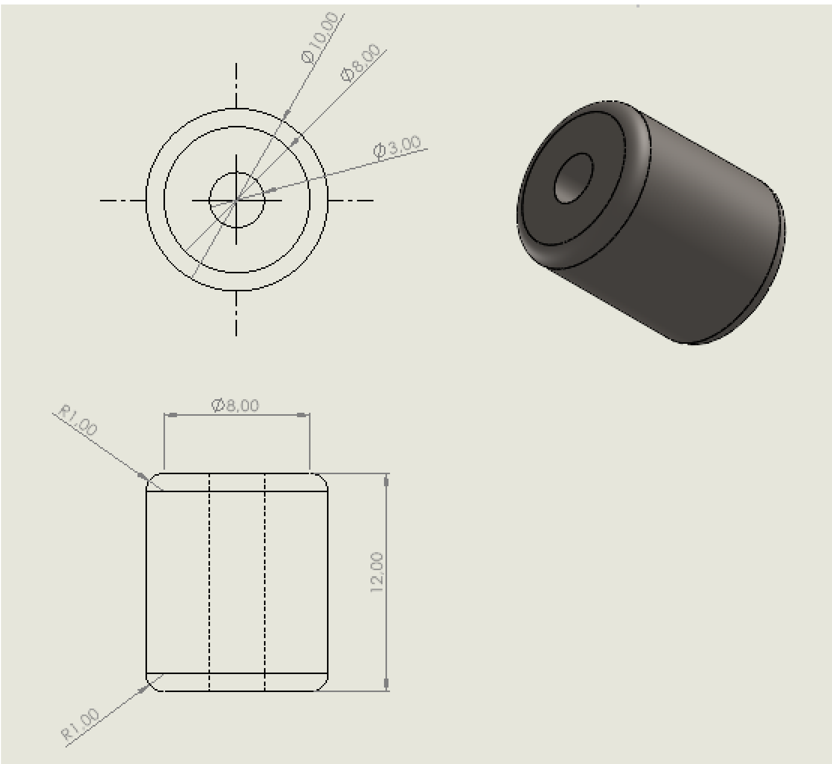

Figure 126 Technical Drawing of UPS Roller.

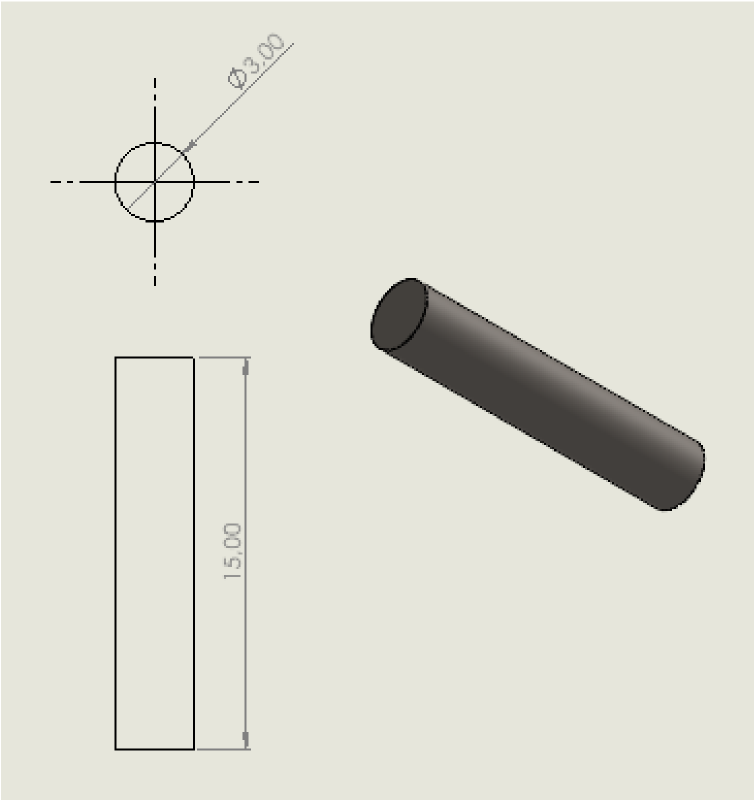

Figure 127 Technical Drawing of UPS Roller Pin.

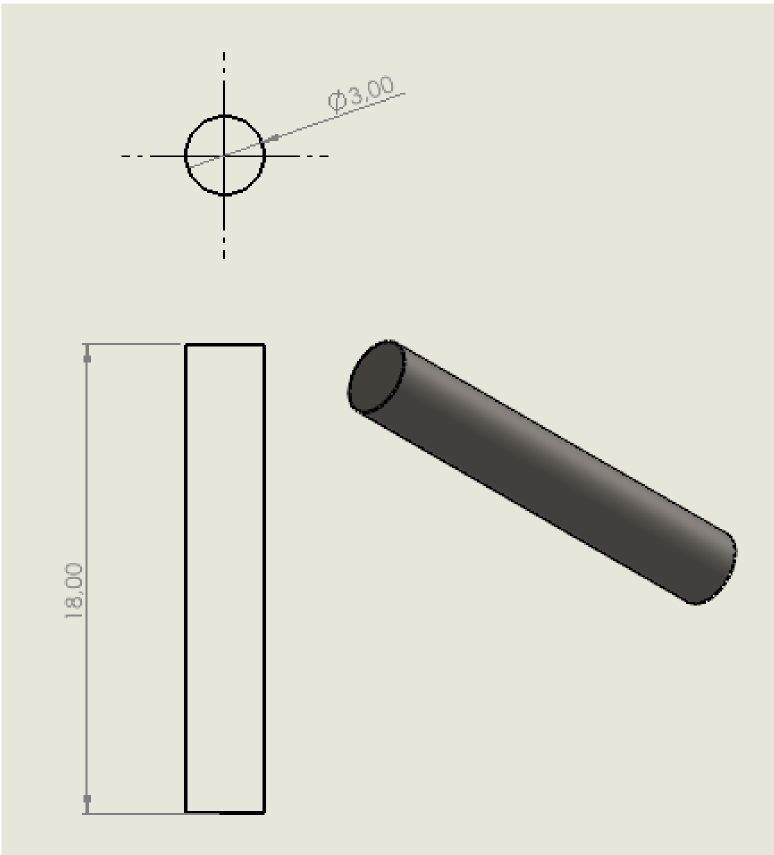

Figure 128 Technical Drawing of UPS Rocker Pin.

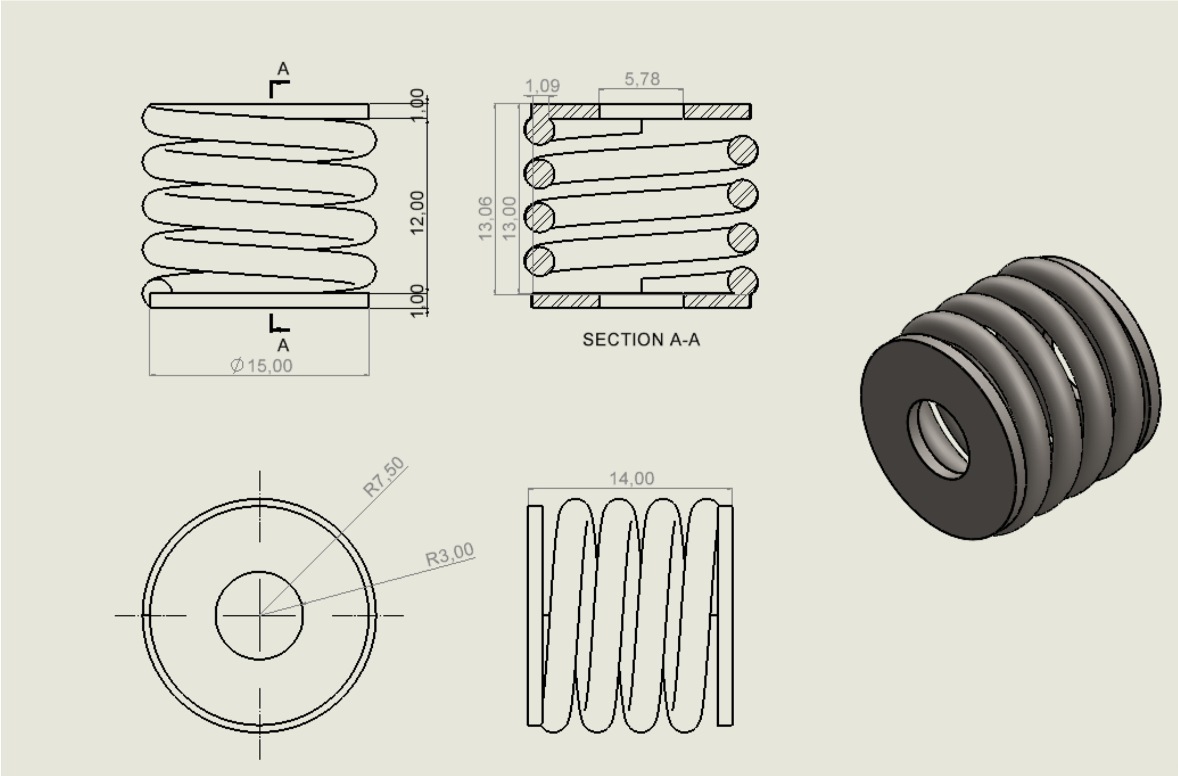

Figure 129 Technical Drawing of UPS Spring.

18. LOTUS ENGINEERING ANALYSIS

We have created the schematic design of a 3-cylinder diesel engine using Lotus Engineering Simulation. This program includes tools such as the Friction Estimator Tool, Combustion Analysis Tool, Port Flow Analysis Tool, and Lotus Concept Valve Train. We designed the schematic of the engine and performed analyses based on the data we had. As a result of our analyses, we obtained information about the performance of each cylinder in the engine we designed and gained overall insights into the entire engine.

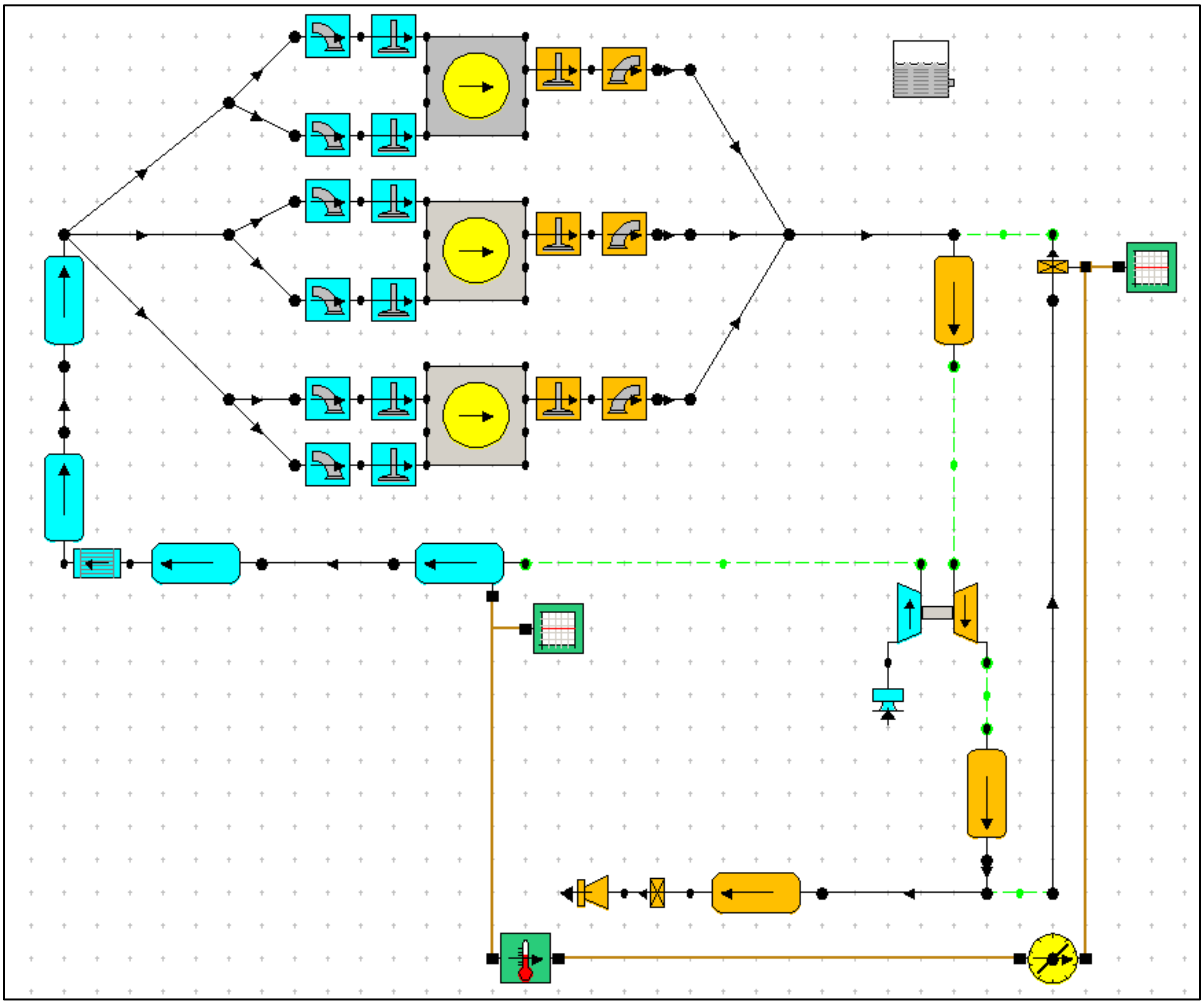

Figure 130 Schematic of the engine in Lotus Engineering Simulation. (LES).

Label	Cylinder One
Bore (mm)	86,0000
Stroke (mm)	68,0000
Cyl Swept Volume (l)	0,39500
Total Swept Volume (l)	1,18500
Con-rod Length (mm)	150,00
Pin Off-Set (mm)	0,00
Compression Ratio	18,00
Clearance Volume (l)	0,023235
Phase (ATDC)	0,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

Label	Cylinder two
Bore (mm)	86,0000
Stroke (mm)	68,0000
Cyl Swept Volume (l)	0,39500
Total Swept Volume (l)	1,18500
Con-rod Length (mm)	150,00
Pin Off-Set (mm)	0,00
Compression Ratio	18,00
Clearance Volume (l)	0,023235
Phase (ATDC)	240,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

Label	Cylinder Three
Bore (mm)	86,0000
Stroke (mm)	68,0000
Cyl Swept Volume (l)	0,39500
Total Swept Volume (l)	1,18500
Con-rod Length (mm)	150,00
Pin Off-Set (mm)	0,00
Compression Ratio	18,00
Clearance Volume (l)	0,023235
Phase (ATDC)	480,00
Combustion Model	
Open Cycle HT	
Closed Cycle HT	
Surface Areas	
Surface Temperatures	
Scavenge-Cylinder	

Figure 131 Specifications of the Cylinders.

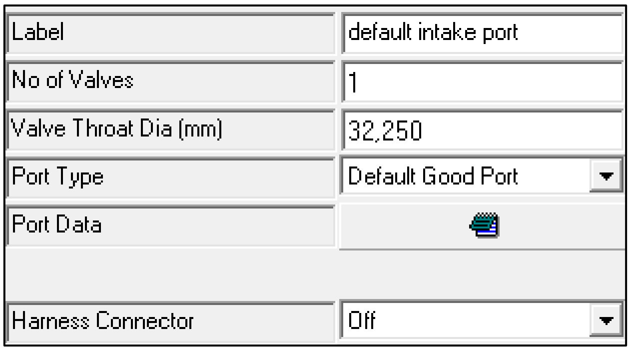

Figure 132 Intake port

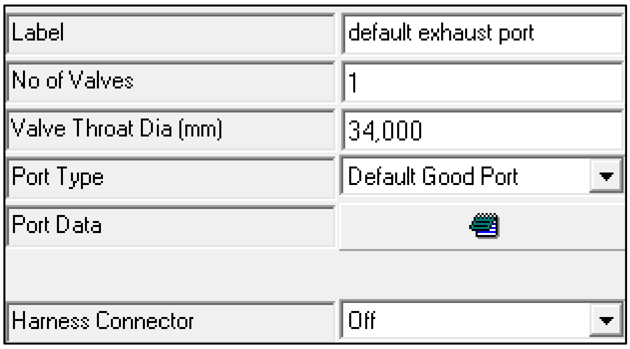

Figure 133 Exhaust port

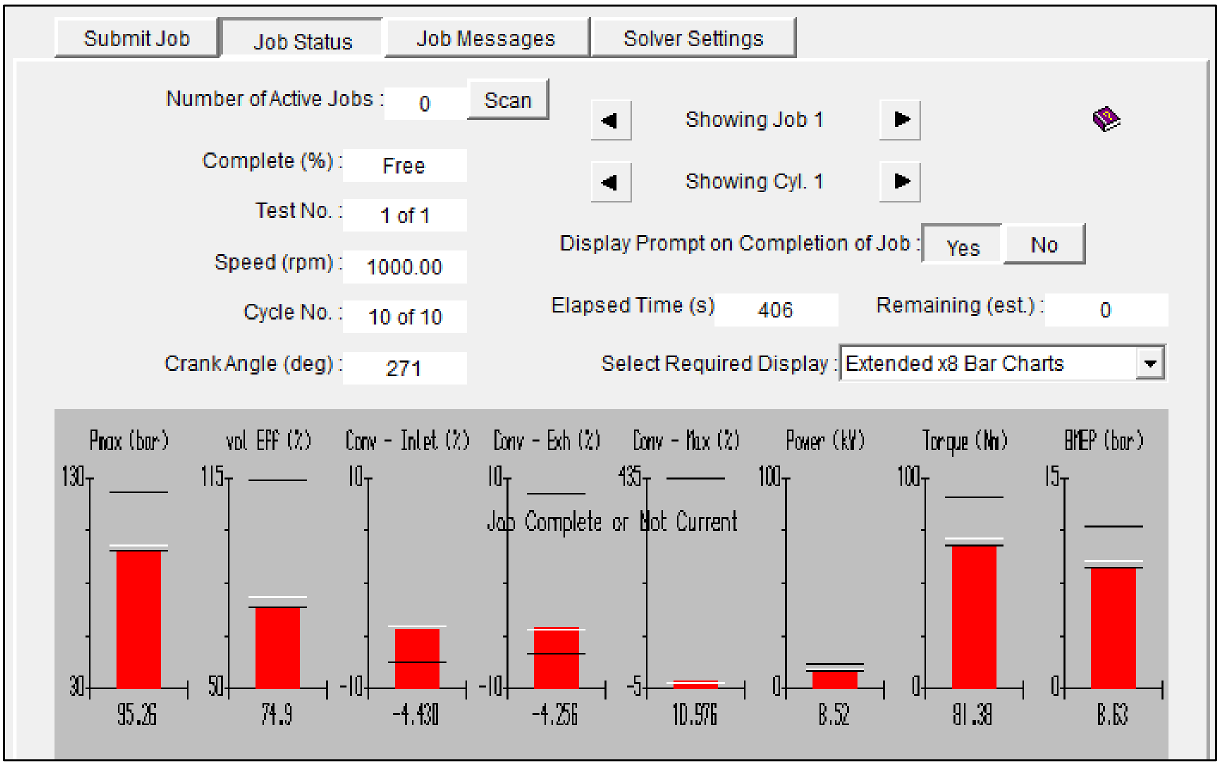

Figure 134 For Cylinder-1 at 1000 rpm.

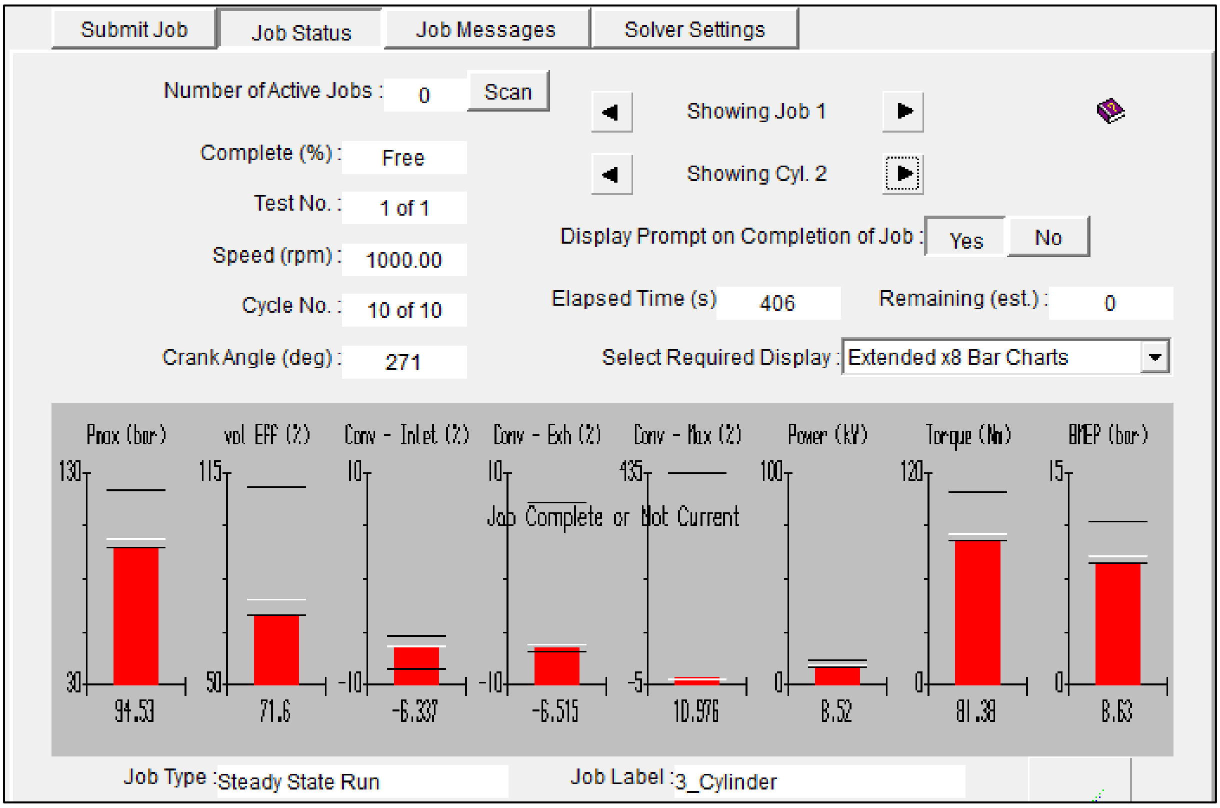

Figure 135 For Cylinder-2 at 1000 rpm.

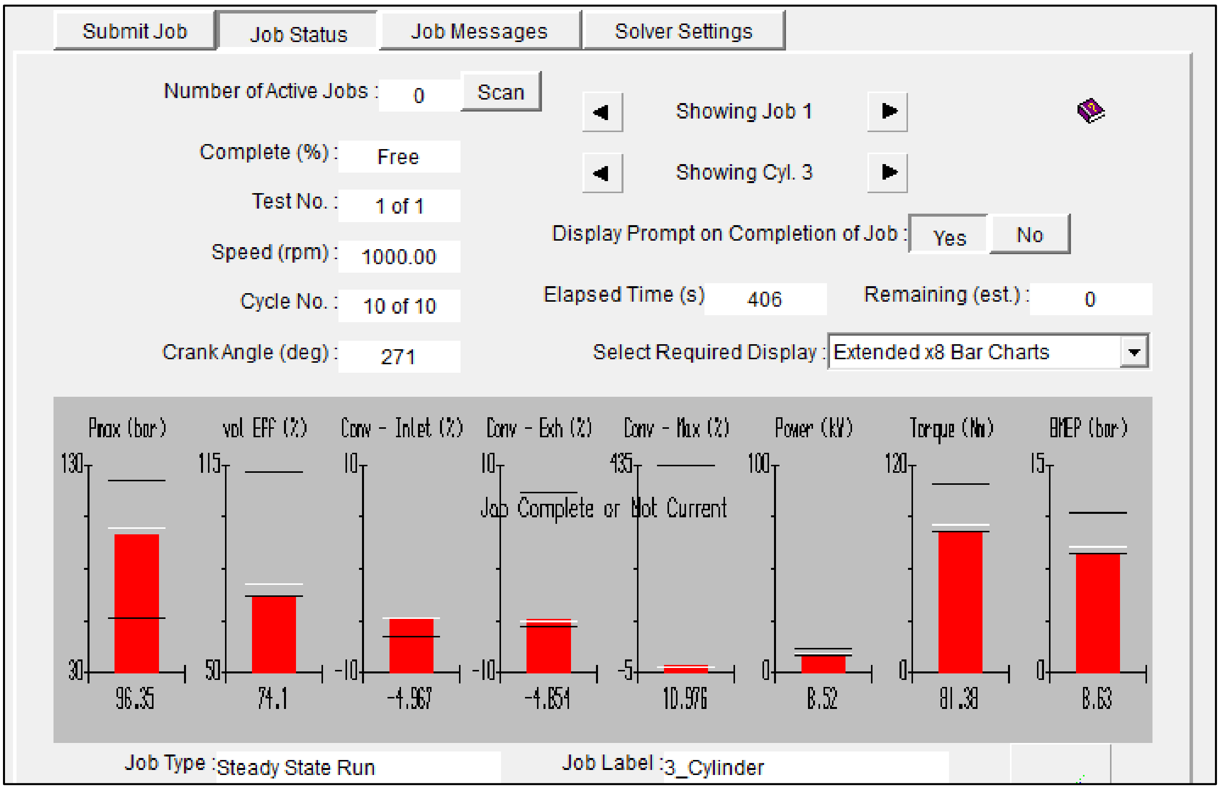

Figure 136 For Cylinder-3 at 1000 rpm.

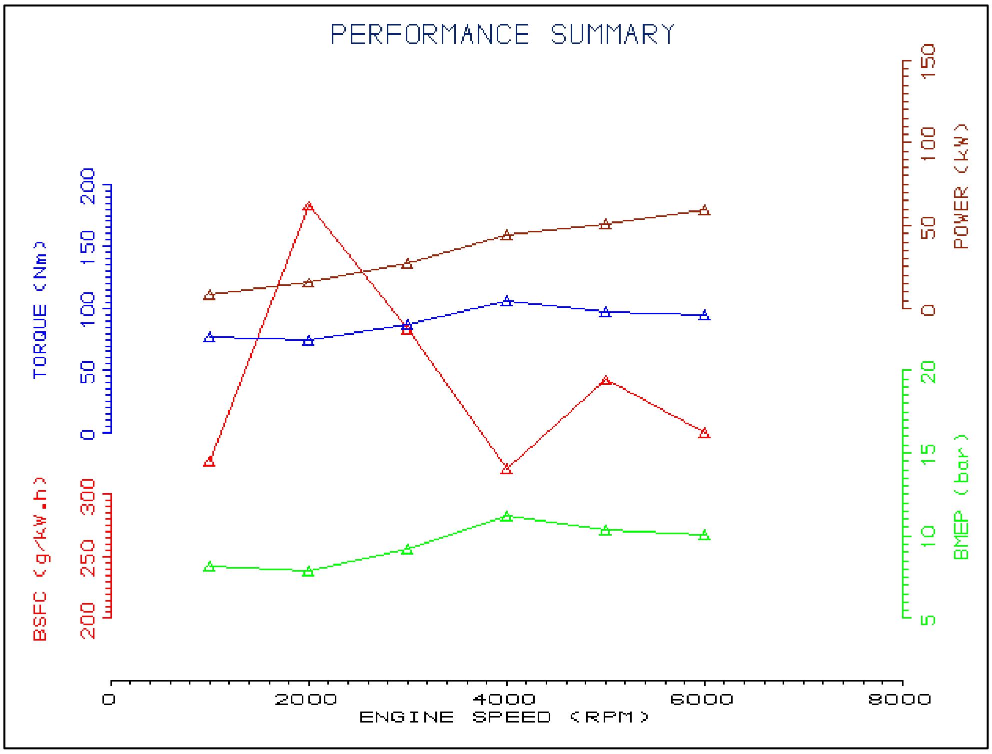

Figure 137 Performance Curve.

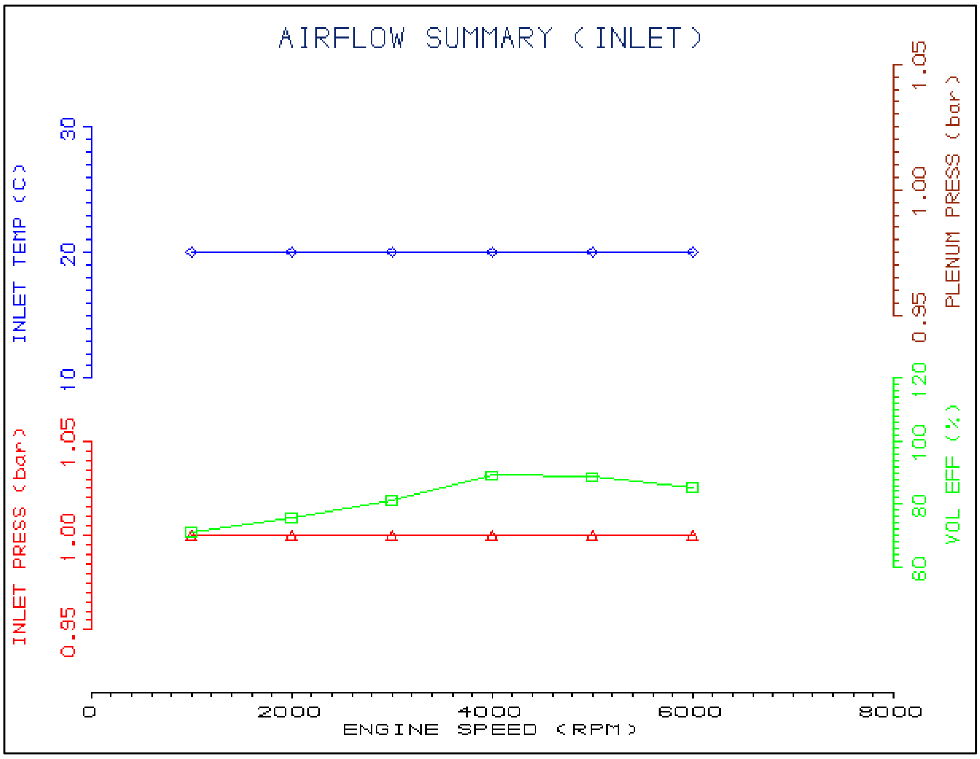

Figure 138 Airflow (Inlet) Curve.

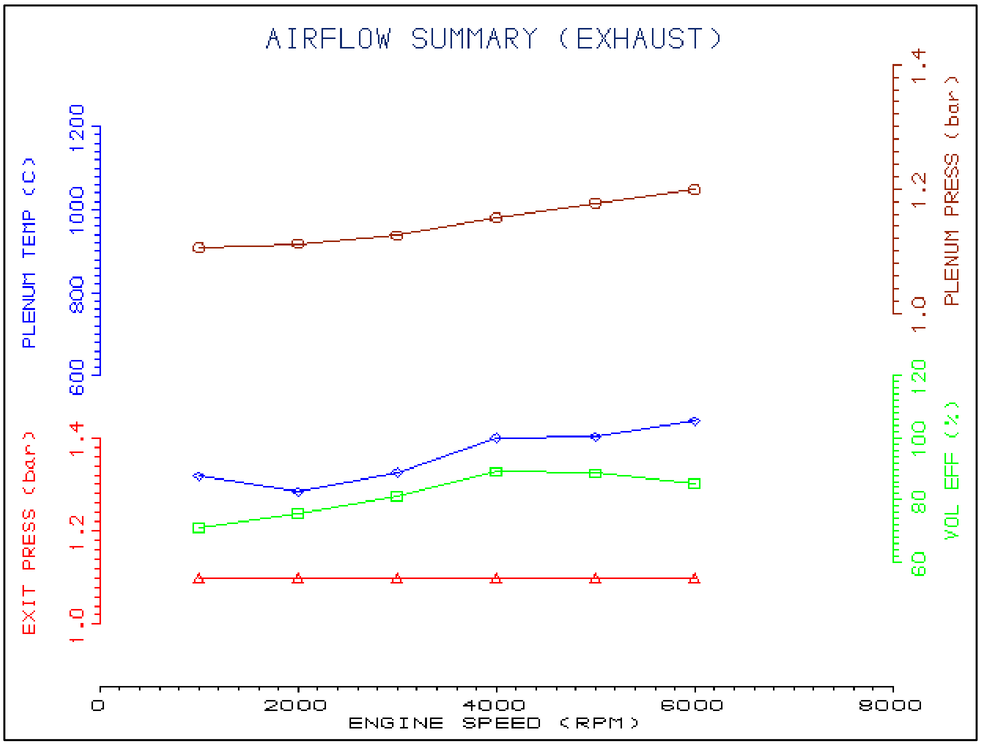

Figure 139 Airflow (Exhaust) Curve.

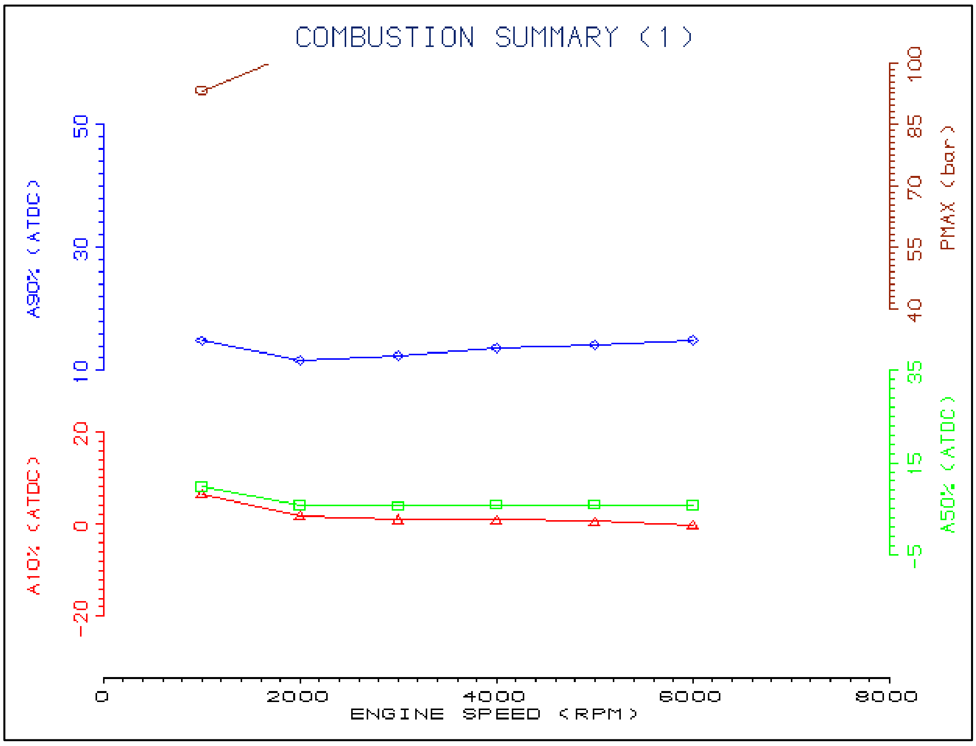

Figure 140 Combustion Curve (1).

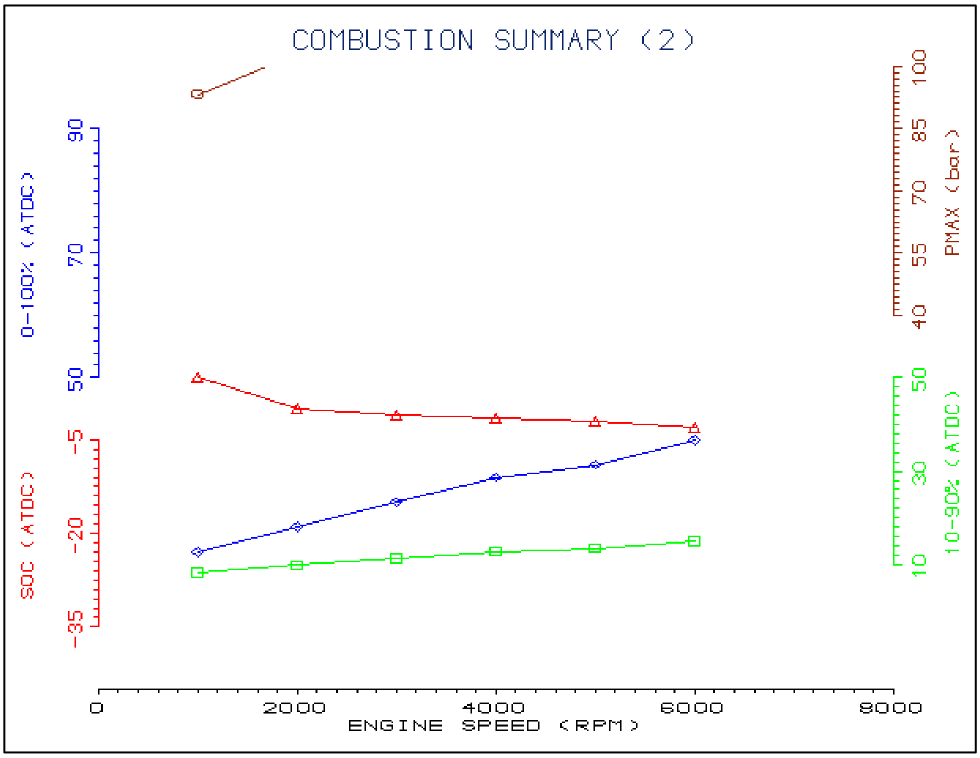

Figure 141 Combustion Curve (2).

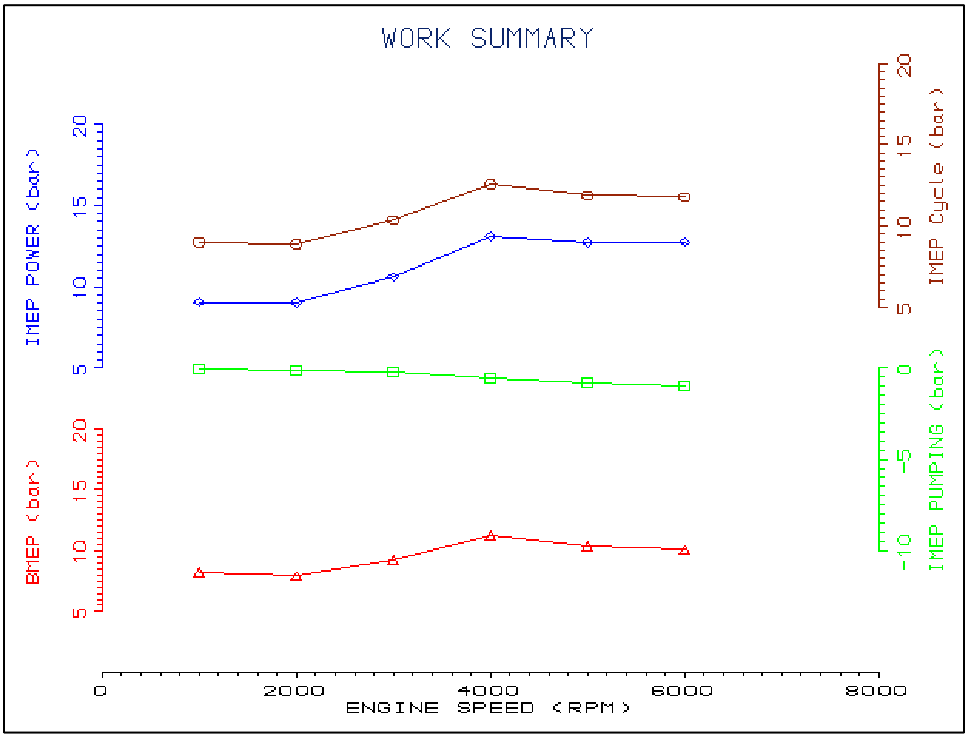

Figure 142 Work Curve.

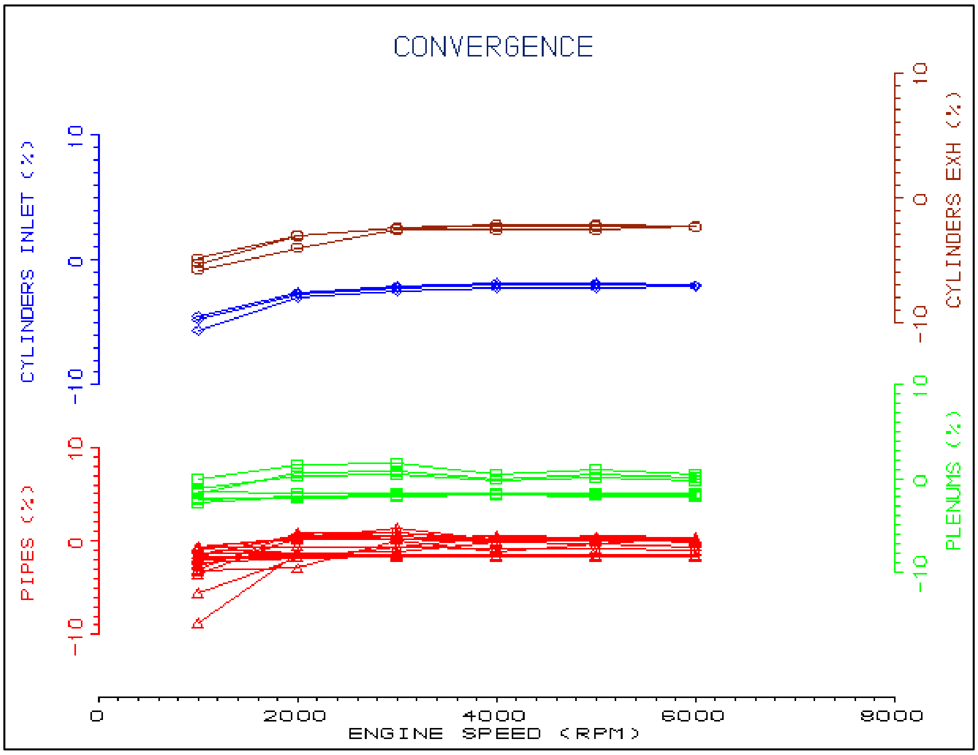

Figure 143 Convergence Curve.

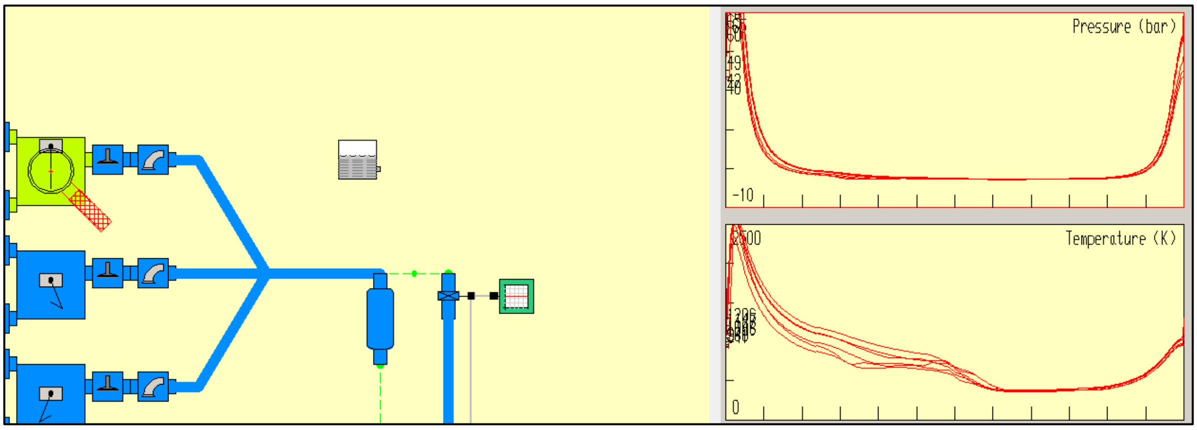

Figure 144 Result viewer for first piston.

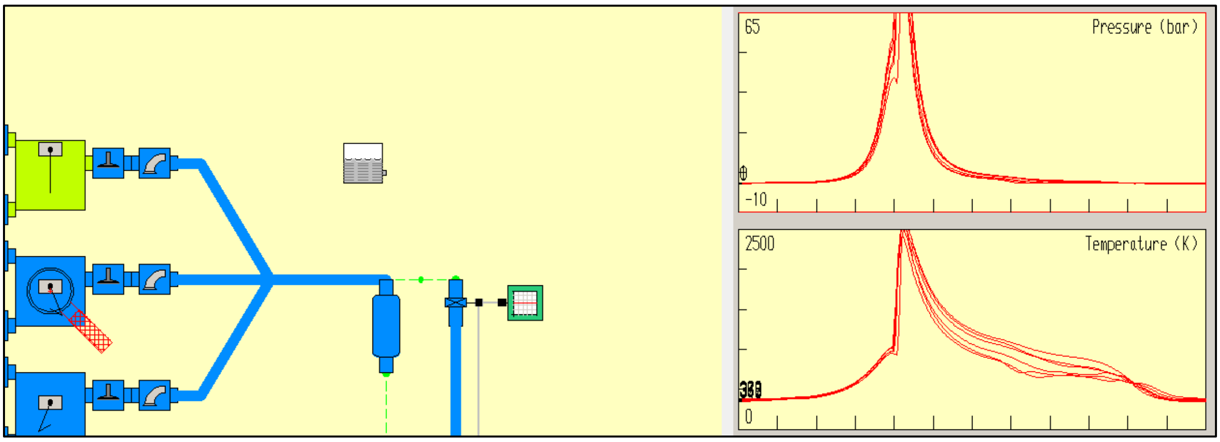

Figure 145 Result viewer for second piston.

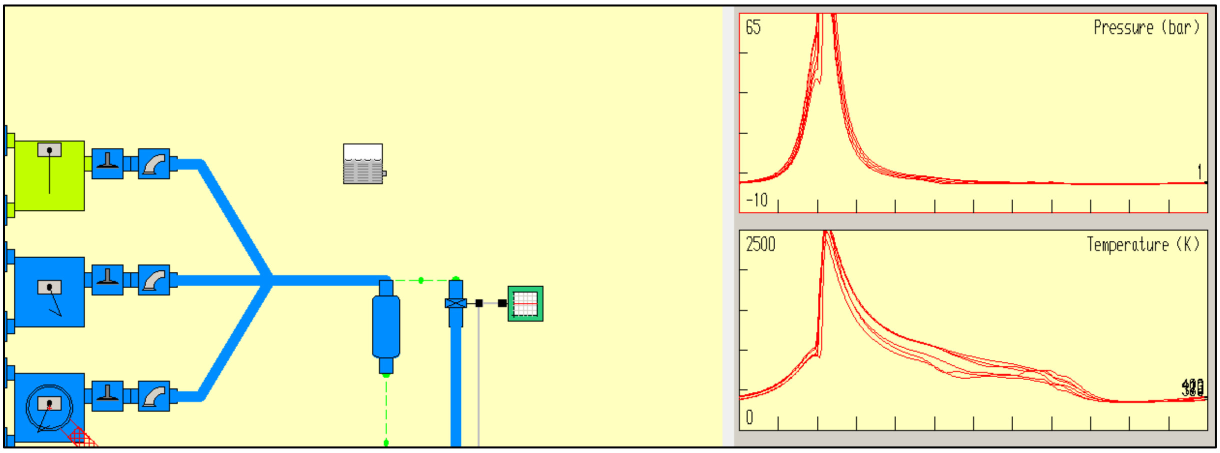

Figure 146 Result viewer for third piston.

19. COST ANALYSIS AND FEASIBILITY

19.1 COST ANALYSIS

Table 16 3-Cylinder Diesel Engine Cost Analysis.

3-CYLINDER DIESEL ENGINE COST ANALYSIS		
PART NAMES	**PROGRESS**	**COST**
Piston	Raw Material	$270,00
	Pouring Process	$70,00
	Machining	$50,00
	Labor Cost	$50,00
Cylinder Block	Raw Material	$700,00
	Pouring Process	$150,00
	Machining	$150,00
	Labor Cost	$50,00
Segman	Raw Material	$5,00
	Pouring Process	$5,00
	Machining	$5,00
	Labor Cost	$5,00
Bearing	Raw Material	$15,00
	Pouring Process	$10,00
	Machining	$10,00
	Labor Cost	$7,00
Connecting Rod	Raw Material	$70,00
	Pouring Process	$50,00
	Machining	$30,00
	Labor Cost	$20,00
Crank Shaft	Raw Material	$550,00
	Pouring Process	$250,00
	Machining	$250,00
	Labor Cost	$100,00
Piston Pin	Raw Material	$10,00
	Pouring Process	$10,00
	Machining	$6,00
	Labor Cost	$5,00
Alternator	Supplier Cost	$500,00
Valve (Spring)	Raw Material	$50,00
	Pouring Process	$20,00
	Machining	$20,00
	Labor Cost	$15,00
Gear	Raw Material	$100,00
	Pouring Process	$50,00
	Machining	$70,00
	Labor Cost	$45,00
Water Pump	Supplier Cost	$150,00
Oil Pump	Supplier Cost	$170,00

Unit Pump System	Supplier Cost	$2.000,00
Rocker	Raw Material	$20,00
	Pouring Process	$15,00
	Machining	$40,00
	Labor Cost	$15,00
Tensioner	Raw Material	$20,00
	Pouring Process	$15,00
	Machining	$10,00
	Labor Cost	$10,00
GearBox	Raw Material	$50,00
	Pouring Process	$20,00
	Machining	$30,00
	Labor Cost	$15,00
Valve	Raw Material	$70,00
	Pouring Process	$50,00
	Machining	$30,00
	Labor Cost	$15,00
	TOTAL	**$6.418,00**

We examined the average prices of components based on information gathered from the internet and incorporated these into our cost analysis table. For elements such as Pouring Process, Machining, and Labor Cost, we estimated pricing based on the time required by the workforce. Labor Cost specifically reflects the expenditure associated with manpower, a pivotal consideration in the manufacturing process. According to our calculations, the total cost of the product amounts to $6.418,00. This figure represents a median estimate, allowing for potential variations in production costs, whether higher or lower. This cost analysis underscores the need for a detailed examination of all aspects contributing to the product's cost. Each stage of production must be carefully assessed to ensure accurate cost projections and optimization. Additionally, it's crucial to recognize that supplier prices can fluctuate over time, impacting overall manufacturing expenses.

19.2 FEASIBILITY

The purpose of this feasibility report is to evaluate the practicality of our joint project with Anadolu Motor Company, focusing on the development of a three-cylinder diesel engine. Through comprehensive market analysis and a review of previous design iterations, we have determined that Anadolu Motor’s entry into the diesel engine sector with this innovative project is both viable and strategic. The three-cylinder engine not only reduces environmental impact compared to traditional four-cylinder engines but also boasts lower production costs and decreased raw material usage. These factors collectively enhance the engine’s sustainability and economic feasibility. By continuing with this project, Anadolu Motor can position itself as a leader in sustainable automotive solutions, capturing a significant market share while contributing to environmental conservation and cost efficiency.

20. CONCLUSION

Three-cylinder engines have surged in popularity due to their potential for enhanced fuel efficiency and reduced emissions. These engines offer several advantages, including superior fuel economy, lightweight and compact design, lower production costs, and diminished emissions. However, they also present certain drawbacks such as increased vibrations and noise, lower power and performance compared to larger engines, heightened engine stress, and restricted applications in larger or heavier vehicles. Manufacturers are continuously striving to mitigate these disadvantages and improve the performance of three-cylinder engines through advanced design and technological innovations.

Anadolu Motor, a company specializing in the manufacture of single-cylinder agricultural engines, aims to become a leading firm in the country by shifting to the production of three-cylinder engines. They seek to develop new projects centered around these engines. In collaboration with Anadolu Motor and Prof. Dr. Mehmet Zafer GUL, we embarked on a joint project.

Our design process commenced with an extensive review of previous designs, focusing on the components and assemblies of pistons, engine blocks, and crankshafts over the years. We identified assembly errors from past designs up to the previous year and made efforts to prevent their recurrence. For the three-cylinder engine, it was essential to update the designs based on the bore and stroke values compatible with the piston used by Anadolu Motor. We opted to use the piston and rod from the Diesel 6LD400 single-cylinder agricultural engine by Anadolu Motor as our reference. Instead of modifying pre-existing designs, we decided to create our design from scratch. Following the design of the pistons and crankshaft, we proceeded with the design of the engine block, valve components, and other engine parts. In the engine block design, we implemented a water-cooled system with a liner configuration. We examined last year’s design and investigated other engines that could serve as references. After visiting Anadolu Motor with our professor, we completed the design of the water-cooled engine system and finalized the assembly of the cylinder liner and the block design.

In addition, we initiated the design process to establish the connection between the crankshaft and camshaft using a similar system to the previous year. A gear connection was considered advantageous for eliminating the tension adjustment problems associated with belt or chain connections between the crankshaft and camshaft. Based on necessary calculations and the distance between the crankshaft and camshaft, we determined that a minimum of four idler gears were required. Given the dual overhead camshaft design of the engine, reducing the number of idler gears would result in improper contact and rotation of the camshaft gears. Conversely, increasing the number of idler gears would lead to more gears and potential power loss. Therefore, we decided to use a belt-chain system for the crankshaft-to-camshaft connection. We considered a 2:1 gear ratio during the design and adhered to ISO standards for the gear design. To mitigate the potential risk of the timing belt breaking or loosening during operation, an adjustable belt tensioner was included. Additionally, protective housing was incorporated to minimize the timing belt's exposure to external factors. This housing, referred to as the gearbox, would encase the belt system, facilitate assembly, and allow for the mounting of the alternator and water pump.

Subsequently, we began designing the placement of components used in the previous year. The alternator and centrifugal pump from the previous year were utilized for concept demonstration purposes. For assembly and engine concept considerations, we developed an assembly strategy using the same designs directly. A unique bracket design for the alternator was created, making it mountable on the gearbox with bolts and nuts. For the centrifugal pump, additional bracket connections for gearbox mounting were considered, and the design was completed with assembly bolts. The centrifugal pump was strategically positioned close to the engine's water cooling system. A V-belt system was designed for the synchronous operation of the alternator and centrifugal pump, and it was mounted on the crankshaft with the aid of a pulley, completing the assembly on the gearbox. The crankshaft length from last year's design was sufficient to accommodate the V-belt, and we utilized these reference measurements in our design.

Upon completing the power transmission line, we designed the rocker cover to isolate the camshafts from the external environment. We decided to replace the common rail system injectors used in the previous design with Unit Pump System (UPS) injectors. We reviewed designs for appropriate mounting on the rocker cover. Due to the unavailability of the UPS system's CAD file, we designed and mounted the BOSCH EDC7 product. The electronic circuit of the UPS system was also drawn to similar dimensions and mounted on the front of the engine above the flywheel gear. Diesel engines require high starting current, and the UPS system ensures a smooth start by providing the necessary high current during engine startup. It prevents engine stoppage during power outages and contributes to fuel savings and improved engine efficiency. The design was aligned with the injection and camshaft system preferences of Anadolu Motor for the three-cylinder diesel engine. The rocker design was scheduled to be finalized in later project stages with Anadolu Motor according to the UPS system.

Lastly, the flywheel gear design was finalized. Measurements from the EA189 engine's flywheel gear were used as a reference, and a suitably sized flywheel gear was designed according to ISO standards. The Bosch SR0792N model starter motor from the previous year’s design was selected, and an additional component was designed and integrated into the engine block for its assembly. The flywheel gear was designed slightly larger than the reference engine’s flywheel gear diameter to ensure full engagement with the starter motor.

Throughout the design, bolt holes were considered for the engine assembly. The assembly sequence and part connections were meticulously planned to ensure step-by-step assembly with bolts.

We created the schematic of the designed engine using LOTUS and utilized our CAD data within LOTUS. By considering the number of cylinders, cylinder diameter, and the number of intake and exhaust valves, we analyzed the operation of the designed engine in a simulation environment. Engine data obtained from the graphs were included in the report.

In conclusion, the motor design process is comprehensive and labor-intensive, requiring significant time and effort. This report primarily focuses on the design and assembly of the engine’s fundamental components. Detailed SOLIDWORKS drawings of the engine, LOTUS schematic, and simulation data are included in the report.

21. REFERENCES

1. https://byjus.com/physics/four-stroke-engine/
2. https://specbee.net/4-stroke-petrol-engine/
3. https://www.britannica.com/technology/diesel-engine
4. https://www.mechanicalbooster.com/2017/03/difference-between-si-engine-and-ci-engine.html
5. https://www.uti.edu/blog/diesel/diesel-engine-history
6. https://www.drive.com.au/news/what-is-a-diesel-particulate-filter-or-dpf/
7. https://dieselnet.com/standards/eu/lez.php
8. https://en.wikipedia.org/wiki/Tesla_Model_3
9. https://www.enginebuildermag.com/2015/10/what-is-selective-catalytic-reduction/
10. https://enginetechforum.org/vehicle-sales-dashboard
11. https://www.cepkolik.com/abd-2040-yilina-kadar-sifir-emisyonlu-agir-hizmet-araclarini-taahhut-ediyor-606085/
12. https://www.autocarindia.com/car-news/the-tech-behind-fords-ecoboost-engine-342233
13. https://journals.sagepub.com/doi/10.1155/2013/287923
14. https://www.howacarworks.com/basics/how-a-fuel-injection-system-works
15. https://automobilegt.com/single-point-injection-spi-a-fuel-delivery-evolution/
16. https://www.cars24.com/blog/what-is-multi-point-fuel-injection-system-mpfi/
17. https://www.spinny.com/blog/index.php/types-of-fuel-injection-systems/
18. https://learnmech.com/what-is-direct-injection-what-is-indirect-injection/
19. https://www.ingenieriaymecanicaautomotriz.com/fuel-system-components-working-principles-symptoms-and-emission-controls/
20. https://www.slideshare.net/AjaySinghLodhi/systems-of-ic-engine-fuel-systempptx
21. https://engihub.com/requirement-of-fuel-filter-in-engine/
22. https://www.dieseltechmag.com/2019/04/fuel-under-pressure
23. https://www.evo.co.uk/hatchbacks/17942/best-small-cars-2023-pocket-rockets-reviewed-and-rated
24. https://tr.wikipedia.org/wiki/Smart_Fortwo
25. https://thekneeslider.com/nembo-32-inverted-3-cylinder-sport-bike-ready-for-production-as-a-2-liter/
26. https://www.actecopowertrain.com/chery-3-cylinder-800cc-utv-atv-engine-product/

27. https://newatlas.com/volvo-new-three-cylinder-engine/35210/
28. https://www.wardsauto.com/technology/mighty-mini-3-cyl-features-bmw-s-latest-tech
29. https://www.directindustry.com/prod/vm-motori/product-60208-1472363.html
30. https://500sec.com/three-valve-technology/
31. https://en.wikipedia.org/wiki/Multi-valve
32. https://www.enginelabs.com/news/video-five-engines-with-five-or-more-valves-per-cylinder/
33. https://blog.ford.com.tr/fiesta-1-0l-ecoboost-powershift
34. https://www.autoevolution.com/cars/renault-twingo-2019.html#aeng_renault-twingo-2019-sce-65-10l-5mt-65-hp
35. https://www.auto-data.net/en/volkswagen-up-facelift-2016-1.0-tsi-90hp-24558
36. https://www.auto-data.net/en/audi-a2-typ-8z-1.4-tdi-75hp-4894
37. https://www.motorreviewer.com/engine.php?engine_id=143
38. https://mymotorlist.com/engines/mercedes/om639/
39. https://www.carscoops.com/2012/05/new-bmw-114i-with-16l-turbo-and-m135i/
40. https://www.motorreviewer.com/engine.php?engine_id=46
41. https://anadolumotor.com/_docs/products/antorad320.pdf
42. https://anadolumotor.com/_docs/products/antor6ld400.pdf
43. Design of piston bowl geometry for better combustion in direct-injection compression ignition engine | Sādhanā (springer.com)
44. https://www.engineaustralia.com.au/wp-content/uploads/2018/04/SB020.pdf
45. https://www.kfz-tech.de/Biblio/Mehrzylinder/Dreizylinder-Reihenmotor.htm#
46. https://toyota-club.net/files/faq/20-08-01_faq_df_r3_en.htm
47. https://www.bosch-mobility.com/en/solutions/pumps/injection-pump/
48. https://www.china-balin.com/industry-news/electronic-unit-pump-vs-common-rail-pump.html