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Engine Performance Characteristics

Powertrain Technology (ACHA4029)

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(03/2026)

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1. Introduction

In this report, an engine dynamometer, or “dyno” will be used to record and evaluate the performance characteristics of a Honda 1.6 litre internal combustion engine. The data collected from the dyno sessions, such as the fuel flow rate, Lambda and Load will be used along with environmental factors to calculate the performance of the engine at different speeds. This report aims to display the data collected in a meaningful way, outlining how the engine performs in real time under controlled conditions.

According to Martyr (2020) A dynamometer is a device that measures the torque produced by a power unit under a test by resisting and controlling rotational speed.



Figure 1 - Eddy current dynamometer (Schenck Pegasus, 2001)

2. Methodology and Equipment

This experiment was conducted using an Eddy-Current W230 Series Dynamometer, Produced by Schenck. This is installed within the Dynamometer cell at UWTSD's IQ building, attached to this dyno is the main focus of this report – A Honda D16 1.6 litre VTEC 4-cylinder engine. VTEC is a mechanical system actuated using oil pressure that allows the engine to operate on two different camshaft profiles depending on the engine's RPM (Kertes, 2015).

The Dynamometer cell contains many systems that are crucial to the operation of the engine, as well as the dyno, such as:

- Sensor recorder modules – feeds live engine data straight to a computer, these sensors record the coolant temperature, fuel flow rate, and lambda sensor.
- Exhaust extraction system – removes harmful emissions produced by the engine out of the building.
- Fuel supply board – made up of the entire fuelling system, a small fuel pump first pumps fuel from the fuel safe via a fuel filter, followed by a fuel flow meter into a swirl pot. This swirl pot is then pumped via the main fuel pump through a regulator into the engine. A return feed is also fitted to run unused fuel first through a cooler back into the swirl pot.
- Fuel safe – a storage enclosure or safe designed to contain the fuel used by the dyno, minimising fire risks.

The engine is connected to the dynamometer directly via a driveshaft, which in turn is connected straight to the crankshaft. This is done so that there are minimal losses in power through the drivetrain when testing, as some power would be lost through the gearbox, differential and wheels.

The dynamometer works because of Faraday's law of electromagnetic induction, where the inner core spins freely, and the outer core is fed an electrical current, producing an electromagnetic field. The rotating part when exposed to the magnetic field produces eddy currents, the interaction between the EMF and the eddy currents slows down the rotating core. (Nazaruddin Sinaga et al., 2019)

The resulting forces try to turn the outer casing of the dyno, which is restricted by a strain gauge, which sends the computer a signal between 0 and 10 volts. This is the only data that the dyno itself produces, but is used alongside the data that the engine itself outputs to determine the torque, power and more.

Before the data can be recorded, the dyno is calibrated using an arm on either side. The distance from the pivot at the centre of the of the dyno to the hook eye at the end of the arms is inscribed onto a plate on the arm, and is used in multiple equations. For this dynamometer this length is 815.776mm. Varying masses are applied to the hook at the end of this hook eye, which rotates the outer casing putting force on the strain gauge, which gives a voltage reading. The mass can be converted into weight, which along with the arm length produces a figure in newtons.

There are two control dials on the computer for the dyno, one to increase the resistance of the electromagnets that slow down the engine, and one to increase the engine throttle. The computer can also control the throttle and resistance of the electromagnet. The engine is run from 1000 RPM in steps of 50 RPM up to its maximum, in this case 5500 RPM. The data is logged at each step and exported to a spreadsheet to calculate further data, and to create graphs to help further understand how the engine is performing.

3. Data and Graphs

						Baro	Humidity	Ambient temp	CF	Arm length	
						mBar	%	Deg C		m	
						1018.9	46	27	1.006263842	0.815776	
Load	Dyno Speed	Fuel Flow Rate	Lambda			brake power					
Newtons	rpm	l/min	Lambda	engine torque (nm)	engine power (kW)	bmp	corrected power (kW)	SFC (kg/kWh)	Thermal Efficiency	%	
102.275	1000	0.0704	1.2658	83.4334904	8.737134683	655.2851	8.791862712	0.360333197	0.22706257	22.71%	
102.756	1050	0.0724	1.26783	83.82587866	9.21713676	658.3669	9.274871445	0.351271715	0.232919926	23.29%	
103.689	1100	0.0737	1.27344	84.58699766	9.74372265	664.3447	9.804755786	0.338254218	0.2418837	24.19%	
104.209	1150	0.0728	1.28476	85.01120118	10.237705	667.6764	10.30183236	0.31800168	0.25728852	25.73%	
105.811	1200	0.0744	1.29181	86.31807434	10.84704913	677.9406	10.91499333	0.30673404	0.266739817	26.67%	
107.51	1250	0.07895	1.29729	87.70407776	11.48043693	688.8262	11.55234857	0.307534869	0.26604522	26.60%	
109.488	1300	0.079	1.29895	89.31768269	12.15932362	701.4994	12.23548769	0.290548288	0.281599256	28.16%	
111.797	1350	0.0796	1.29469	91.20130947	12.89328137	716.2934	12.97404285	0.276089731	0.296346342	29.63%	
114.268	1400	0.0835	1.2855	93.21709197	13.66633946	732.1253	13.75194325	0.273234112	0.299443511	29.94%	
115.783	1450	0.0847	1.27818	94.45299261	14.34208667	741.8321	14.43192323	0.264102015	0.309797644	30.98%	
116.985	1500	0.08865	1.2795	95.43355536	14.99066782	749.5334	15.08456699	0.264459033	0.309379418	30.94%	
117.788	1550	0.0932	1.27766	96.08862349	15.59668454	754.6783	15.6943797	0.267229421	0.306172058	30.62%	
118.471	1600	0.0959	1.28235	96.6457985	16.19315896	759.0543	16.29459035	0.264842497	0.308931469	30.89%	
118.772	1650	0.09875	1.29028	96.89134707	16.74162293	760.9829	16.8464898	0.263778986	0.310177027	31.02%	
118.656	1700	0.10005	1.29942	96.79671706	17.23209846	760.2396	17.3400376	0.259644766	0.315115853	31.51%	
118.861	1750	0.10305	1.31053	96.96395114	17.76957213	761.5531	17.88087792	0.259341293	0.315484591	31.55%	
119.584	1800	0.1093	1.3149	97.55375718	18.38845001	766.1854	18.50363235	0.265812674	0.307803995	30.78%	
119.934	1850	0.11415	1.31849	97.83927878	18.95455483	768.4279	19.07328316	0.269316507	0.303799358	30.38%	
120.176	1900	0.11745	1.31892	98.03669658	19.50611983	769.9784	19.62830308	0.269266782	0.30385546	30.39%	
120.948	1950	0.12055	1.31484	98.66647565	20.14804188	774.9247	20.27424602	0.26756852	0.305784036	30.58%	
122.157	2000	0.12555	1.31653	99.65274883	20.87122291	782.6709	21.00195695	0.269010646	0.304144773	30.41%	
122.845	2050	0.12785	1.32098	100.2140027	21.51349094	787.0789	21.64824804	0.265760536	0.307864302	30.79%	
123.796	2100	0.1309	1.32287	100.9898057	22.0881822	793.1721	22.34793074	0.263581451	0.310409483	31.04%	
124.794	2150	0.13435	1.32164	101.8039501	22.92090127	799.5664	23.06447507	0.262123893	0.312135536	31.21%	
125.137	2200	0.1377	1.31652	102.0837613	23.51841027	801.764	23.66572587	0.261834352	0.312480701	31.25%	
126.028	2250	0.14105	1.30465	102.8106177	24.2241811	807.4727	24.37591754	0.260390198	0.3142213754	31.42%	
126.66	2300	0.14495	1.29646	103.3261882	24.88667418	811.5522	25.04256037	0.260466578	0.314121614	31.41%	
126.822	2350	0.14985	1.28229	103.4583439	25.46021122	812.5599	25.61968995	0.263205761	0.310852549	30.99%	
126.69	2400	0.1537	1.27304	103.3506614	25.9748543	811.7142	26.13755667	0.264619225	0.30919213	30.92%	
126.552	2450	0.15565	1.26984	103.2380844	26.48711394	810.83	26.65302502	0.26279381	0.311339836	31.13%	
126.438	2500	0.1596	1.27446	103.1450859	27.00332034	810.0996	27.17246486	0.264311686	0.30955189	30.96%	
126.239	2550	0.1626	1.27876	102.9827465	27.50003638	808.8246	27.67229225	0.264416115	0.309429635	30.94%	
126.161	2600	0.16805	1.27634	102.9191159	28.02192801	808.3248	28.19745293	0.268189117	0.305076443	30.51%	
125.847	2650	0.17145	1.28027	102.6629623	28.48972671	806.313	28.66818185	0.269122403	0.304018472	30.40%	
124.911	2700	0.17465	1.28371	101.8993959	28.81137543	800.316	28.99184532	0.271084849	0.301817613	30.18%	
123.927	2750	0.1784	1.2812	101.0966724	29.11375162	794.0114	29.29611555	0.274029504	0.298574353	29.86%	
123.689	2800	0.18005	1.27448	100.9025177	29.58616343	792.4865	29.77148648	0.272147983	0.300638575	30.06%	
123.389	2850	0.1831	1.26036	100.6577849	30.04144696	790.5644	30.22962183	0.27256378	0.30017995	30.02%	
122.519	2900	0.1879	1.2531	99.94805974	30.35295539	784.9902	30.5430815	0.276838472	0.295544484	29.55%	
121.837	2950	0.19255	1.23943	99.39170051	30.70440989	780.6206	30.89673745	0.280442232	0.291747007	29.17%	
121.709	3000	0.199	1.22735	99.28728118	31.19201932	779.8059	31.38740119	0.285305558	0.28677388	28.68%	
121.123	3050	0.20605	1.2193	98.80923645	31.55920109	776.0405	31.75688292	0.291976074	0.280222214	28.02%	
121.124	3100	0.21005	1.20692	98.81005222	32.07682986	776.0523	32.27775405	0.292841007	0.279394551	27.94%	
120.851	3150	0.21605	1.19274	98.58734538	32.5207344	774.3032	32.72443913	0.297094473	0.275394493	27.54%	
120.596	3200	0.21795	1.18481	98.3793225	32.96727739	772.6694	33.17372889	0.295648103	0.276741779	27.67%	
120.84	3250	0.22305	1.17378	98.57837184	33.55008462	774.2327	33.76023704	0.29730982	0.27519502	27.52%	
121.633	3300	0.2255	1.16118	99.22528221	34.28979594	779.3135	34.50458179	0.294091378	0.278206666	27.82%	
122.181	3350	0.2285	1.15104	99.67232746	34.96616677	782.8426	35.18518931	0.292239439	0.279969678	28.00%	
122.933	3400	0.2342	1.14117	100.285791	35.70647182	787.6428	35.93013151	0.293319272	0.278938992	27.89%	
123.475	3450	0.23605	1.12669	100.7279416	36.39130855	791.1154	36.61925795	0.290072781	0.282060873	28.21%	
123.428	3500	0.24195	1.11975	100.6896001	36.90466594	790.8143	37.13583092	0.293187192	0.279064652	27.91%	
124.205	3550	0.24545	1.10622	101.3234581	37.6675154	795.7926	37.90345875	0.291404805	0.280771561	28.08%	
124.066	3600	0.25505	1.09697	101.2100652	38.15529568	794.902	38.39429441	0.298931135	0.273702443	27.37%	
123.967	3650	0.25755	1.09401	101.1293034	38.6546099	794.2677	38.89648578	0.297963936	0.274590888	27.46%	
123.815	3700	0.26445	1.09659	101.0053054	39.13582815	793.2938	39.38096878	0.302182764	0.270757275	27.08%	
123.767	3750	0.2651	1.09808	100.9661482	39.64931368	792.9863	39.8976707	0.299002418	0.273637191	27.36%	
123.509	3800	0.2693	1.09907	100.755678	40.09421772	791.3332	40.34536155	0.300369102	0.27329138	27.24%	
122.672	3850	0.27375	1.10533	100.0728735	40.3464862	785.9705	40.59921202	0.30342339	0.269650213	26.97%	
122.157	3900	0.2759	1.11704	99.65274883	40.69888467	782.6709	40.95381604	0.303158562	0.269885769	26.99%	
121.184	3950	0.28285	1.12259	98.85899878	40.89233607	776.4368	41.14847919	0.309324919	0.264505627	26.45%	
118.734	4000	0.28455	1.12451	97.8963831	41.00674106	768.8764	41.2636008	0.310315866	0.263660969	26.37%	
117.442	4050	0.2871	1.1222	96.86034758	41.07992711	760.7394	41.33724527	0.312538969	0.261785537	26.18%	
116.5	4100	0.28895	1.12394	95.80636499	41.13455823	752.4614	41.39221859	0.314135131	0.26045537	26.05%	
116.5	4150	0.29305	1.12233	95.037904	41.30223604	746.426	41.56094671	0.317299076	0.257858241	25.79%	
115.931	4200	0.2949	1.12179	94.57372746	41.59569784	742.7803	41.8562467	0.31704945	0.258061264	25.81%	
115.034	4250	0.29715	1.12456	93.84197638	41.76521234	737.0332	42.02682302	0.318171802	0.257150952	25.72%	
114.391	4300	0.3022	1.12278	93.31743242	42.02036829	732.9134	42.28357722	0.321614227	0.254398515	25.44%	
114.016	4350	0.30605	1.11943	93.01151642	42.36962302	730.5107	42.63501963	0.323026707	0.253286122	25.33%	
113.871	4400	0.3092	1.11986	92.8932289	42.8021272	729.5817	43.07023295	0.323053744	0.253264924	25.33%	
113.985	4450	0.3099	1.11873	92.98622736	43.33185257	730.3121	43.60327643	0.319826883	0.255820214	25.58%	
113.306	4500	0.31445	1.11563	92.43231546	43.55770248	725.9617	43.83054103	0.322839957	0.253432637	25.34%	
113.074	4550	0.3171	1.10953	92.24305542	43.9514093	724.4753	44.22680453	0.322643703	0.253586792	25.36%	
112.195	4600	0.3194	1.10569	91.52598832	44.08906379	718.8434	44.3652307	0.323969915	0.252548703	25.25%	
111.061	4650	0.32055	1.09782	90.60089834	44.11782308	711.5778	44.39417013	0.32492442	0.25180681	25.18%	
109.973	4700	0.3207	1.09558	89.71333405	44.15536435	704.6069	44.43194656	0.324800085	0.251903204	25.19%	
108.654	4750	0.32485	1.08827	88.6373255	44.08987535	696.1559	44.36604735	0.329491827	0.248316271	24.83%	
107.076	4800	0.32455	1.08396	87.35003098	43.9069145	686.0455	44.18194046	0.33055927	0.247514407	24.75%	
105.24	4850	0.3257	1.08221	8							

3.1 - Equations

The data in figure 1 displays the data from the dyno session, which can provide a further understanding of how the engine is performing.

Engine Torque (Nm): Engine torque is the engines rotation force (Rosamond, 2024).

Engine torque is calculated by multiplying the load on the dyno, by the radius length of the centre to the hook on the calibration arms mentioned previously.

$$T = W \times R$$

Engine Power (kW): Engine power, or brake power is the usable power delivered by the engine to the load (Heywood, 2018).

$$P = \frac{2\pi NT}{60} \div 1000$$

Where N is the engine speed (RPM), and T is the engine torque. The result is divided by 1000 to convert it to kilowatts from watts.

Corrected power (kW): The corrected power is the engines measured power output when compensating for atmospheric conditions.

$$P_s = \frac{1.01325}{p_a} \times \sqrt{\frac{T_a}{293}} \times P$$

Where Ps is corrected power, P is measured power, pa is ambient pressure, Ta is ambient temperature, 1.01325 is standard pressure in bar, and 293 is standard temperature in Kelvin.

Brake Mean Effective Pressure (or BMEP): BMEP is a way of measuring how effectively an engine can convert the pressure within a cylinder into usable torque (Heywood, 2018).

$$BMEP = \frac{4\pi T}{V_d}$$

Where T is torque and Vd is the engine displacement.

Specific Fuel Consumption (kg/kWh): a measure of how efficiently an engine is running by displaying the amount of fuel it uses relative to the amount of power it is making. (Yun et al., 2023)

$$SFC = \frac{V \times 0.75 \times 3600}{t \times 1000 \times P}$$

Where 0.75 is the conversion factor from litres of fuel to kg, 3600 converts time from seconds to hours for fuel used, V is the volume of fuel being measured and t is the time taken to use the fuel in seconds.

Thermal Efficiency (%): the thermal efficiency of an engine is how effectively an engine converts the energy of the fuel into useful work done by the engine, a higher percent means that less energy is wasted in other forms such as friction, heat and noise.

$$\eta_T = \frac{BP_c}{SFC \times CV}$$

Where BP_c is the corrected brake power in Watts, and CV is the calorific value of the fuel, in this case 44,000,000J/kg.

3.2 - Graphs

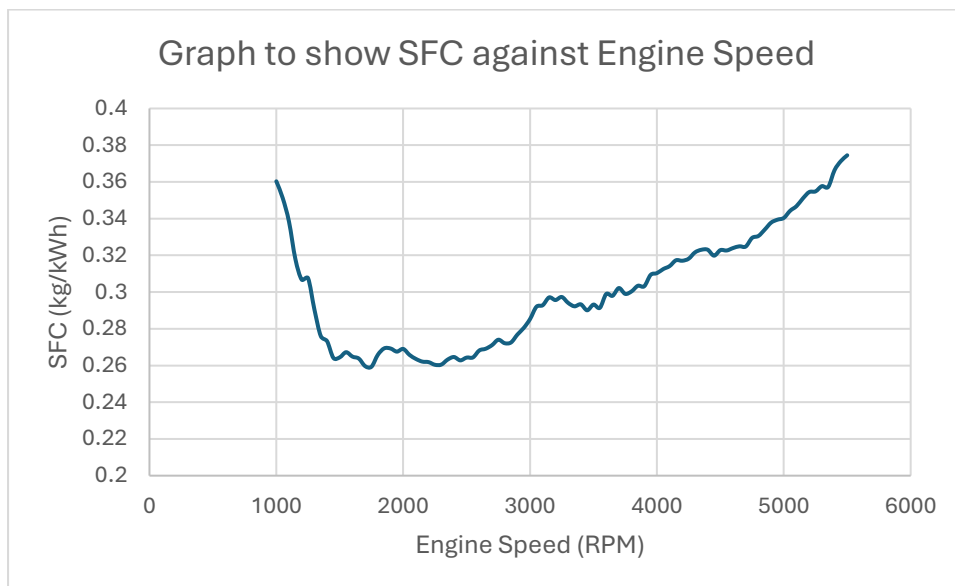


Figure 3 - Graph comparing SFC to Engine Speed

In figure 3, we can see past about 1500rpm, there is a clear positive relationship between the SFC, or Specific Fuel Consumption and the engine speed. The data suggests that this particular engine is the most efficient between 1500 and 2500 RPM, above this point the fuel consumed increases substantially with engine speed. Between 1000 and 1500RPM, the SFC drops substantially. At a lower RPM, mechanical friction becomes more of a problem than when the engine produces more power. Mechanical friction from bearings, piston rings, oil pumps, water pumps, and any other accessories a car may have such as air conditioning have a relatively constant load on the engine. What this means is that much more of the energy produced is wasted on just overcoming mechanical friction, as it's a larger percentage of the overall power and torque produced.

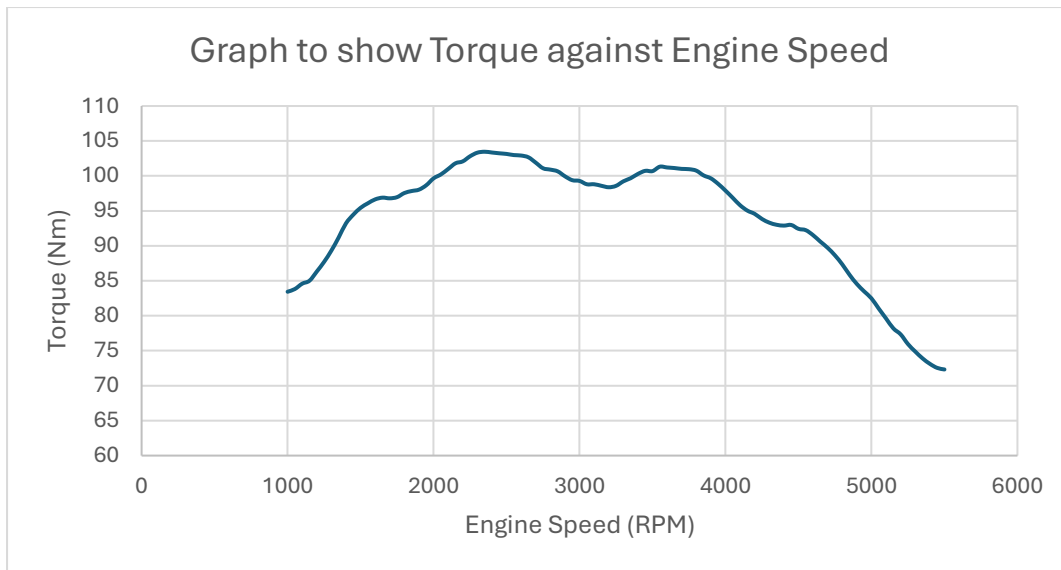


Figure 4 – Graph comparing Torque to Engine Speed

In Figure 4 we can see that this engine produces its peak torque at around 2300 RPM, holding relatively steady until a sharp drop off above 4000 RPM. At higher engine speeds, especially without forced induction, it can be difficult to get large enough volumes of air into the cylinders, as the valves do not remain open long enough. Generally, engines such as this Honda D16 are optimised for road vehicles, so they will be more power efficient at mid-range loads, that the majority of its users will achieve when driving. This allows the engine to remain at a lower RPM, with more efficient power delivery and fuel consumption (AMC Performance, 2024).

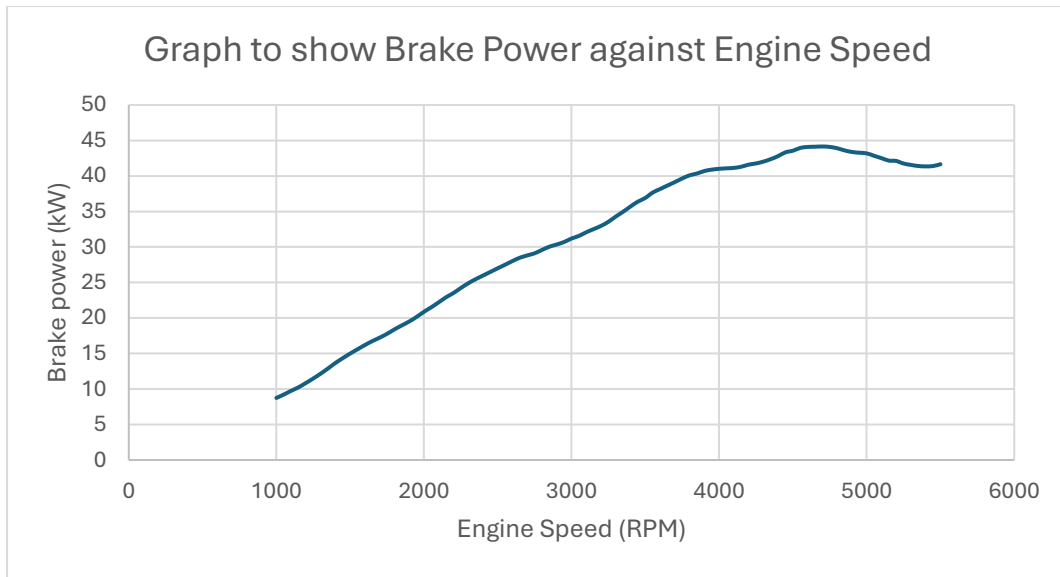


Figure 5 - Graph comparing Brake Power to Engine Speed

Figure 5 displays how the engine produces power through its RPM range, peaking at around 44kW at 4700 RPM. Generally, naturally aspirated engines produce power curves in this way as the way as brake power is the result of multiplying the RPM by the torque (divided by a constant). Therefore, higher RPM and higher torque produces higher brake power, until the torque decreases significantly. Figure 6 compares the torque against the brake power.

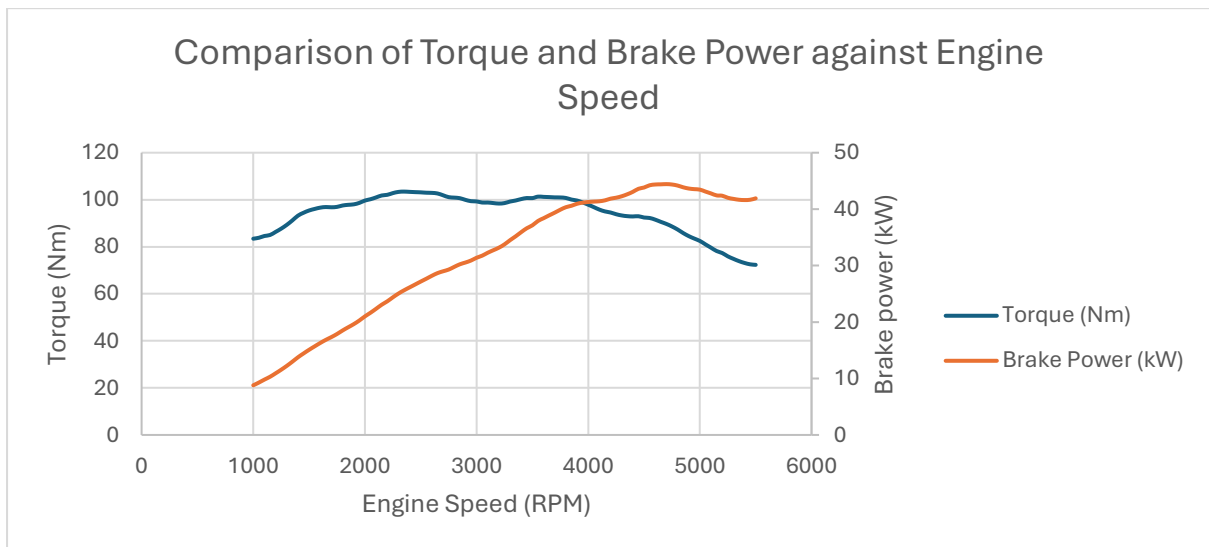


Figure 6 - Graph comparing Torque and Brake power to Engine Speed

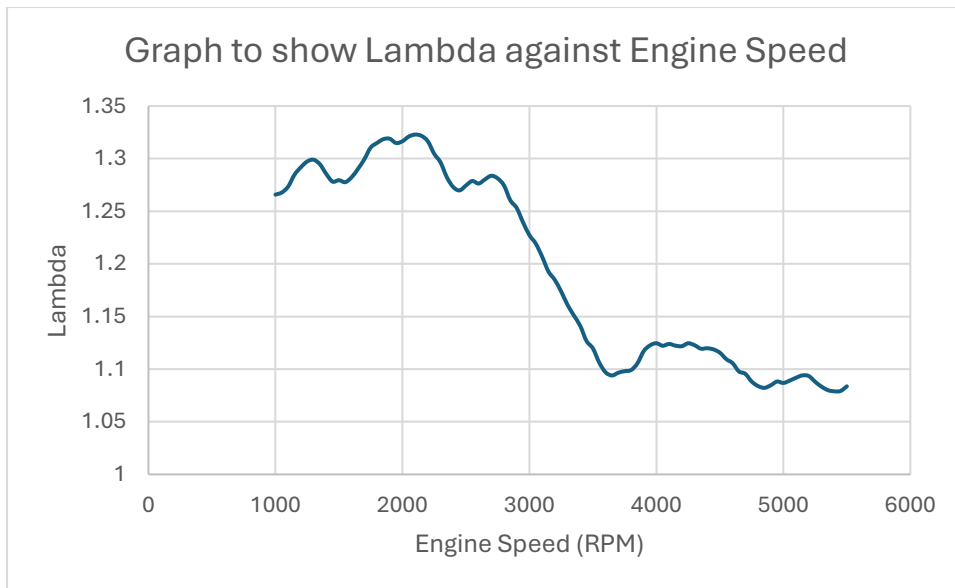


Figure 7 – Graph comparing Lambda to Engine Speed

Lambda, or Stoichiometric air to fuel ratio is the ratio of the air to fuel mixture, relative to an ideal mixture, which would be 1, where anything above 1 would be considered lean, and below would be considered rich. The data displayed in figure 7 suggests that this engine is running lean. This could be due to potential leaks in the air intake, or an issue with the fuelling system.

4. Conclusion

To conclude, the data collected from the lab sessions using the dynamometer gives a clear picture of how the Honda D16 engine operates throughout its RPM range. The results of which shows where the engine makes peak torque and power, as well as at what RPM the engine is most efficient. The process of calibrating and operating the eddy-current Dynamometer is an important part of this, ensuring that the data recorded is accurate.

However, it is also important to take other factors into account, such as the lambda sensor readings. The data suggests that the engine is running lean, which could indicate a potential fuelling issue, especially at the lower RPM range. This issue doesn't seem to persist in the higher RPM ranges, where the lambda reading gets closer to 1. This is especially evident when you look at the peak power the engine makes, which tops out at about 44kW. This value deviates significantly from what would be expected from this engine, given the displacement and age.

5. Evaluation

Due to unfortunate technical problems with the dynamometer and engine, the data could not be collected first hand. This meant that instead we were relying on prerecorded data, and YouTube videos (UWTSD WISA Workshops, 2020) to explain the processes required to complete the experiment. If completed again, I think it would be helpful to have the experience of completing the workshop session first hand.

Furthermore, to improve this investigation, completing multiple runs on the dynamometer would help to rule out any outliers and improve the accuracy of our measurements.

With all of this considered, I believe that the report was still beneficial for my knowledge and understanding, and was still able to be completed without any major problems.

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