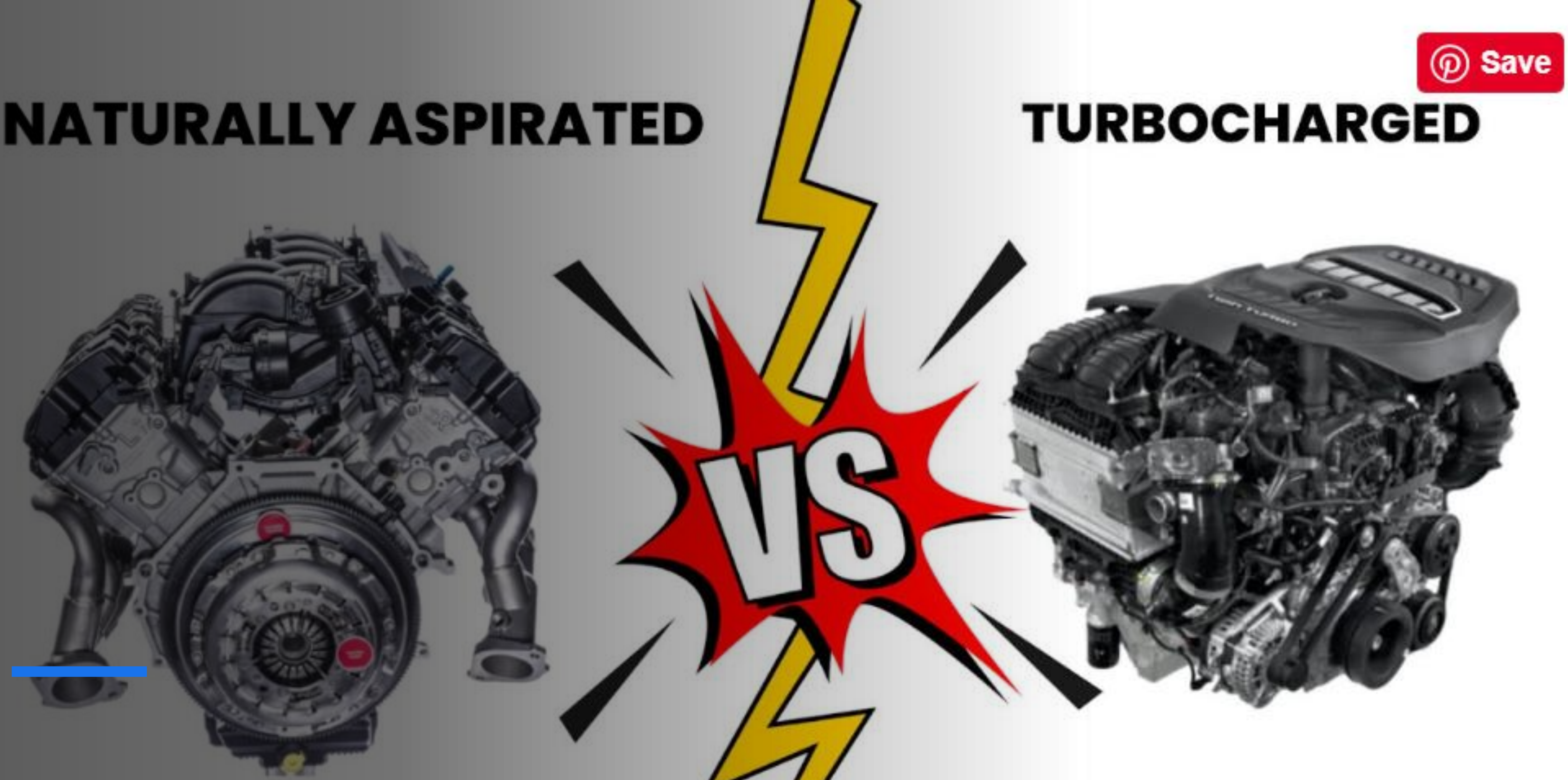


RITCHY HISNE

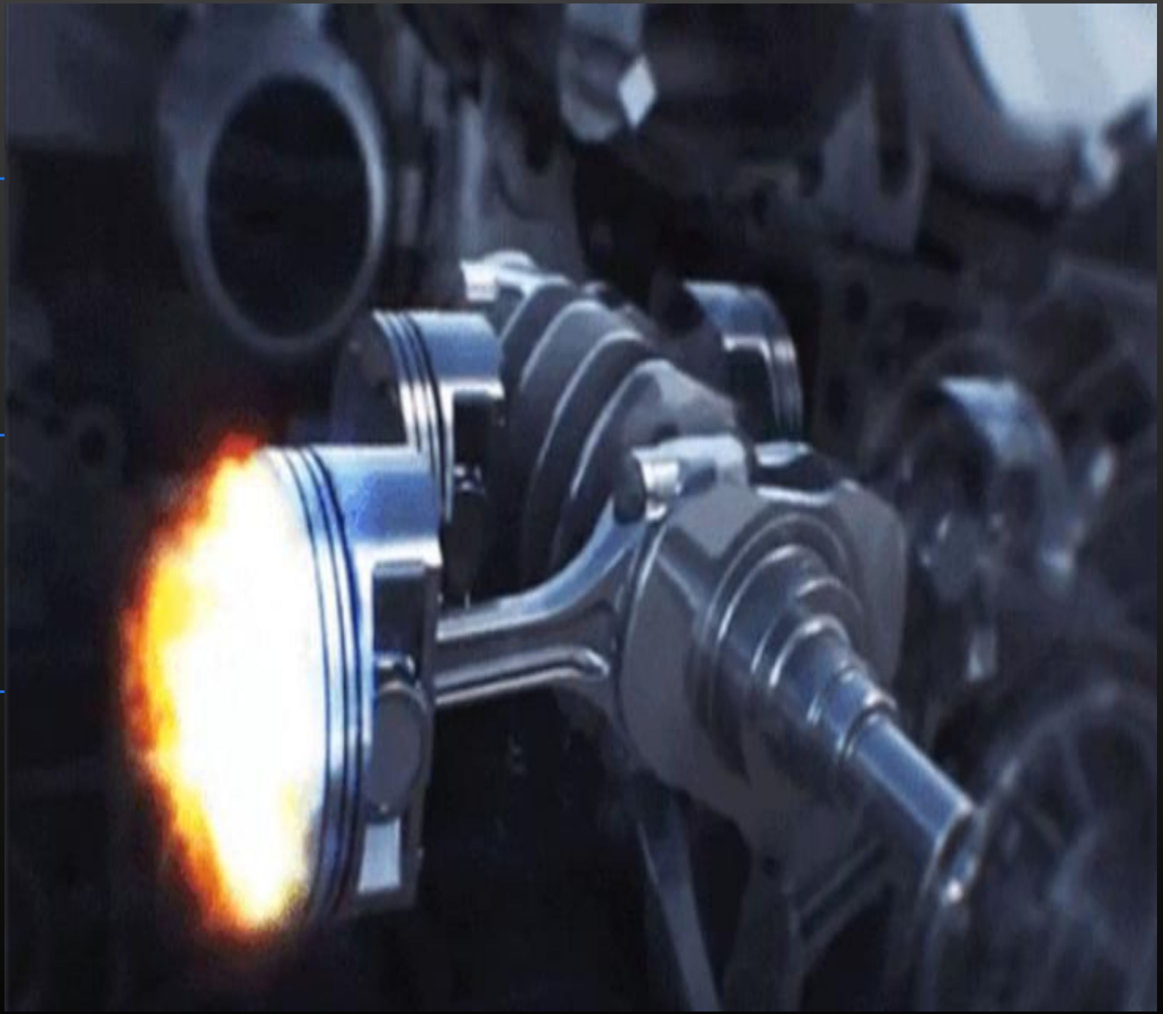
ENGINEERING THERMODYNAMICS

Introduction

Modern internal combustion engines are designed to optimize power output, fuel efficiency, and emissions while maintaining reliability. Two common configurations used to achieve these goals are naturally aspirated and turbocharged engines.

A naturally aspirated engine relies on atmospheric pressure to fill the cylinders during the intake stroke.
A turbocharged engine, in contrast, uses exhaust gas energy to drive a turbine–compressor system, increasing intake air density and enabling higher work output per cycle.

This project examines Ford's 2.0 L Duratec (Naturally Aspirated) and 2.0 L EcoBoost (Turbocharged) engines to analyze how turbocharging influences thermodynamic performance, efficiency, pressure conditions, and overall system design complexity.



History

Alfred Büchi (1879–1959): A Swiss engineer who invented turbocharging. In 1905, he patented the first design that used exhaust gas to spin a turbine and compress the intake air.

1879–1959

1930s–1940s

Turbochargers were used in airplane engines to help them keep power at high altitudes.

1970s

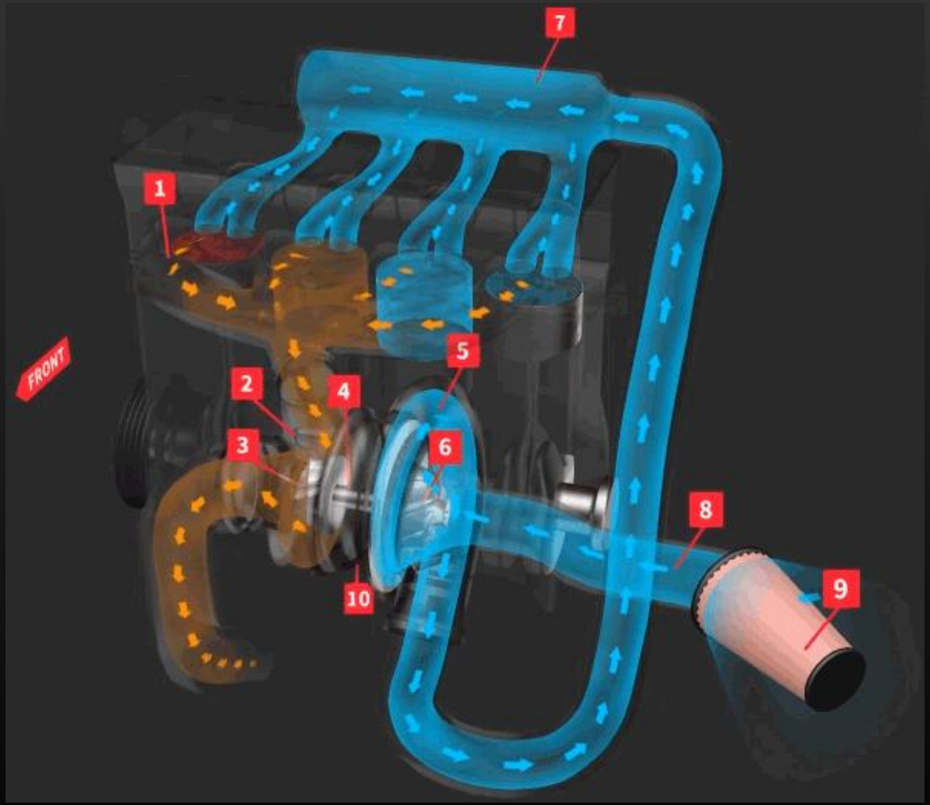
Vehicle manufacturers like Porsche and BMW began using turbos in sports cars to increase performance.

2000s

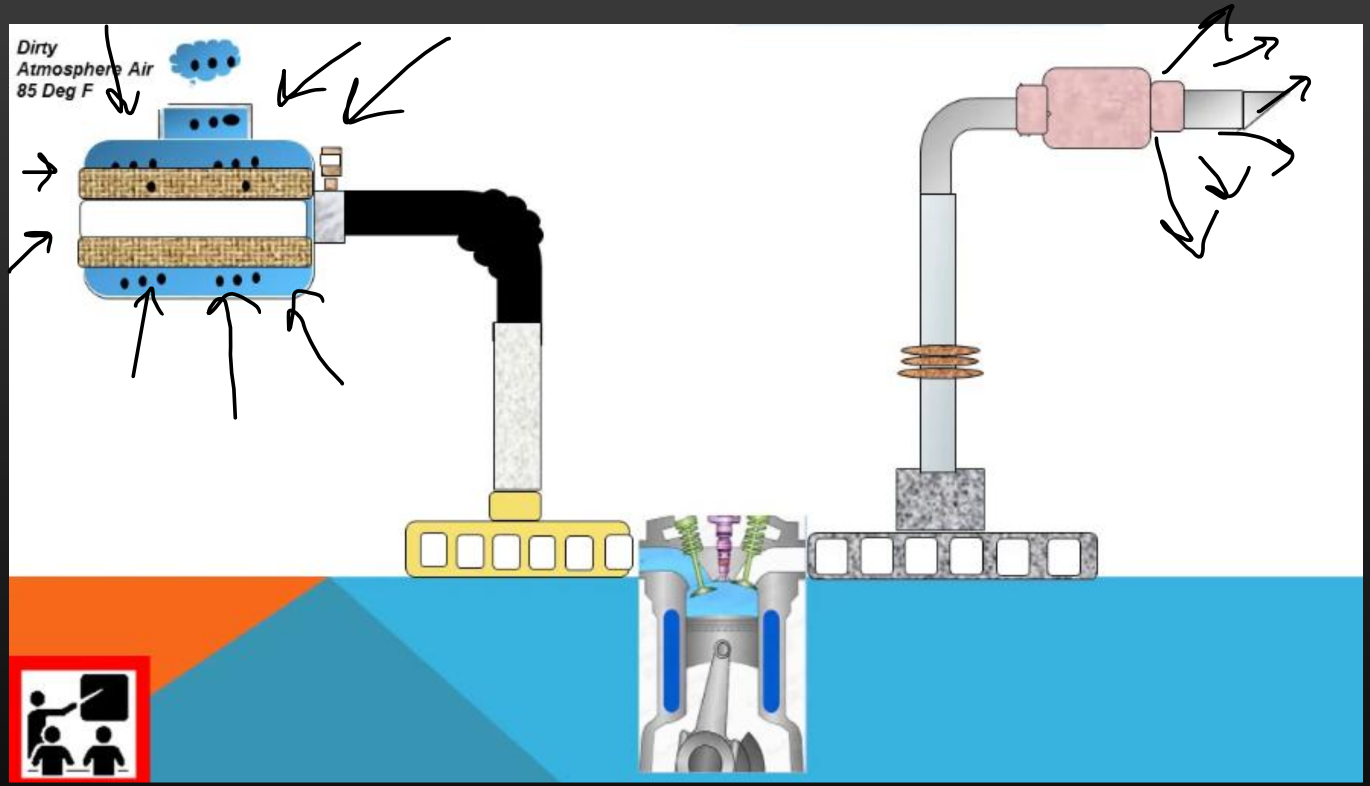
and later:
Ford's EcoBoost engines made turbocharging common in everyday vehicles by giving more power, better fuel use, and lower emissions.

Turbocharge Engine

- A turbocharger works by using exhaust gas to spin a turbine. The turbine is connected to a shaft that also spins a compressor on the intake side. As the compressor spins, it pulls in fresh air and squeezes it, increasing the air pressure before it enters the engine. This high-pressure air allows the engine to burn more fuel and produce more power. After the exhaust gas spins the turbine, it leaves the system through the exhaust pipe. In simple terms, the turbo uses wasted exhaust energy to push more air into the engine and boost performance.



Naturally Aspirated Engine

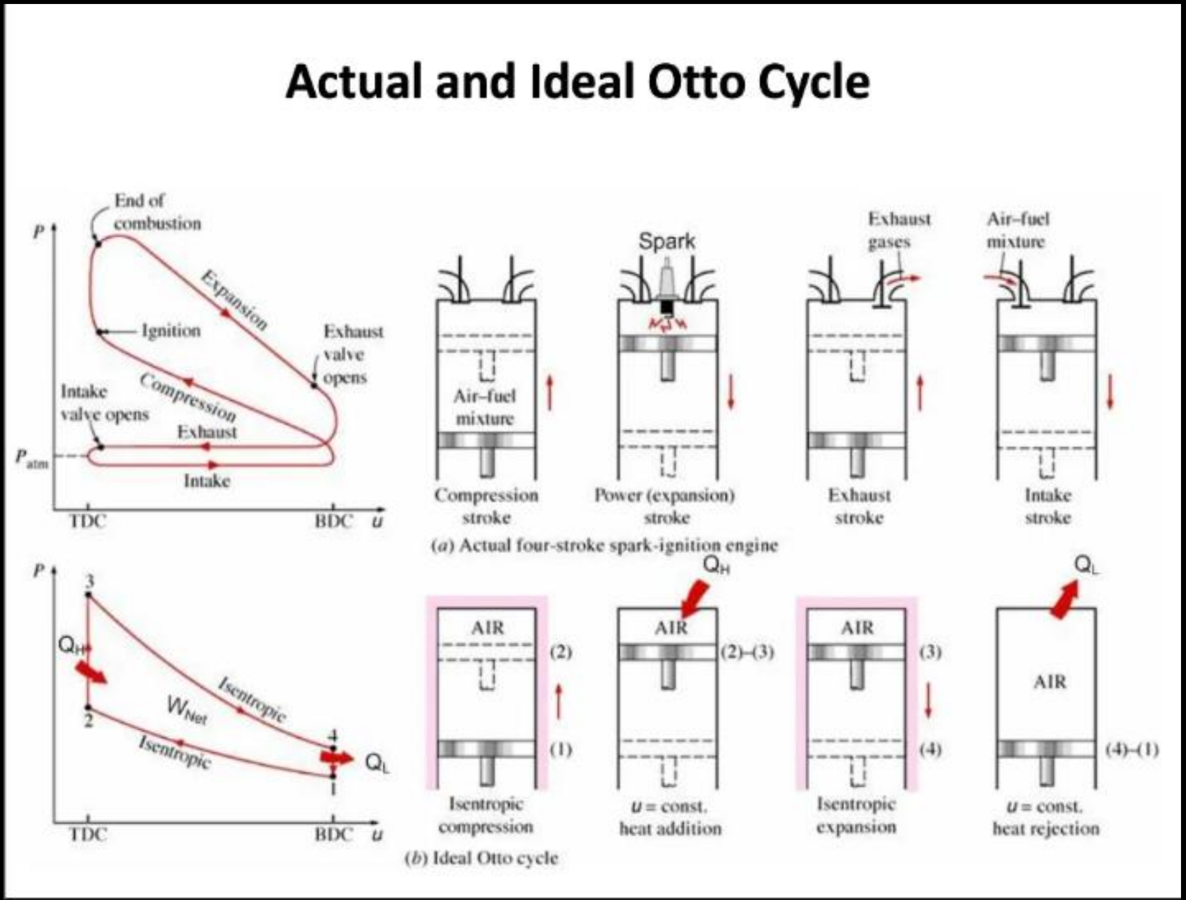


- A naturally aspirated engine pulls air into the cylinders using normal atmospheric pressure. Air first passes through the air filter to remove dirt and dust, then moves through the intake pipe and into the intake manifold. The clean air enters the cylinder, mixes with fuel, and burns to make power. After combustion, the exhaust gases leave through the exhaust manifold and pass through emissions parts before exiting the tailpipe. This system does not use a turbocharger, so air pressure stays at normal atmospheric levels.

Ford Engine Specifications

Parameter	Naturally Aspirated (Duratec 2.0L)	Turbocharged (EcoBoost 2.0L)
Displacement	2.0 L (1999 cc)	2.0 L (1999 cc)
Compression Ratio	10.8:1	9.3:1
Power	~160 hp	~245 hp
Torque	~200 N.m	~370 N.m
Bore x Stroke	87.5 mm × 83.1 mm	87.5 mm × 83.1 mm

Thermodynamics Background



- Actual Otto Cycle
- Intake Stroke:
  The piston moves down with the intake valve open, drawing air–fuel into the cylinder at low pressure.
- Compression Stroke:
  The piston rises with both valves closed, compressing the mixture and increasing pressure and temperature.
- Power Stroke:
  The spark ignites the mixture, causing a rapid pressure rise that pushes the piston down and produces work.
- Exhaust Stroke:
  The piston moves up with the exhaust valve open, forcing the burned gases out of the cylinder.
- Ideal Otto Cycle
- Process 1 → 2 (Isentropic Compression):
  The air is compressed adiabatically, so pressure and temperature increase with no heat transfer.
- Process 2 → 3 (Constant-Volume Heat Addition):
  Heat is added instantly at constant volume, creating a sharp pressure rise.
- Process 3 → 4 (Isentropic Expansion):
  The hot gases expand adiabatically, pushing the piston down and producing the net work output.
- Process 4 → 1 (Constant-Volume Heat Rejection):
  Heat is rejected at constant volume, dropping the pressure back to the starting state.

Important Calculations

Otto efficiency (NA)

Compression Ratio: 10.8
Heat ratio: 1.4

$$\eta_{otto} = 1 - \frac{1}{r^{\gamma-1}} \Rightarrow 1 - \frac{1}{10.8^{(1.4-1)}}$$

$$\boxed{\eta_{otto} = 61.4}$$

Otto efficiency (Turbo)

Compression Ratio: 9.3
Heat Ratio: 1.4

$$\eta_{otto} = 1 - \frac{1}{9.3^{0.4}}$$

$$\boxed{\eta_{otto} = 59\%}$$

Work done (NA)

Bore (b) = 87.5mm
stroke (L) = 83.1mm

Piston area $= \frac{\pi b^2}{4} \Rightarrow \frac{\pi (0.0875)^2}{4}$

$A = 0.00601\ m^2$

IMEP = 12.6 bar = 1.26×10^6 Pa

$$W = IMEP \times A \times L$$

$W = 1.26\times10^6 Pa \times 0.006001 m^2 \times 0.0875 m$

$W = 630.6 \frac{N}{m^2} \times m^3 \Rightarrow W = 630.6 J$ (per cylinder)

multiply by 4

$$\boxed{W = 2.52 kJ}$$

Work done by a Turbo charged

Bore (b) = 87.5mm = 0.0875m
stroke (L) = 83.1mm = 0.0831 m
Pisto area = $0.00601\ m^2$
IMEP = 23.3 bar $\Rightarrow 2.33\times10^6$ Pa

$W = 2.33\times10^6 Pa \times 0.00601 m^2 \times 0.0831 m$

$W = 1166 \frac{N}{m^2} \times m^3$ $\quad W = 1166 J$ (per cylinder

multiply by 4 Culinder

$$\boxed{W = 4.66 kJ}$$

IMEP is the average pressure that pushes the piston during the power stroke, and it shows how much work the engine produces per cycle (Indicated mean mean effective pressure)

Calculations summary

Category	NA Engine	Turbo Engine
Carnot Efficiency	69.6%	70.8%
Otto Efficiency	61.4%	59.0%
IMEP Work per Cycle (per cylinder)	630 J	1166 J

- Pros (EcoBoost Advantages-Turbocharger)
- 30–40% more work per cycle
- Higher torque (370 Nm vs 200 Nm)
- Better fuel efficiency
- More power (160 hp vs 245 hp)

- Cons (EcoBoost Disadvantages-Turbocharger)
- More heat in the engine
- More complex design (turbo, intercooler, extra parts)
- Slight delay before the turbo makes full power
- Cost more money to repair

Performance Comparison Summary

Conclusion

- This project shows that the turbocharged EcoBoost engine makes more power and uses fuel better because it pushes more air into the cylinders. The naturally aspirated Duratec engine is simpler, runs cooler, and has no delay in response, but it cannot match the power of the turbo engine. Both engines have good qualities. The EcoBoost is best for drivers who want strong performance, while the Duratec is better for people who want a simple and reliable engine. In the end, it depends on what you want the engine to do.

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