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# 1. Introduction

The aim of this paper is to present and analyse data in order to provide a suitable outline of characteristics of performance within a given engine. The engine being studied is a 1.6L Honda VTEC D16. Key performance data regarding the engine was collated using a dynamometer, standard equations from a handout and in class preparation, allowing a detailed analysis of behaviour to be developed.



Figure 1 - Eddy Current Dynamometer W230 (Dadt, 2001)

## 2. Testing equipment

The equipment used to conduct the test process was a Schenck w230 Eddy current dynamometer. The inner core of the dynamometer, powered by the engine, moves independently from the outer casing which is current fed. This produces an electromagnetic field which then outputs a resistive load, working against the engine to slow it down. The reaction of this results in the outer casing partially rotating. This rotation is dictated and restricted by a strain gauge which signals the computer system within the control cell. This signal operates on a range between 0 and 10 volts. UWTS WISA Workshops (2021) state that this is the only information the dynamometer provides us with, and all other information comes from various sensors attached to the engine itself in the same manner they would if placed in a vehicle.

The system is calibrated using torque arms secured either side of the outer casing which are made to a specified distance; in this case 815.776mm.

This is important for the process used in the test, in which a load cell (mass, kg) is suspended from one of these arms. Using this mass, multiplied by gravity, and the distance (in meters) from the centre of the casing, the torque of the engine can be calculated. For example, when 10 kg is placed on the torque arm, the outer casing will be affected by the weight, but restricted by the strain gauge, which will then give a reading, for example 2 volts, to the computer. As more weight is added, more voltage will be produced from the gauge. At every interval of weights, the tester should take a reading of the voltage to enable a data set to be formed from this experiment.

For further testing, the electromagnetic current within the dynamometer can be adjusted to apply different strain to the strain gauge. From the control centre, the throttle can be adjusted to measure the torque at different RPM ranges within the engine's capability.

## 3. Results

### 3.1 Excel Tables

See Table 1 for a sample of results from the dynamometer.

The Load (N), Dyno Speed (rpm), Fuel Flow Rate (l/min) and Lambda readings are taken during the testing. Using this information and known equations, it is then possible to calculate the Corrected Power (kW), Torque (Nm), BMEP (kPa), SFC (g/kWh), Overall Thermal Efficiency (%) and Brake Power of the engine (kW). See Table 3 for Equations.

Table 1 - Excel spreadsheet of Experiment Data

| Load    | Dyno Speed | Fuel Flow Rate | Lambda  |  | Corrected Power | Torque   | BMEP     | SFC         | Overall Thermal Efficiency | Brake Power |
|---------|------------|----------------|---------|--|-----------------|----------|----------|-------------|----------------------------|-------------|
| Newtons | rpm        | l/min          | Lambda  |  | kW              | Nm       | kPa      | g/kWh       | %                          | KW          |
| 102.275 | 1000       | 0.0704         | 1.2658  |  | 8.731832399     | 83.4564  | 655.465  | 360.0741278 | 0.227225939                | 8.739533771 |
| 102.756 | 1050       | 0.0724         | 1.26783 |  | 9.211543177     | 83.8489  | 658.5477 | 351.0191607 | 0.233087509                | 9.219667649 |
| 103.689 | 1100       | 0.0737         | 1.27344 |  | 9.737809499     | 84.61022 | 664.5271 | 338.0110227 | 0.242057733                | 9.746398132 |
| 104.209 | 1150       | 0.0728         | 1.28476 |  | 10.23149206     | 85.03454 | 667.8597 | 317.7730461 | 0.257473637                | 10.24051612 |
| 105.811 | 1200       | 0.0744         | 1.29181 |  | 10.8404664      | 86.34178 | 678.1267 | 306.5135069 | 0.266931734                | 10.85002757 |
| 107.51  | 1250       | 0.07895        | 1.29729 |  | 11.47346983     | 87.72816 | 689.0154 | 307.3137597 | 0.266236637                | 11.48358929 |
| 109.488 | 1300       | 0.079          | 1.29895 |  | 12.15194452     | 89.34221 | 701.6921 | 290.3393918 | 0.281801864                | 12.16266239 |
| 111.797 | 1350       | 0.0796         | 1.29469 |  | 12.88545686     | 91.22635 | 716.4901 | 275.8912304 | 0.29655956                 | 12.89682168 |
| 114.268 | 1400       | 0.0835         | 1.2855  |  | 13.6580458      | 93.24269 | 732.3264 | 273.0376643 | 0.299658957                | 13.67009204 |
| 115.783 | 1450       | 0.0847         | 1.27818 |  | 14.33338292     | 94.47893 | 742.0358 | 263.9121327 | 0.31002054                 | 14.3460248  |
| 116.985 | 1500       | 0.08865        | 1.2795  |  | 14.98157047     | 95.45976 | 749.7392 | 264.2688945 | 0.309602013                | 14.99478404 |
| 117.788 | 1550       | 0.0932         | 1.27766 |  | 15.58721941     | 96.11501 | 754.8855 | 267.0372906 | 0.306392346                | 15.60096716 |
| 118.471 | 1600       | 0.0959         | 1.28235 |  | 16.18333186     | 96.67234 | 759.2628 | 264.652083  | 0.309153742                | 16.19760536 |

Table 2 – Given Value in Dynamometer Room

| Baro   | Humidity | Ambient temp |
|--------|----------|--------------|
| mBar   | %        | Deg C        |
| 1018.9 | 46       | 27           |

Table 3 - Equations for Calculated Measurements

|                            |                                                                                               |
|----------------------------|-----------------------------------------------------------------------------------------------|
| Corrected Power            | $= BP \times \frac{P_{Amb}}{P_{ref}} \times \frac{Temp_{ref}}{Temp_{ambient}}$                |
| Torque                     | $= \text{Newtons} \times \text{Torque arm length}$                                            |
| BMEP                       | $= \frac{4 \times \pi \times \text{Torque}}{\text{Engine capacity}} / 1000$                   |
| SFC                        | $= \left( \frac{\text{Fuel Flow Rate} \times 0.745}{60} \times 3600 \times 1000 \right) / BP$ |
| Overall Thermal Efficiency | $= (BP \times 1000) / \left( \text{Fuel Flow} \times \frac{0.745}{60} \right) \times 44e^6$   |
| Brake Power                | $= \frac{2 \times \pi \times \frac{RPM}{60} \times \text{Torque}}{1000}$                      |

## 3.2 Graph Data

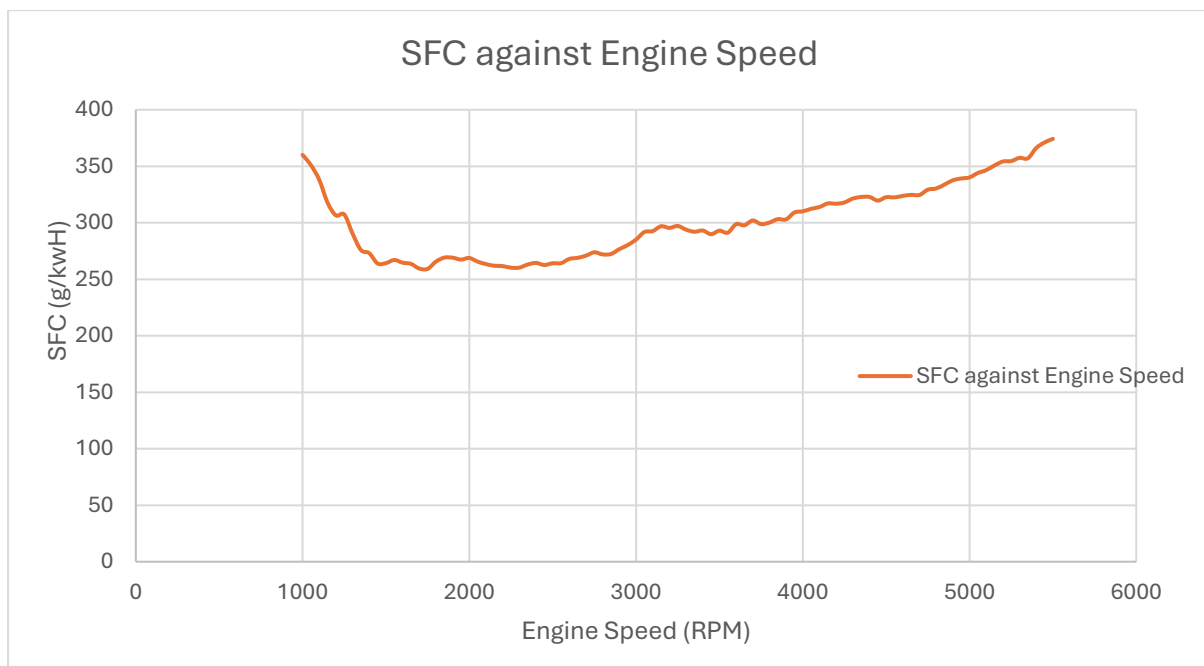


Figure 2 - Graph of Engine Speed against SFC

Figure 2 shows the relationship between the tested engine speed and SFC. It can be seen here that it is not a linear relationship. A paper from SAE international shows that SFC varies across operating points and can strongly depend on operating conditions. (Hong et al., 2024)

In this example, at mid RPM ranges, the SFC decreases and the engine becomes more efficient as it consumes less fuel. This could be because the throttle would be at a more open position allowing more airflow into the engine, giving the fuel a larger allowance to mix with the air. At lower speeds the air is present in the engine for longer allowing it to change temperature more; whereas in the mid-range speed, the air is combusted faster after entering the chamber, which means the combustion happens at a more optimal point in the process. At higher speeds, the heat in the chamber is higher and therefore decreases the efficiency of the combustion to produce power. At higher speeds the engine also pumps more fuel to maintain the power requirements and maintain the air-fuel mixture.

Another reason SFC may increase again with engine speed is how VTEC works. Being that this is a VTEC engine, this is an important factor to consider. As engine speed increases with throttle response, a set of locking bolts join rockers to force them to activate on a higher seated cam profile, which forces the valves to open longer, allowing more air into the chamber at higher operation ranges. (Honda, 2025)

The low-profile and high-profile cam lobes allow an engine to perform softer at idle for example, and then shift into a higher performance profile when under load.

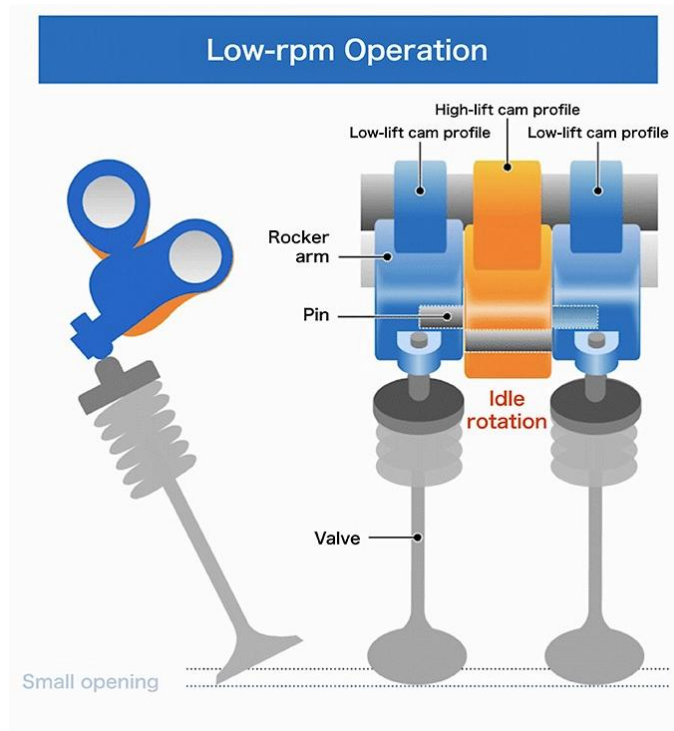


Figure 3 - Low cam profile (Honda, 2025)

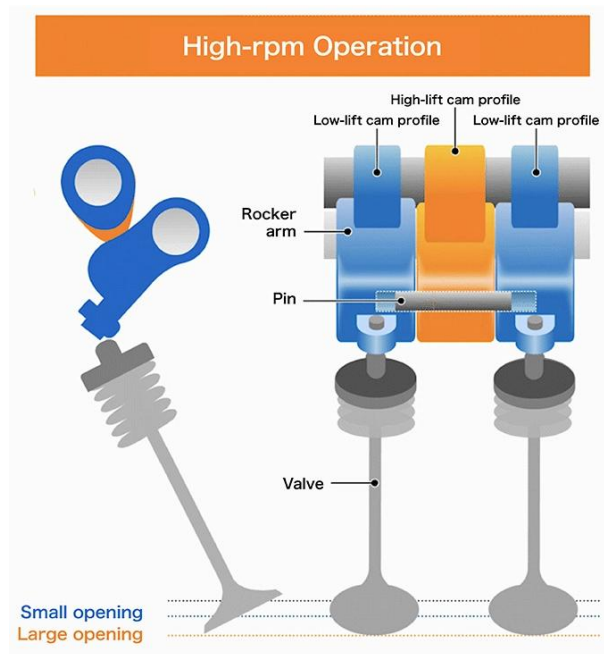


Figure 4 - Higher cam profile (Honda, 2025)

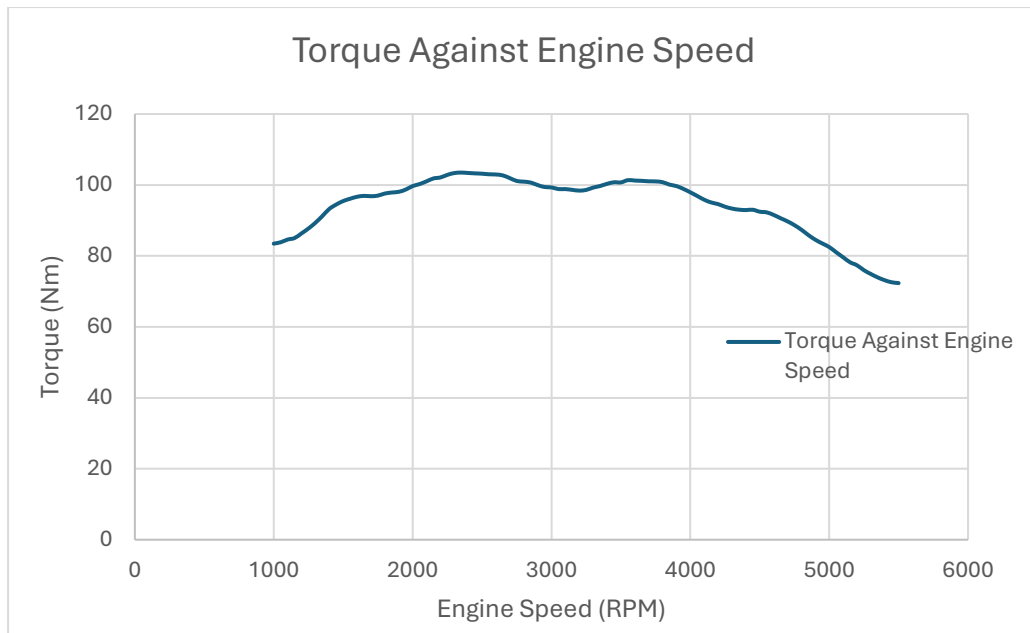


*Figure 5 - Engine Speed vs Torque*

The primary reasoning for why the torque result varies with engine speed in Figure 5 is likely down to volumetric efficiency. Volumetric efficiency tends to peak at an intermediate speed, reducing again at the lowest and highest speeds, based on factors affecting the air flow rate (Burke, 2000).

At mid speeds, the dynamics of the intakes and valve timing help with airflow by creating a vacuum to help ‘breathe’ air into the cylinder, utilising the exhaust gas flow as the intake starts, to help pull the clean air in. At higher speeds and temperatures, this is negated and becomes less effective.

Another reason for torque variation is that as the engine speed increases, more friction works against the engine in areas such as the bearings and crankshaft. Sometimes factors like timing can affect the power output of an engine. In an engine with less-than-ideal set up, factors such as valve float may force the valves to stay open and reduce cylinder compression.

Valve float is when the valve springs fail to push the valves back into the correct positions in time with the combustion cycle. This is more often found at the higher RPM ranges and can be reduced by using stronger springs or lighter valves.

Heywood (2018) states that an engine may lose torque at higher speeds due to ‘pinking’ or ‘knock’. This is when the air-fuel mixture combusts while the piston is still in its upward travel during the cycle, causing the engine to lose power and torque, overcoming this premature ignition. Some engines contain knock sensors which allow them to react to this premature ignition and adjust the timing to minimise the impact of this phenomenon.

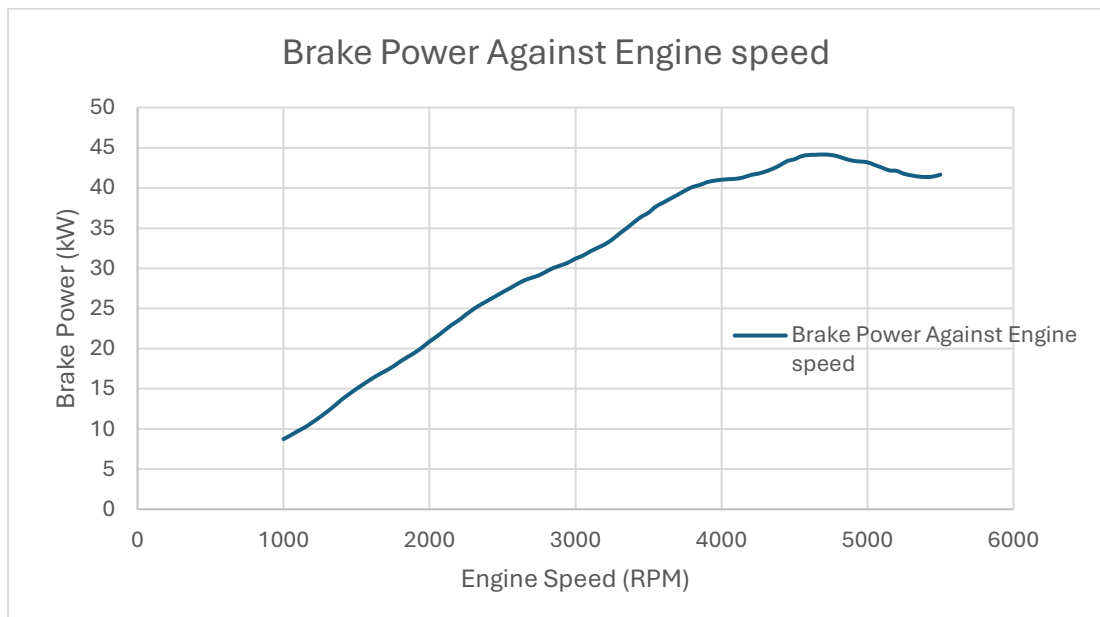


Figure 6 - Engine Speed vs Brake Power

The graph in Figure 6 shows a much more linear relationship between engine speed and brake power, until the 4000rpm range, where the power starts to drop off.

To check the data mathematically, here is an example of a brake power calculation to find power at 2000 RPM, where the  $N$  value is engine speed, and the  $T$  value is the torque value at the same RPM, found on the graph in Figure 5.

$$BP = \frac{2\pi NT}{60}$$

$N = 2000 \text{ RPM}$

$T = 100 \text{ Nm}$

$$BP = \frac{(2 \times \pi \times 2000 \times 100)}{60}$$

$$BP = 20.9 \text{ kW}$$

Using this equation, it can be expected that the brake power at 2000 RPM should be around 20.9 kW. Looking at Figure 6, this appears to be the output value from the engine with the given data.

As the engine throttle is opened, the engine power and speed increases. This correlation plateaus towards the higher speeds due to the throttle meeting its widest position; limiting further increases in airflow into the chamber.

As the engine speed increases and completes more cycles per second, more combustion cycles occur, leading to a greater rate of energy release, and consequently a raise in brake power output (Heywood, 2018). This increase in speed then stabilises with throttle position, restricting further gains in power, which can be observed as the peak power output in Figure 6.

At high engine speeds, brake power begins to decrease due to a combination of factors, many of which were analysed earlier in the sections for “Torque Against Engine Speed” and “SFC against engine speed”. Airflow limitations reduce volumetric efficiency; valve train issues like valve float affect compression and frictional losses further reduce overall engine performance.

Considering one reason that the power output wavers at high RPM due to losses in thermal efficiency, studies such as those from Liu and Liu (2025) and Kang et al. (2023) highlight the importance of thermodynamics. Simply put, the reduction in energy converted into useful work versus losses of energy to heat transfer play a big role in reduction of power output. This supports the observed reduction in brake power at higher engine speeds.

With higher RPM ranges, the engine is forced to work harder, increasing friction within different systems, which is one example where this heat energy loss can occur due to thermodynamics.

There is also a mathematical reason that the brake power begins to fall:

$$P = \frac{(2\pi NT)}{60}$$

P = Brake Power, N = Engine speed and T = Torque.

As discussed previously, the torque in an engine drops off as the RPM rises.

As the equation multiplies a constantly rising factor (Engine Speed) with a value that has a variable gradient (Torque), the eventual outcome is that the final calculated value (Power Output) will start to level off and decline.

There is a trend between the graphs in Figures 2, 5 and 6 that show, at low engine speeds, poor volumetric efficiency and combustion lead to low torque, low power, and high SFC. As speed increases, improved cylinder filling and combustion raises torque, resulting in increasing power and decreasing SFC.

At higher speeds, airflow limitations, increased friction, reduced combustion time, and potential parasitic losses cause torque to decline, which in turn causes brake power to plateau and SFC to rise.

## 4. Discussion, clarifications and conclusion

In Table 1, there is a section showing Lambda readings taken from the engine. This ties into the 'Stoichiometric ratio', the ratio of fuel to air mixture mentioned in previous sections. The 'Stoichiometric ratio' is the ideal mixture that leaves no unburned oxygen or fuel in the combustion chamber. In real engines, a mixture of fuel <14.7:1 is considered 'running rich'. This means that there is more fuel present within the mixture than the stoichiometric value and often outputs more power at the cost of efficiency.

A value >14.7:1 is considered 'running lean', meaning there is more air present in the mix, often resulting in better fuel economy but producing a lower power output.

In engineering this is also often referred to as "lambda" ( $\lambda$ ). Lambda 1 is equivalent to the stoichiometric ratio value, with a figure of less than 1 being considered lean, and more than 1 being considered a rich mixture.

The main key takeaway is that the engine performs best within mid-engine speed ranges, specifically between the 2000 to 3000 rpm range as seen in Figures 2 and 5, producing peak engine power at 4000 to 5000 rpm, at about 44.1 kilowatts of power. This engine would likely perform best at consistent cruising speeds around outer roads of a city as this would be roughly within this powerband. One main issue with this data is that the engine performs very badly. The engine in question is a 4-cylinder 1.6 L Honda CRX VTEC engine which according to a popular car enthusiast website, should make 148hp (~110.364 kW) at 7600 RPM (EncyCARpedia, 2023). This shows just how severely the engine being studied here is underperforming during operation.

This could be due to many factors such as poor maintenance, poor assembly or even an indication of component failures.

## 5. Evaluation

Unfortunately, due to limitations involving the dynamometer, the testing could not be completed practically. However, analysis of provided data still enabled students to evaluate the performance trends of the engine.

With the lack of experimental validation, certain learning outcomes involving methodology could not be fully achieved. However, the University did provide students with videos on the equipment set up and the testing processes to allow for a level of understanding to be achieved.

Given the opportunity to work with this data set again in the future, it would be valuable to perform the test practically and then compare the live data against the values given to the students to help further establish their knowledge.

As the data was provided by the university, it is more than likely credible. However, it is always better to collect data personally where possible to ensure that equipment has been calibrated within a short timeframe of completing the test, and to allow testers to observe any real time anomalies in engine behaviour leading up to testing or during testing. These variations in behaviour could then be assessed by the student to allow for a deeper understanding and experimental evaluation of the engine's behaviour.

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