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wenzhangaA Comparative Study of Engine Configurations: Fuel Consumption, Efficiency, and Application-Specific Advantages

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Abstract:

This research paper will investigate fuel consumption, efficiency, and applications-specific advantages of different engine configurations – Inline-4, V8, and flat engines. The engines will be evaluated through brake-specific fuel consumption, focusing on the engine itself solely, neglecting the mass of the vehicle, engine, and fuel load. Data collection will be conducted using the AngeTheGreat engine simulator, providing accurate fuel consumption data, RPM, and kph for analysis. Results show that the Inline-4 engines are the most fuel efficient, V8 engines generate the most incredible power, and the flat four engine offers the lowest brake-specific fuel consumption value. However, there are also inevitable minor errors that occurred during the simulation; although they do not affect the results heavily, they are still not negligible. Overall, the study highlights how engine configuration can directly impact the performance, leading manufacturers to extract the most out of its advantages to serve their purpose in specific applications.

Keywords: Brake-specific fuel consumption; fuel consumption; efficiency; Inline-4; V8; flat four.

1. Introduction

Internal combustion engines (ICEs) are one of the most revolutionary and common developments throughout human history that powered the transportation industry for over a century. It is especially dominant in vehicles such as trucks, supercars, and modern-day cars. Behind each vehicle, there are different configurations used–Inline-4 (I4), V8, and flat engine– which possess characteristics in terms of fuel consumption, power output, thermal efficiency, balance, and mechanical complexity. Furthermore, each configuration serves its purpose for different types of vehicles. Understanding the advantages and disadvantages of the various configurations will be crucial to benefit different vehicle types. Moreover, examining each configuration will provide a thorough understanding of the impact on overall engine

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performance and efficiency, as it becomes increasingly relevant for manufacturers to conform to strict emission regulations while maintaining high performance.

Among the ways to evaluate each engine configuration, brake-specific fuel consumption (BSFC) will be used as an indicator of thermodynamic efficiency in this research paper. BSFC will measure the fuel consumed per unit power produced per hour, and will be expressed in grams per kilowatt-hour ([1]. This measurement will ensure an accurate comparison between different configurations regardless of their sizes, and directly show how effectively an engine is able to convert chemical energy to mechanical energy. A lower BSFC measure shows that the engine works at a high efficiency, while a higher BSFC measure shows that the engine works less efficiently [1].

Fuel economy (measured in litres per 100km) will be taken into consideration while evaluating an engine's efficiency. Sources such as engine simulators by AngeTheGreat and calculations will provide accurate data across different types of engines to analyse. Moreover, some traditional V6 engines are being downsized to an I4 turbo engine in order to reduce weight, improve efficiency, and meet emissions requirements. Therefore, it is crucial to understand how each engine configuration benefits different vehicles.

For any kind of configuration, they have their own tradeoffs. An I4 engine is compact, lightweight, and cost-effective, which suits small cars and hybrids. However, an I4 engine will suffer from balance issues, which will require an expensive balance shaft to mitigate vibrations. V8 engines provide immense torque and power, often used in SUVs, Rear Wheel Drive, and longitudinal engine layouts. However, due to its large size, there will be a higher fuel consumption compared to the other smaller engine configurations. Meanwhile, flat engines (flat-4 or flat-6) offer a low center of gravity, since the engine's layout is flattened, which will improve handling for the driver but come with an increased engine width and complexity to design.

In general, this research paper will dive into the relationship between how engine configurations affect fuel consumption by comparing multiple engine layouts through the use of BSFC and calculations. Data will be obtained from real-world vehicle data, manufacturer specifications, and simulations in order to generate a precise and accurate evaluation for the best balance of efficiency and performance for different vehicle types. In addition, this paper will provide insight into reasons why certain configurations dominate specific parts of the automotive market.

2. Technical Background

Before delving into the impact of engine configuration on fuel consumption an examination into the fundamental mechanical and thermodynamic characteristic of each layout will be prerequisite. Engine configuration is the arrangement of cylinders, the number of cylinders, in the engine block. This will consequently affect the engine's design in aspects such as engine size, smoothness, fuel efficiency, thermal performance, and even handling. In the following sections the paper will examine the commonly seen engine configurations inline-4, V8, and flat engines.

2.1 I4 Engine

The inline-4 engine is one of the most common configurations seen in modern vehicles– Toyota Prius, Honda Accord, and Chevrolet Malibu– that are compact, hatchback, and hybrids. This layout contains four cylinders aligned vertically in a single row. This simple design results in a smaller engine footprint, lower manufacturing cost, and lighter weight. These designs can benefit the engine's fuel economy overall.

The inline-4 engine operates on a four-stroke cycle, firing at a sequence of 1-3-4-2, so that it can evenly distribute the combustion forces [2]. However, a drawback of secondary imbalance comes with this in-line layout and a limited number of cylinders. This can cause vibrations when the engine reaches high speeds. To counteract it, manufacturers add an additional component, a balance shaft, in order to reduce vibration while at the same time increasing mechanical complexity.

Based on a thermodynamic perspective, the relatively small size of the engine reduces internal friction losses, which allows the engine to warm up quickly, reducing cold-start inefficiencies. I4 engines operate at a lower displacement level, weight and size, which can lower specific fuel consumption [3]. In addition, with only four pistons operating, parasitic losses are reduced, which improves BSFC values.

2.2 V8 Engines

V8 engines are arranged in a "V" shape, as the name suggests. It consists of eight cylinders in 90 90-degree arrangement. This engine is built for high torque and large power output, making it the best suited for trucks, muscle cars, and high-performance cars. Although the V8 engine is mechanically more complex compared to the I4 engines, it improves the engine's smoothness because its firing order is L-R-L-L-R-L-R-R [4].

At lower RPMs, a V8 engine will produce high torque that can benefit towing and acceleration. However, this benefit comes with costs in mechanical losses. Since there are extra moving parts–pistons, valves, and camshafts– friction will increase, ultimately causing more wear to the engine [4].

Based on the earlier descriptions, it is clear that V8S exhibit a higher fuel consumption compared to I4S. As well as BSFC will be consequently higher, but on the other hand, V8 engines produce much higher HP and torque, as there is a higher power-to-weight penalty. In general, modern technological advancements have increased the efficiency of V8 engines, allowing V8 engines to still be competitive in the automotive market.

2.3 Flat (Boxer) Engine

The flat engine, also known as the flat engine, is designed horizontally where the cylinders lie opposite each other in two distinct banks. When the engine operates, each piston's movement is counterbalanced by the opposing cylinder, which permits superior balance and minimal vibration without using balance shafts [5].

In most car designs, the flat engine is located at the bottom of a car, which can drastically improve the vehicle's handling and cornering stability due to its low centre of gravity. These characteristic makes the flat engine a valuable configuration in race cars, since lap times are significantly impacted during corners.

Fuel consumption in flat engines is moderate, as they use direct injection to enhance fuel economy. This will lead to a moderate BSFC value as well, probably placing the flat engine between the I4 and V8 engines.

3. Methodology

This methodology is specifically designed to obtain accurate data for analytical purposes. Engine models will be selected from real-world production vehicles, which are only naturally aspirated gasoline engines, to ensure consistency, excluding hybrid, diesel, or turbo engines. Engines that are selected for the simulation are Honda B18C5 I4 1.8L, Chevrolet V8 7.4L, and Subaru EJ25.

3.1 Data Collection Sources

Data for fuel consumption (L/100km and MPG), engine specifications (displacement and horsepower), and BSFC values will be simulated and calculated from this source: AngeTheGreat Engine Simulator. BSFC values will not be available in the two sources; they will be calculated using known formulas.

3.2 Data Approach and Normalisation

To better compare the engines and calculations, metrics will be used. All charts, tables, and calculations will be processed through Excel with assumptions kept constant through each configuration.

3.3 Assumptions

The fuel consumption of each engine will be measured within five hours at 120kph, where their RPMs are kept constant. This will simulate a steady state of a vehicle cruising on the highway. After collecting data from the five trials, the average fuel consumption will be taken and used in the BSFC equation:

$$BSFC = \frac{m_{fuel} \times 3600}{P_{brake}} \tag{1}$$

For consistency, during BSFC calculations the density of gasoline will be assumed to be 750kg/ m^3 , engines will operate at their highest gear, and there are no fuel loads: fuel is being directly injected into the engine.

4. Results and Discussion

According to table 1 and figure 1, the I4 engine demonstrated the lowest fuel consumption among the engines, with only 0.61L/km. This confirms the expectation that the I4 engine is the most fuel-efficient vehicle in the cruising state. While the V8 engine consumes around six times more fuel than the I4 engine, making it the least fuel-efficient engine amongst the three. Despite the engine only running at 2400RPM, its large displacement and power output result in consuming more fuel. The flat-four engine sits between the two engines, consuming 0.94L/km; the fuel consumption is still significantly lower than the V8 engine but slightly higher than the I4 engine.

Table 1. Engine Comparison

Engine	Fuel consumption (L/100km)	Speed (kph)	Revolution Per Minute (rpm)	Power (kW)	BSFC (g/kWh)
Inline 4	0.61	120	3800	18.4	29.84
V8	3.86	120	2400	110.4	31.5
Flat-four	0.94	120	3700	37.9	22.3

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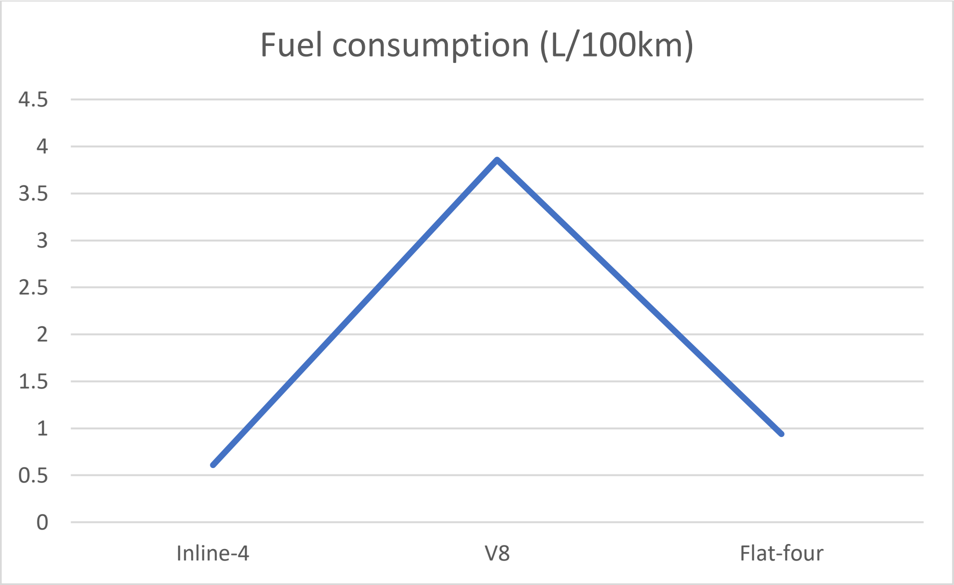

Fig. 1 Fuel Consumption Among the Three Engines

Referring to figure 2, the V8 engine is the most powerful engine, 110.4kW, with the cost of high fuel consumption. The flat engine again falls between the two engines, offering 37.9kW of power, which indicates a favorable power-to-fuel ratio. The I4 engine, while most fuel efficient, produces the least amount of power,18.4kW, demonstrating the trade-off of fuel efficiency.

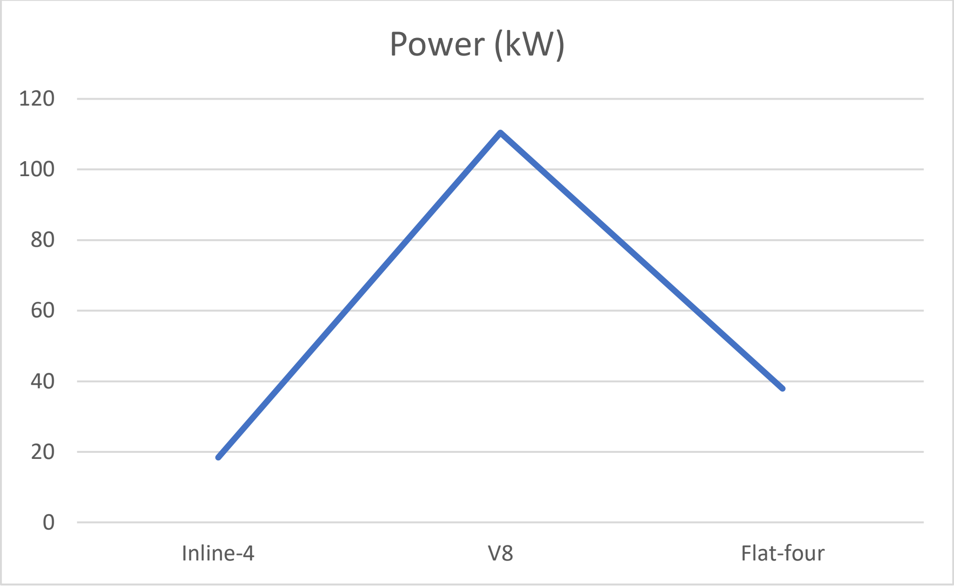

Fig.2 Power Among the Three Engines

BSFC in figure 3 reflects how much fuel mass is converted to 1kWh of brake power. According to figure 3, the flat-four engine shows the lowest BSFC value, presenting the best thermal efficiency engine. Despite the flat-four engine consuming more fuel than the I4 engine, to some degree, its better thermal efficiency counteracts the higher fuel consumption. I4 engines perform well in terms of BSFC, 29.84g/kWh, presenting a reasonably efficient power production. However, V8 not only consumes more fuel, but it also has the highest BSFC value, 31.5g/kWh. This reveals that V8 engines prioritize power and torque over efficiency.

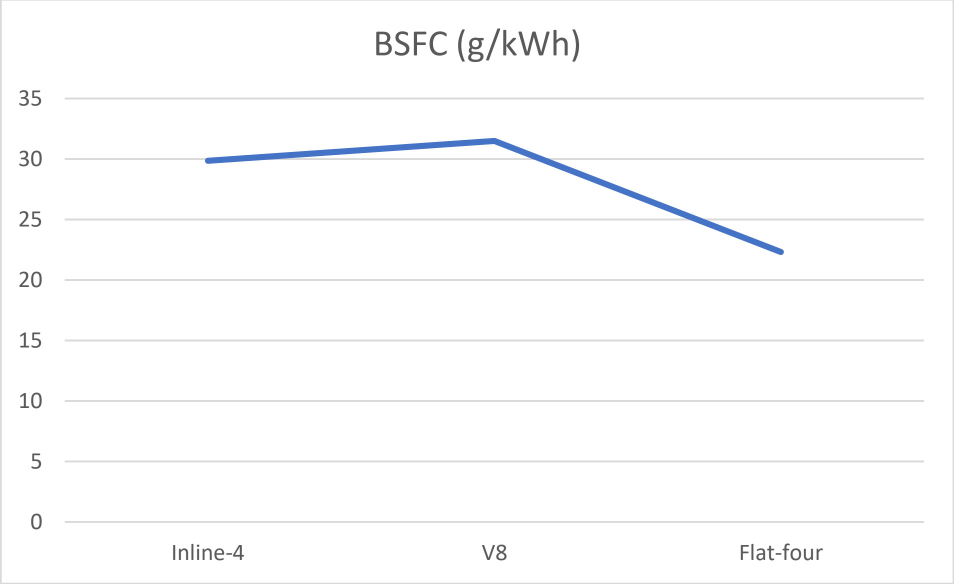

Fig. 3 BSFC value among the three engines

In general, these results reflect the trade-offs between an engine's performance and efficiency. The I4 engine is the most fuel-efficient, but it is the least powerful engine. The V8 engine is the most powerful engine, but the worst in efficiency. However, the flat-four engine finds a balance between these two engines. It is able to produce sufficient power while keeping fuel consumption at a minimum [6].

Furthermore, the results reflect exactly where they are applied in the real world. The Honda B18C5 I4 1.8L was applied in some Honda Integra models. These Honda cars are designed especially for passengers/family, and engineered with a focus on practicality, efficiency, and cost-effectiveness, all of which are aligned with the mechanical characteristics of an I4 engine. Since I4 engines are compact and lightweight, it further reduces fuel consumption at the same time, favoring relatively low BSFC. The low power output may seem like a disadvantage when compared to the other engines, but in a passenger car scenario, it is beneficial, as it suits everyday driving scenarios, reliability, and fuel economy. In an urban environment, excess power will not be required, and as the engine produces less power, it will reduce the stress on the engine [7]. It will simultaneously increase the longevity of the engine and improve fuel economy for the driver and passengers [8]. Therefore, these points become a strong selling point for manufacturers and a strong buying point for consumers, since consumers often demand an affordable, reliable, and fuel-efficient vehicle. As a result, the I4 engine is always a competitive engine in the market.

In contrast, the V8 engine has a completely different design philosophy. As it prioritizes power output and torque over fuel efficiency, it is commonly used in muscle cars and pick-up trucks. To an extent, their emphasis will outweigh the efficiency setbacks. The Chevrolet V8 7.4L are used in models such as Chevrolet R20 and R/V30 trucks, Chevrolet Chevelle, and Chevrolet El Camino. Torque is especially beneficial for pick-up trucks; it enables the car to operate under heavy-duty work in loaded conditions. It especially targets North American citizens in suburban cities, where most consumers require vehicles that can both support daily life commutes and work-related activities, such as construction, agriculture, and landscaping [9]. Moreover, in some unfavorable environments, the V8 engine's high torque and power will overcome the off-road conditions and steep hills. However, this is not the only selling point of V8 engines; the instant throttle response and linear torque curve are experiences that car enthusiasts seek. In general, these points put the V8 engine in a competitive position in the automobile market.

The flat-four engine is commonly used in a competitive environment, such as motorsport. Due to its low center of gravity, balanced weight distribution, efficiency, and balanced fuel-to-power ratio, it becomes a top choice for race car manufacturers. The Subaru EJ25 is, in fact, used in a rally racing car, Subaru Impreza WRX, winning three consecutive World Rally Championship manufacturer titles and three driver titles. In addition, the flat engine layout was also used in GT3 race cars, the Porsche 911 GT3 R, claiming victories in the World Endurance Championship. The flat engine layout significantly helps vehicle balance and handling, which are crucial in motorsport. The low profile allows it to be mounted lower in the chassis, enhancing the car's cornering stability, weight transfer, and maneuverability [10]. From a thermodynamic perspective, the flat engine layout also offers a low BSFC value. In racing, fuel consumption is critical, as it can determine

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whether a team wins or loses. With a lower BSFC value, it allows the car to race in longer stints per fuel load, which leads to fewer pit stops: a pit stop is generally 30-40 seconds long, depending on the track. In conclusion, flat engines may not be the best in fuel consumption and efficiency, but the balance and layout make them uniquely suited for motorsport.

5. Assumptions

In conducting this study, assumptions were made to ensure consistency in evaluating engine configurations. These assumptions isolate the engine, removing external influences that may potentially affect the analysis.

While collecting data for calculating the BSFC value, the paper assumed that it only measures the performance of the engine, neglecting the mass of the vehicle, fuel load, mass of the engine, and passenger weight. Other factors, such as aerodynamic drag, rolling resistance, and drivetrain loss, are all excluded from the BSFC evaluation. These assumptions allow a direct examination, only focusing on the engine itself without other variability. However, it is acknowledged that these results will differ greatly from real-world situations. This also explains why fuel consumption and BSFC are significantly lower than the expected and averaged values found online. When the external factors, such as mass, are taken into account, it will require the engine to exert more power to propel the vehicle, consequently consuming additional fuel.

The engine's startup behavior is also considered in fuel consumption and is assumed to be a minor but not negligible effect on the data collected. In the simulator, the device started measuring fuel consumption immediately after the engine was started. As the engine accelerates to 120 km/h with gear shifts till the highest gear, it tends to involve more air-fuel mixture, consequently increasing fuel consumed. Although during the experiment, an effort was made to keep a steady state condition during data collection, the excess fuel consumed in the initial phase had a minor impact on the total fuel consumed per 100km.

In conclusion, this study aims to measure and assumes an idealized engine's internal performance, neglecting real-life factors. The assumptions impacted the data collected, far lower than the official values given by car manufacturers, but still remained relatively accurate. While these assumptions eliminated real-life factors, it is still accurate in maintaining an accurate evaluation of engine configurations.

6. Conclusion

Overall, the study demonstrated that engine configurations can immensely impact an engine's fuel consumption, power output, and BSFC values. At the same time, this research highlights the importance of selecting the best-fit engine configurations for a specific application in real life, maximizing the advantages of the specific layout. The I4 engine proved to be the most fuel-efficient, aligning with the widespread usage in passenger vehicles. The V8 engine, despite its high fuel consumption, serves its purpose in pickup trucks and muscle cars due to the high-power output. The flat engine offering a balance between fuel consumption and power output, combined with the stability, became particularly efficient in motorsport events.

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