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Engine Performance Analysis

Thermodynamics and Combustion (ACHA5011)

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1 Introduction

To understand the cylinder head and valve train design principles, a workshop investigation is carried out to produce a detailed analysis of the valve train and piston dynamics of the chosen engine, developing technical skills and being able to apply thermodynamics and mechanical principles in a real-world engineering scene. For this investigation, a 2-litre Duratec cylinder head is used for the flowbench testing.

2 Components Technical Information

Component	Inlet Mass (kg)	Outlet Mass (kg)
Camshaft	2.13	2.1
Valves	0.055 X 2	0.051 X 2
Inner Valve Spring	0.017	0.017
Outer Valve Spring	0.049	0.049
Retainer	0.0156	0.0156
Buckets	0.041 X 2	0.041 X 2

Bore	Stroke	Compression Ratio
79mm	81.4mm	11.16:1

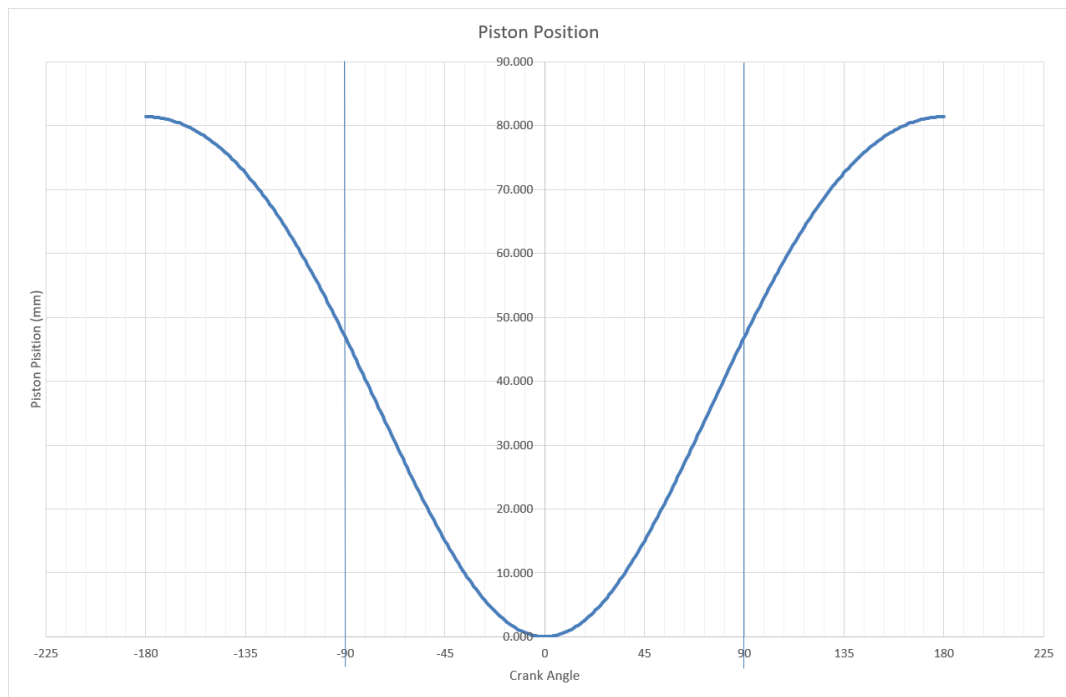
Apart from the camshafts' mass, the components' mass, bore, stroke and compression ratio were already provided by the lecturer. When weighing components, a mechanical scale or digital scale is used. Most of the time, a high-grade digital scale is used for its precision. To measure the bore of the engine, either a digital or mechanical bore gauge is utilised and for the bore, a mechanical or digital vernier calliper. Each has its pros and cons when using either mechanical or digital.

With mechanical measuring equipment, they can be cheaper than a digital tool, can provide a more accurate reading depending on the brand, and they don't require batteries. Cons are that these can be harder to use and read for beginners, calibrated manually and slower for repetitive measurements.

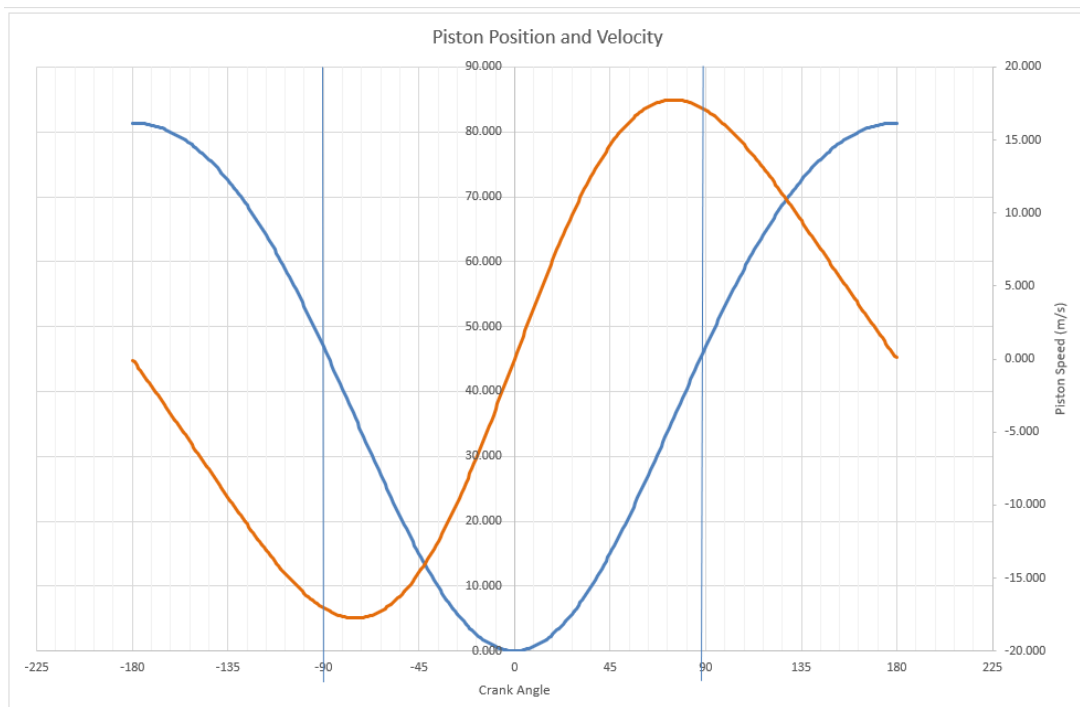
With digital measuring equipment, they are beginner-friendly as they provide a straightforward measurement, calibrated by just a button and are great for repetitive measurements. Downsides are that they require batteries, can't read minuscule measurements depending on the brand, and can be expensive.

3 Piston Motion Analysis

3.1 Piston Position vs. Crank Angle



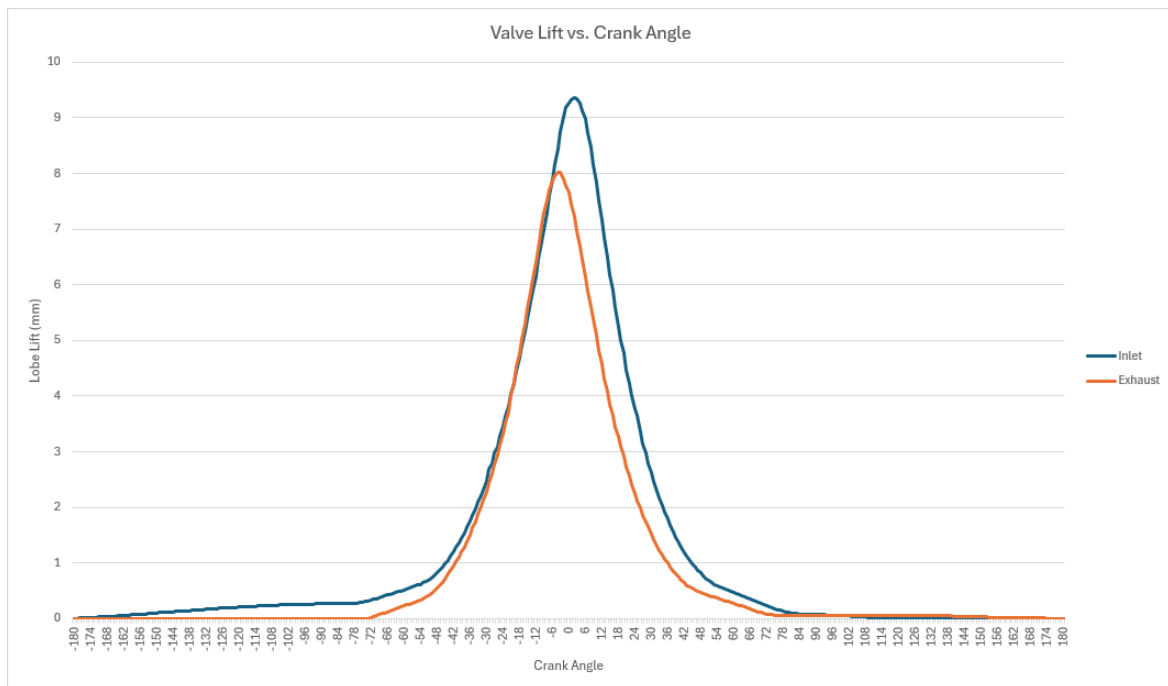
3.2 Piston Velocity vs. Crank Angle



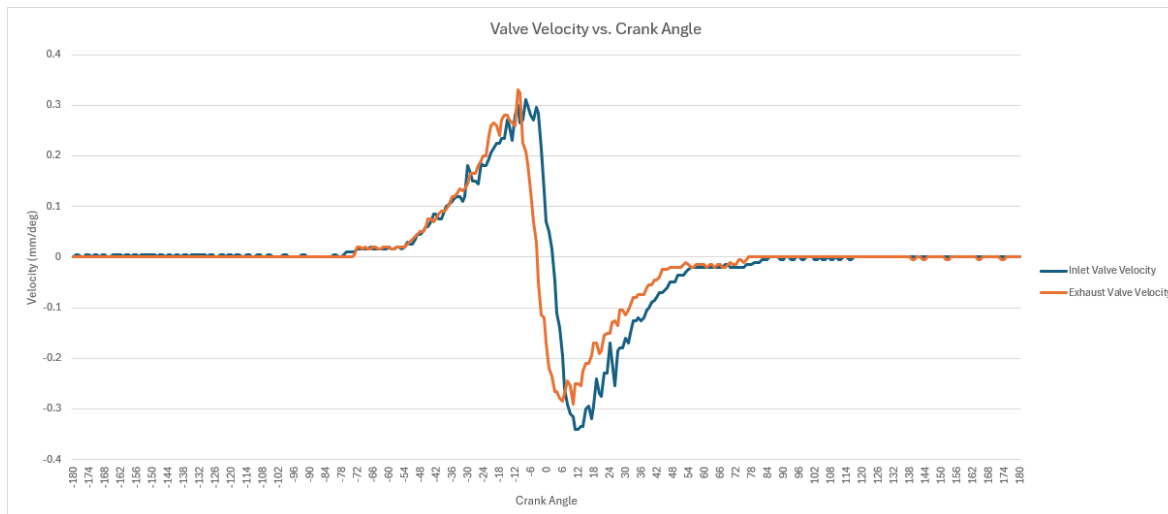
The Mean Piston Speed is 10.85m/s.

4 Camshaft and Valve Motion Analysis

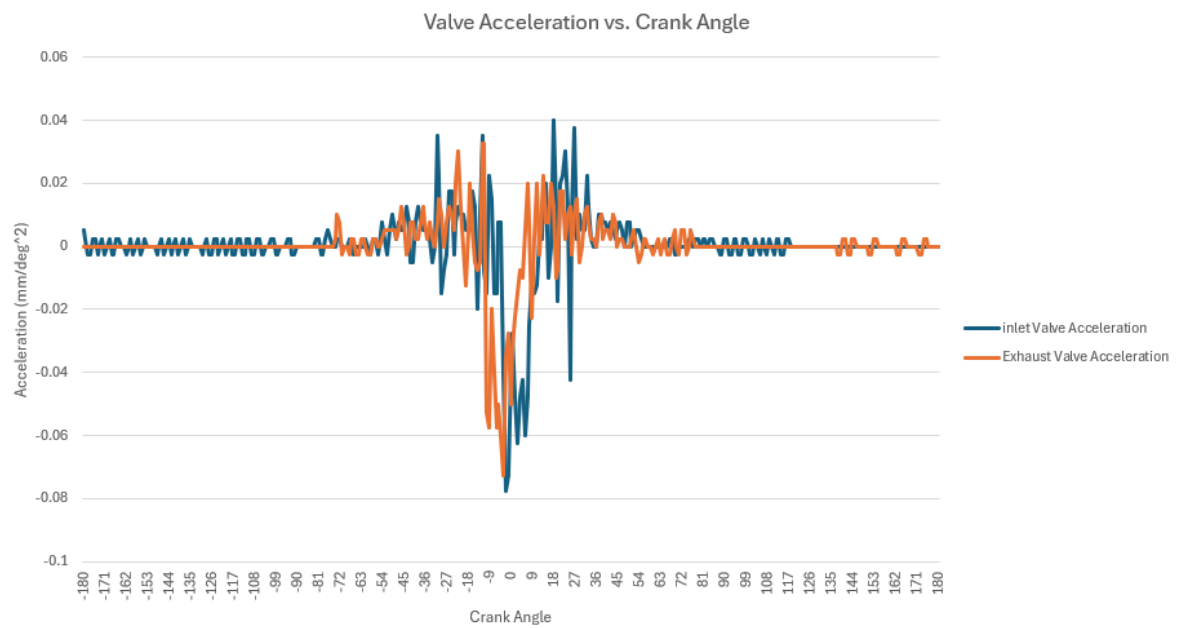
4.1 Valve Lift vs. Crank Angle



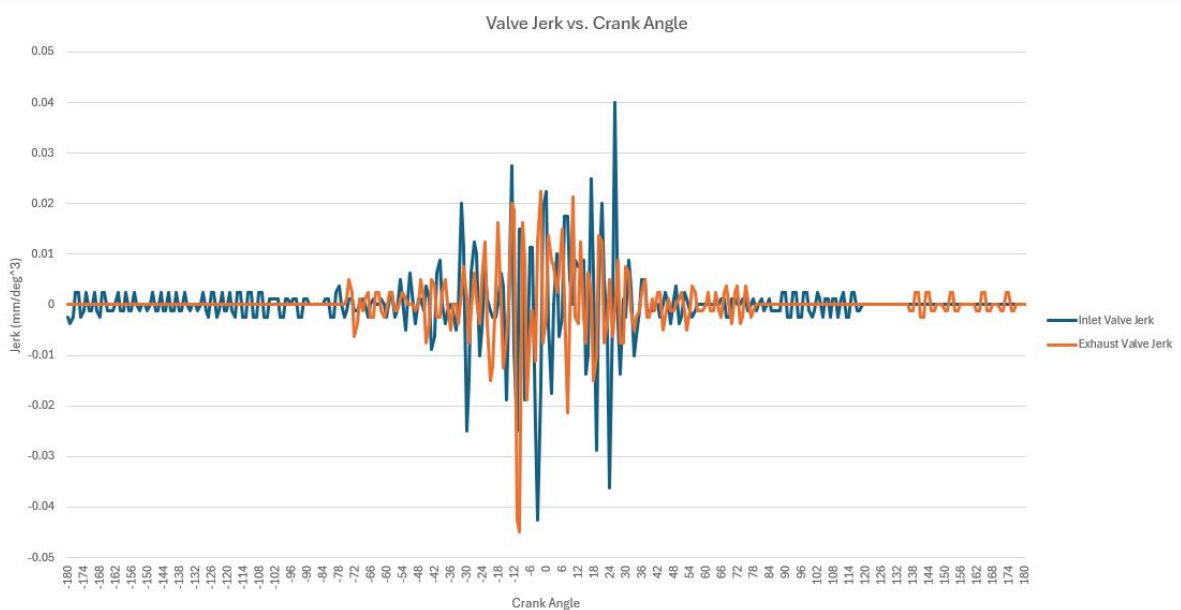
4.2 Valve Velocity vs. Crank Angle



4.3 Valve Acceleration vs. Crank Angle



4.4 Valve Jerk vs. Crank Angle



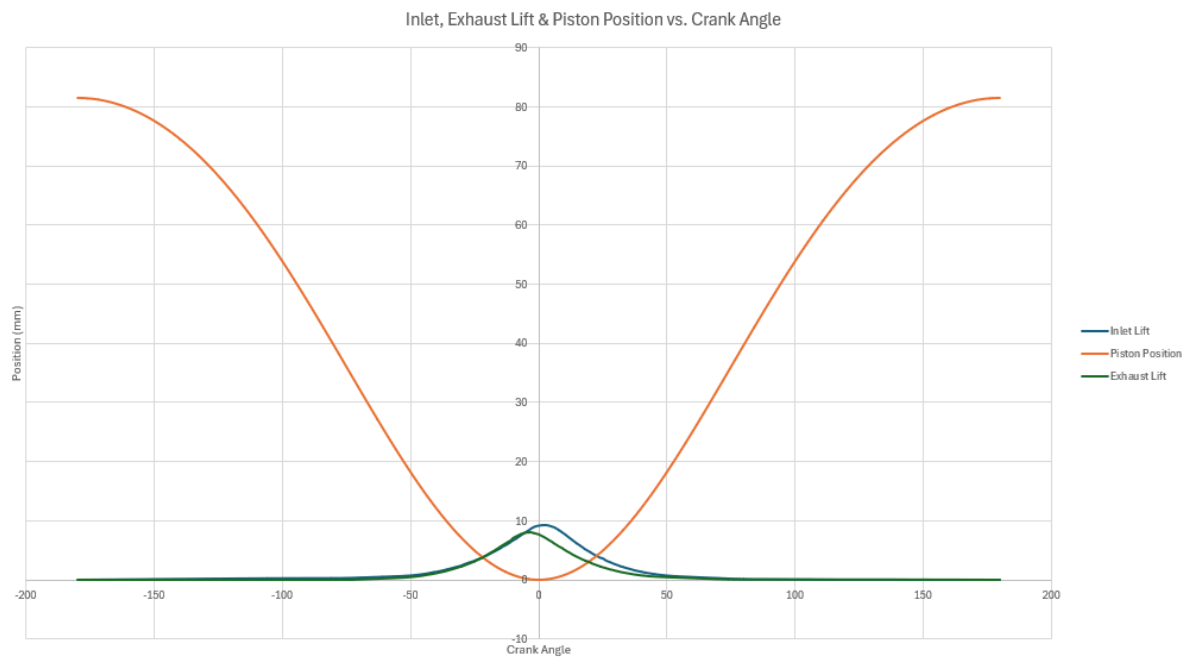
5 Dynamic System Assessment

5.1 Estimation of Valve Float RPM

Estimated Valve Float RPM for Intake: 3900RPM

Estimated Valve Float RPM for Exhaust: 3938RPM

5.2 Valve Lift, Piston Position vs. Crank Angle



5.3 Effects of Lightweight Components

To increase the float RPM and mechanical rev limit by 25%, it is by reducing the mass of the valvetrain by around 36%. When RPM increases by 1.25, the inertial force increases by 1.25^2 . Therefore, $1/1.25^2$ gives 0.64 of the original value.

Depending on the alloy, titanium is 40-45% lighter than the original components, assuming that these are made of steel. (Reher, 2013). If some components are replaced with titanium, such as the Valves, retainer and Springs, the new total mass of the intake and exhaust would be 27% less than the original. Theoretically, 36% is required; the 27% represents a practical and cost-effective balance. Further reducing the mass can be expensive, as titanium is expensive and isn't as durable or long-lasting as steel. If budget isn't an issue, replacing all components with titanium can achieve a higher percentage reduction, therefore increasing the float RPM and mechanical rev limit more than 25%.

6 Flowbench Testing and Data Collection

A flow test on the 2-litre Duratec cylinder head is carried out on both the inlet and exhaust sides.

The equipment used for this investigation is the SuperFlow SF-600.

SuperFlow SF-110 Test Data											
											
Test Description:						Test Number					
Head Description: 2 Litre Duratec						Serial Number					
Intake Valve:						Valve Seat Angle					
Intake Port:						Port Volume					
Radiused Inlet:						Port Length					
Exhaust Valve:						Exhaust Seat Angle					
Intake Manifold:						Runner Length					
Cylinder Bore:						Stroke					
Test Operator:						Head Porter					

Test Setup Data												
	Diameter		Stem		Lift Increments		Effective Area		Leakage		Seat Width	
Intake Valve	35	mm	5.5	mm	1.75	mm	9.38	sq.cm	0	litres/sec		mm
Exhaust Valve	30	mm	5.5	mm	1.5	mm	6.83	sq.cm	0	litres/sec		mm

Valve Lift/Diameter (L/D) Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50		
A. Intake Valve Lift (mm)	1.75	3.5	5.25	7	8.75	10.5	12.25	14	15.75	17.5		
B. Exhaust Valve Lift (mm)	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15		

Range	1	2	3	4	5	6
E. Intake	16.5	33.2	69.7	138.2	207.8	279.5
F. Exhaust	19.5	37.1	75	148.5	219.6	284.6

Intake Valve Test Data											
1 Test Number	1	2	3	4	5	6	7	8	9	10	11
2 Test Pressure	25	25	25	25	25	25	25	25	25		
3 Valve Lift (A)	1.75	3.5	5.25	7	8.75	10.5	12.25	14	15.75	17.5	
4 Flow Range (1-6)	2	3	4	4	4	4	4	4	4		
5 Flow Scale Reading (%)	87	74	52	64	72	77	80.5	84	86		
6 Flow Scale (5./100)	0.87	0.74	0.52	0.64	0.72	0.77	0.805	0.84	0.86		
7 Raw Test Flow l/s (6. x E)	28.884	51.578	71.864	88.448	99.504	106.414	111.251	116.088	118.852		
8 Leakage (l/s)	0	0	0	0	0	0	0	0	0		
9 Test Flow (l/s) (7-8)	28.884	51.578	71.864	88.448	99.504	106.414	111.251	116.088	118.852		
10 Test Flow (l/s/sq cm)	3.078	5.497	7.659	9.426	10.604	11.340	11.856	12.371	12.666		

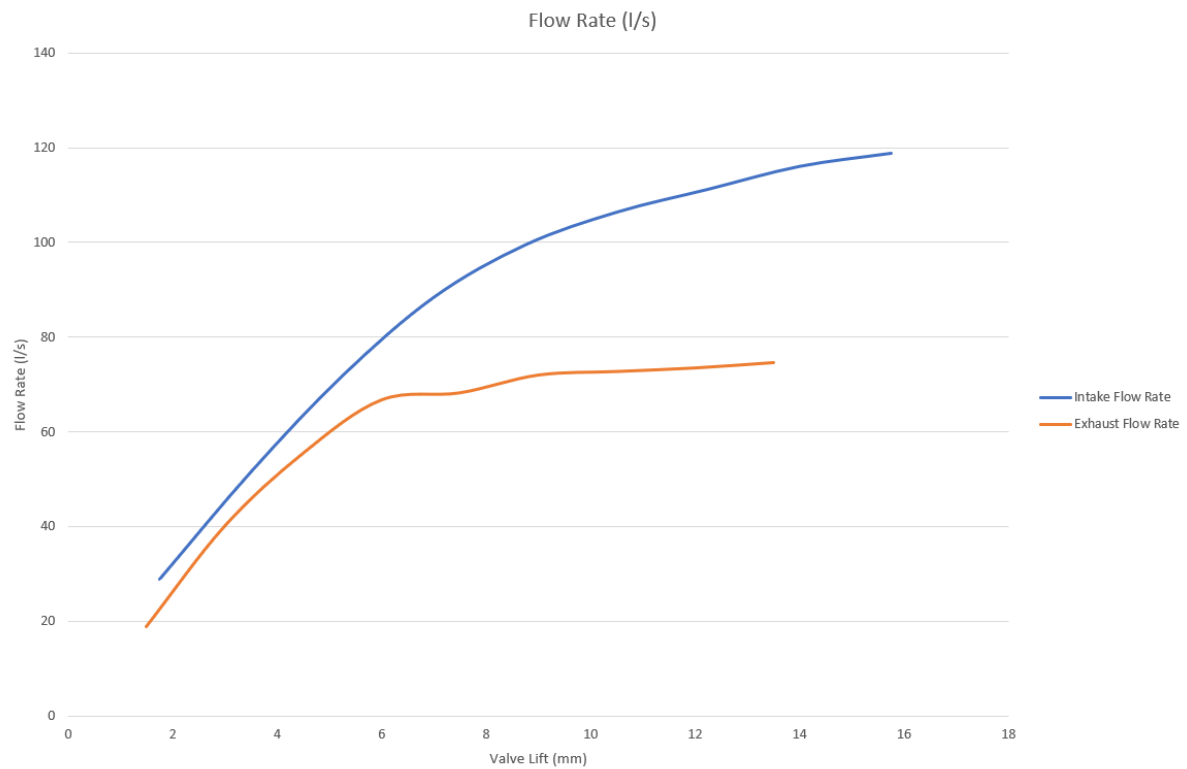
Average Flow _____ l/s Maximum Flow _____ l/s

Exhaust Valve Test Data											
1 Test Number	1	2	3	4	5	6	7	8	9	10	11
2 Test Pressure	25	25	25	25	25	25	25	25	25	25	25
3 Valve Lift (A)	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15	
4 Flow Range (1-6)	2	3	3	3	3	3	3	3	3		
5 Flow Scale Reading (%)	51	53.5	74	89	91	96	97	98	99.5		
6 Flow Scale (5./100)	0.51	0.535	0.74	0.89	0.91	0.96	0.97	0.98	0.995		
7 Raw Test Flow l/s (6. x E)	18.921	40.125	55.5	66.75	68.25	72	72.75	73.5	74.625		
8 Leakage (l/s)	0	0	0	0	0	0	0	0	0		
9 Test Flow (l/s) (7-8)	18.921	40.125	55.5	66.75	68.25	72	72.75	73.5	74.625		
10 Test Flow (l/s/sq cm)	2.770	5.874	8.125	9.772	9.991	10.540	10.650	10.760	10.924		

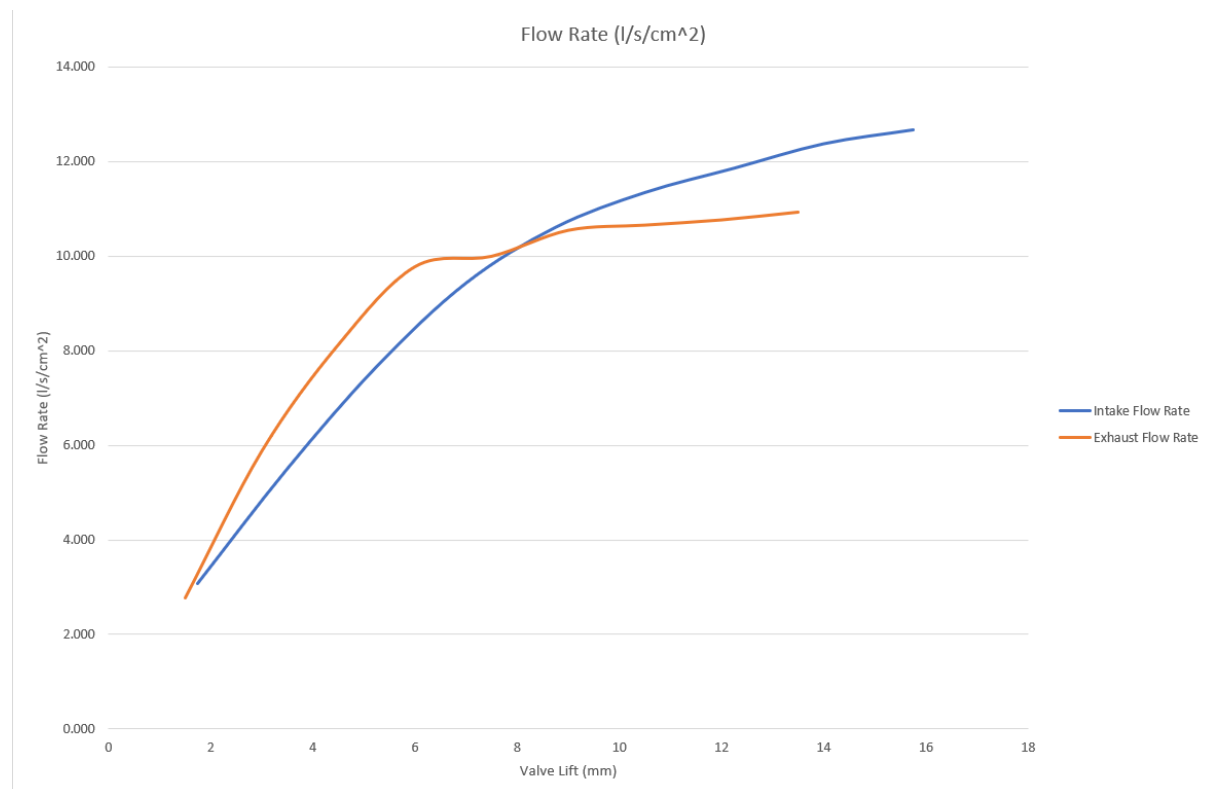
Average Flow _____ l/s Maximum Flow _____ l/s

7 Data and Analysis Graph

7.1 Flow Rate (l/s) vs. Valve Lift



7.2 Flow Rate (l/s/cm²) vs. Valve Lift



7.3 CF vs. Valve Lift



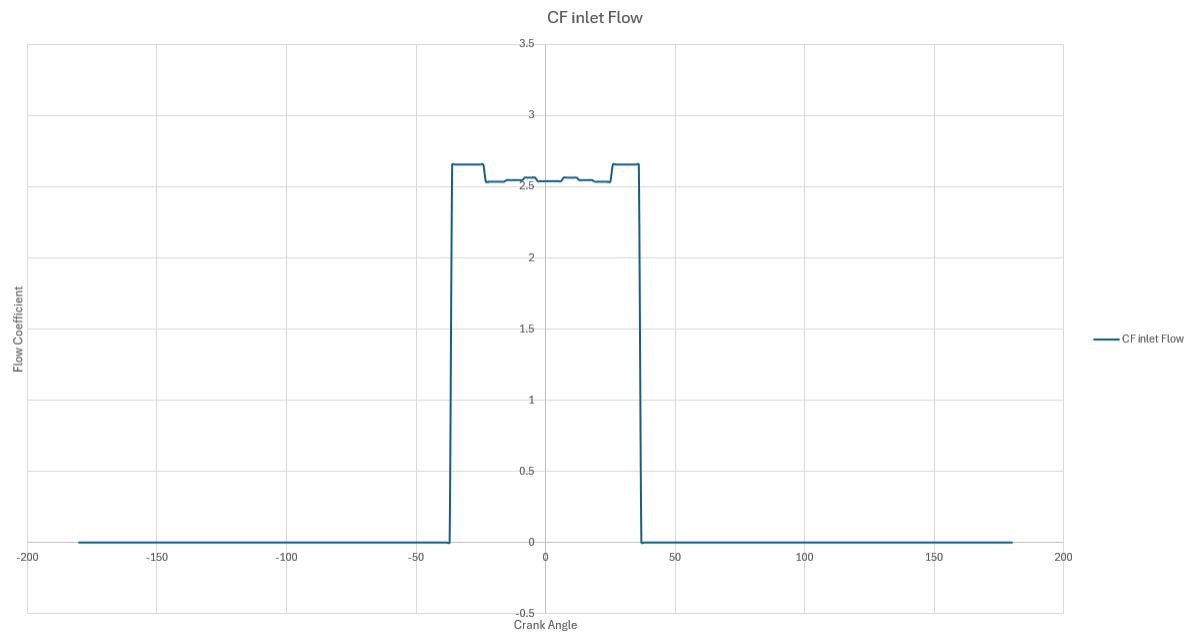
The marker at 8.75mm for intake and 7.5mm exhaust represents the lift equal to one quarter of the valve diameter. This corresponds to $L/D = 0.25$.

Before the markers, the main restriction is the valve itself, which isn't fully open, restricting the flow rate due to the curtain area; therefore, increasing the valve lift initially increases the curtain area almost linearly. This results in the high flow rate on the graphs. As it goes after the marker, the flow rate starts to flatten as the curtain area is no longer the limiting factor, but the port itself. Flow gains decrease and levels.

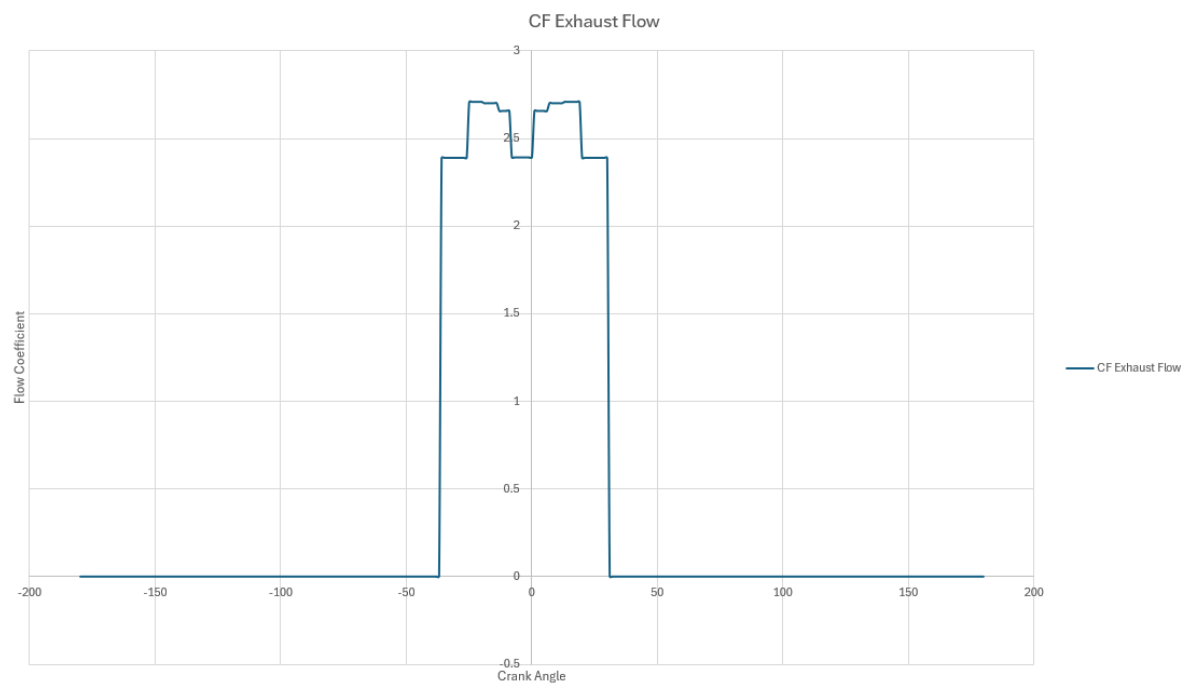
The Coefficient flow graph shows the efficiency of both the intake and the exhaust with valve lift. The intake port shows a stable CF fluctuating between 2.5 and 2.7 as valve lift increases, suggesting a well-designed port with minimal flow loss. On the exhaust port, it starts relatively low, then reaches peak coefficient at 3mm valve lift. As valve lift further increases, the CF descends steeply, indicating port restriction at high-lift.

8 Integration with Valve Kinematics

8.1 CF vs. Crank Angle Inlet Valve



8.2 CF vs. Crank Angle Exhaust Valve



9 Performance Assessment

9.1 Estimated Engine Speed for Maximum Power Achieved

- Mean CF: 2.569 (From result)
- Intake Effective Area: 9.38cm² (From result)
- Ideal Flow: 4.18 (From SF manual 25 Test pressure, L/D ratio of 0.25)
- Assumed Volumetric Efficiency: 0.8 (*Volumetric efficiency*, 2025)
- Intake Valve per Cylinder: 2 (Inline 4 Engine)
- Displacement per Cylinder: 0.5L (2.0-Litre Duratec Engine)
- Flow per valve: 100.737 l/s (Mean CF X Effective Area X Ideal Flow)
- Peak/Mean Factor: 10 (Assumption)

Initially, the peak/mean factor was 6.67. This value was obtained from the SF600 manual. It states, “The maximum intake air flow rate for a single cylinder will be about 2.5 times the average airflow for the cylinder because the intake occurs during only 40% of the total cycle”. Therefore, the example was used for this calculation.

$$\frac{120 \times 2 \times 100.737}{6.67 \times 0.5 \times 0.8} = 9061 \text{RPM}$$

Assuming that this engine is a typical road car engine, this rpm value would be too high. Therefore, the peak/mean factor was increased to 10. The new value calculated is 6044RPM.

9.2 Comparison

Looking at the specification online, the max power at RPM is 166hp at 6500RPM. While looking through vehicle applications, 6 of the vehicles with the same engine reach max power at 6000RPM. (*Ford 2.0L Duratec 20 Engine*, 2025). Therefore, the calculations and assumptions are accurate.

9.3 Discrepancies and Limitations of Engine Speed Estimation

There are discrepancies and limitations when it comes to estimating with calculations and result data. Flowbench testing does not represent the engine in real conditions. Cold air is used for the test; air temperature differs with the seasons and weather. This method assumes that all cylinders get equal flow, but realistically, cylinders rob each other from the shared manifold.

Assumption of data for calculations. For example, the peak-to-mean factor of 6.67 provided a high RPM; this can differ from different engines. Another is the volumetric efficiency of the engine. The specific VE for an engine isn't always available except for an estimation.

10 Flow Potential and Tuning Insight

The flow profile and the RPM estimate both provide good evidence that the cylinder head is more suited to high RPM performance than low RPM. At low lift, the flow is still decent, but a strong plateau at higher lift indicates more power is produced. More evidence shows that other vehicles that have this engine produce their max power around 6000-6500RPM, further supporting this statement. (*Ford 2.0L Duratec 20 Engine*, 2025).

Specifications

Metric	Value
Bore	87.5 mm
Stroke	83.1 mm
Compression ratio	10.8:1 / 12.1:1
Max power @ RPM	166 hp @ 6,500 rpm
Max torque @ RPM	149 lb-ft @ 4,500 rpm
Cylinder head	Aluminum
Cylinder block	Aluminum
Camshaft drive	Chain

Vehicle Applications

Vehicle	Transmission	Drive Wheels	Power (horsepower) @ RPM	Torque (lb-ft) @ RPM
Ford C-Max (2007 - 2010)	Five-speed manual / Four-speed automatic / Continuously variable automatic (CVT)	FWD	145 @ 6,000	136 @ 4,500
Ford EcoSport (2004 - 2018)	Six-speed manual / Four-speed automatic / Six-speed automatic	AWD	140 @ 6,000	136 @ 4,500
Ford EcoSport (2018 +)	Six-speed automatic	AWD	166 @ 6,500	149 @ 4,500
Ford Fiesta ST (2004 - 2008)	Five-speed manual	FWD	150 @ 6,000	140 @ 4,500
Ford Focus (2004 - 2011 / Europe only)	Five-speed manual / Four-speed automatic / Six-speed dual-clutch automatic	FWD	143 @ 6,000	136 @ 4,500
Ford Focus (2011 - 2018)	Six-speed manual / Six-speed dual-clutch automatic	FWD	160 @ 6,500	146 @ 4,450
Ford Focus (2008 - 2011 / US only)	Five-speed manual / Five-speed automatic	FWD	140 @ 6,000	136 @ 4,500
Ford Mondeo (2000 - 2007)	Five-speed manual / Six-speed automatic	FWD	145 @ 6,000	136 @ 4,500
Ford Transit Connect (2010 - 2012 / US only)	Four-speed automatic	FWD	136 @ 6,300	128 @ 4,750

Figure 1 Technical Data of 2.0 Litre Duratec Engine

Implementing trumpets may improve air flow, because the flowbench test on the cylinder head was done on a bare port, not including area changes and bends in the intake. With the behaviour of the engine preferring high RPM, Short and straight trumpet runners ITB would be ideal to further increase power at high RPM. (Simon, 2025).

11 References

Ford 2.0L Duratec 20 Engine (2025) *FORD AUTHORITY*. Available at:

<https://fordauthority.com/fmc/ford-motor-company-engines/ford-duratec-engine-family/ford-2-0l-duratec-engine/> (Accessed: December 7, 2025).

Reher, D. (2013) *Tech Talk #76 – The Titanium Solution*, *Reher Morrison*. Available at:

<https://rehermorrison.com/tech-talk-76-the-titanium-solution/> (Accessed: December 6, 2025).

Simon, A. (2025) *Trumpet Length and it's Effect on Torque | High Performance Academy*, *HP*

Academy. Available at: <https://www.hpacademy.com/technical-articles/trumpet-length-and-its-effect-on-torque/> (Accessed: December 7, 2025).

Volumetric efficiency (2025) *HP Wizard*. Available at: [https://hpwizard.com/volumetric-](https://hpwizard.com/volumetric-efficiency.html)

[efficiency.html](https://hpwizard.com/volumetric-efficiency.html) (Accessed: December 6, 2025).

SF600-Manual (2004). (Accessed: December 7, 2025).