SI and CI Engines

Lab #4

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Abstract

This lab measures and analyzes the performance of spark-ignition (SI) and compression-ignition (CI) single-cylinder engines. For the SI engine, students determine bore, stroke, and clearance volume to compute displacement and compression ratio, verify functional condition with spark/compression checks, and log oil temperature and speed at idle, half, and full throttle. The CI station uses a hydraulic dynamometer to apply load while recording torque, speed, exhaust temperature, intake pressure drop (airbox/orifice manometer), and timed fuel usage from a graduated pipette. From these data, students calculate brake power, bmep, fuel and air mass flows (with ambient corrections), air–fuel ratio, volumetric efficiency, bsfc, and brake thermal efficiency, and estimate exhaust heat losses. Results are shown as torque–speed, power–speed, bsfc–power, and efficiency–heat-loss plots, and compared with typical small-engine benchmarks to assess measurement quality and engine health. The exercise links thermodynamic cycle concepts with hands-on instrumentation and uncertainty-aware analysis to reveal how design, condition, and operating point govern engine performance.

Objective

The objective of this lab is to understand Spark ignition and compression ignition engines. Spark ignition engines are engines that require spark to ignite the fuel that is inputted into the engine while compression ignition engines use compression to ignite the fuel. Usually spark ignition engines use gas as fuel while compression ignition engines use diesel as fuel. Understanding the engine means being able to point out what certain components on the engine do and how they make up the engine. This is a more conceptual part for understanding the basics of the engine, however, engineering will be applied to better understand the capabilities of the engine. This will require taking measurements of key components that will later be used in calculating variables such as torque and power. These measurements can include parts from the engine like the bore size and stroke length as well as the valve vane volume. A lot of these measurements can be done using measuring tools like a dial caliper but other measurements that need to be done are through spark tests, compression tests, and dyno tests, which all require the user performing the lab to understand how to do these tests. While some verify theory like the spark test and compression test, the dyno test, using a dynamometer, is a test that can help apply different scenarios to the motor and allows to measure variable points throughout the RPM range. The dynamometer test doesn't directly give a measurement for what we need, but the setup and how the dynamometer applies different loads, which will be explained in the introduction, makes the engine either work harder to provide more torque or work lighter to provide less torque. These scenarios are what will later help apply the measured variable points in the RPM range to graphs that are used to show the capabilities of the engine and how they perform with respect to that RPM range. For the scope of this experiment, gas ignition engines were the only ones used to perform all tests.

<u>Introduction</u>

The general concept of an internal combustion engine is to turn chemical energy into mechanical energy. To best understand how the engine is supposed to do that, it's important to understand how the internal components of the engine are placed and look.

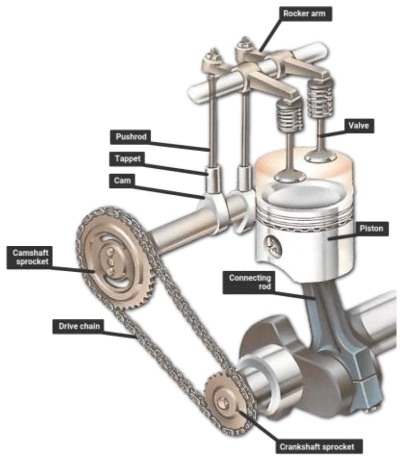

Figure 1:Internal components of a 1-cylinder engine

As seen in figure 1, the internal components of the engine are comprised of the crankshaft, piston, camshaft, pushrods, rocker arms, and valves. This may not be within the scope of the class where the focus is just understanding the power and torque ratings for engine, however, it is still important to know how the engine is even generating power. Starting with the cycle of the engine, it follows a four-stroke cycle which will now be described in detail. The first stroke is called intake and during this stroke the piston is going down the cylinder, and the intake valve is open. While it's going down, the negative pressure inside the cylinder allows the air and fuel mixture to be sucked in through the intake valve where the stroke is completed as the cylinder reaches the bottom and the valve closes back up. The next stroke is compression, and the piston is moving up. Keep in mind that the piston is currently moving with the power that was generated from the previous cycle so it may seem like its moving with no input forces where in reality, it does have forces acting on it. During compression, the piston moves all the way up until it reaches the top dead center and the fuel and air mixture is fully compressed. The next stroke is the ignition stroke which happens after the spark plug provides spark to the air and fuel mixture, igniting the fuel. This ignition under a very pressured chamber causes an enormous force on the piston to be pushed back down where that force is then transferred in a reciprocative motion to the crankshaft so it can be used in later strokes. Now, there is an example of that reciprocative motion transferring the force back into the piston to be pushed up for the last stroke which is called the exhaust stroke. This piston is now moving up again but this time, the exhaust valve is open. This makes for a setting where the piston is actively pushing the post-ignition fumes outside of the cylinder chamber, so they don't interfere with the new fuel and air mixture that is introduced into the next cycle.

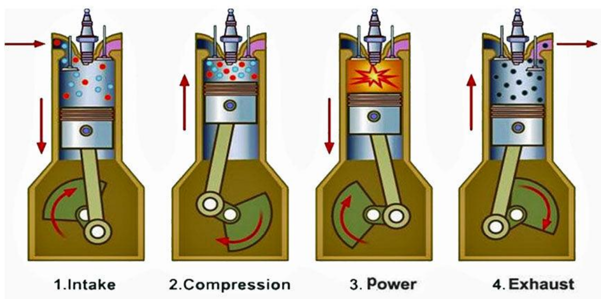

Figure 2: Four-Stroke cycle of an engine

Again, in figure 2, is a visual representation of the four-stroke cycle which will be the basis of the machinery that will be studied in this lab, however, as stated before, the internal analysis of how all the energy is transferred within the engine is outside the scope of the class and is not the focus for this lab but now this clear demonstration of how the engine generates power can be used to better help understand the rest of the lab.

Now, beginning the process of what variables may be needed for the lab to perform any calculations at the end, the lab follows several stations. Some of which are to better understand specific components and subsystems of the engine, while others are simply for measurement purposes, but all follow theoretically meaningful procedures that will be later given.

Starting with the simpler concepts and like fluids involved, the only fluid going inside of the engine are gasoline. Fuel rate is important because with more fuel, the engine can generate more power so it should be crucial for one to be able to calculate the flow rate. The units for the flow rate are mass/time and the formulation for which application flow rate is needed is shown later in the report.

Another concept that should be quickly reviewed, again, for a better understanding of engines is the components involved with strictly air, being the valve cover hose, air box, and exhaust. These components work together to best input clean air flow and reject any harmful air flow. The valve cover has a tube as shown in figure 3 to redirect any air trapped inside the valve cover back into the air intake filter which already has air traveling through it by default. This air then goes through the engine and leaves the process as harmful air. The exhaust is meant to further trap any harmful contaminants from entering the atmosphere as well reducing the sound from the engine.

Figure 3:Air box assembly, exhaust, and valve cover

The fuel system itself is also important apart from the fuel. It’s important to know that these engines are not fuel injected which takes a weight off of engineers in the aspect that they don’t have to the time for any fuel injection. As shown in figure 4, the engine uses a carburetor which uses pressure to mix fuel and air before entering the combustion chamber, so no timing of fuel injectors is needed. This is effective and cheap for smaller engines but now rarely seen on newer or bigger engines. Two more components seen in figure 4 are the throttle linkage and governor. Being directly connected to each other, the governor is a component that will open when a certain rpm is reached. This opening up will move the throttle so that it reduces the speed, therefore not running the engine at open throttle at all times.

Figure 4: Fuel system with carburetor, throttle linkage, and governor

How does one ignite the fuel. This is where spark is important. The spark plug is what is responsible for providing the key input in ignition. Without the spark, there would be no ignition, and the motor would just die. During the lab, a station regarding the spark and how intense the spark is, given different scenarios, will be tested to see what correlations can be made with the spark and crank speed. Ideally a good spark is one with a ground and lots of input current which in this case would come from a fast crank since the magnet brazes the solenoid more.

Now, thinking back to how the four-stroke operated, two of the cycles consisted of compression and intake which this is important for the pressure that is related to the system. This pressure helps both the amount of fuel and air that is entered into the engine but also the overall pressure force that is being applied to the piston as it ignites with the fuel and air mixture. First, a test can be done to verify that the compression ratio that is found is correct. Using equation 1d to find the compression ratio, it's clear that a few more measurements need to be taken because the ratio is the volume inside the chamber at bottom dead center over top dead center. These volumes are found in equations 1a, 1b, and 1c.

$$V_{Displacement} = \frac{\pi}{4}(Bore^2)(Stroke)(Number\ of\ Cylinders) \tag{1a}$$

$$V_{Gasket} = \pi\left(\frac{Bore}{2}\right)^2 (Thickness\ of\ Gasket) \tag{1b}$$

$$V_{Valve\ Vane} = \frac{4}{3}\pi\left(\frac{Diameter\ of\ play\text{-}doh\ ball}{2}\right)^3 \tag{1c}$$

$$C_r = \frac{V_{Displacement} + V_{Gasket} + V_{Valve\ Vane}}{V_{Gasket} + V_{Valve\ Vane}} \tag{1d}$$

Once the compression ratio is verified with the theoretical value, the value for displacement volume which is found in equation 1a, will play a crucial factor to finding the brake mean effective pressure of the engine, an important variable for later finding the power of the engine. To use the displacement and get a value of pressure, another variable will be used. This is torque, as Nm over the displacement will give the value for pressure as shown in equation 2a.

$$bmep(4stroke)[Pa] = 4\pi\frac{Torque(N*m)}{V_{Displacement}(m^3)} \tag{2a}$$

Now that the brake mean effective pressure can be calculated, that pressure can be used to find the power throughout the volume of the displacement at the given angular velocity that the engine is rotating at which is shown in equation 2b.

$$BrakePower_{theoretical}\ (watts) = bmep(Pa) * V_{Displacement}(m^3)\frac{RPM}{2revs*60} \quad (2b)$$

Before going over other tests or stations that will need to be performed to best understand engines, there are variables in equations 2a and 2b which were not explained as to where they came from. From this station and any station prior, they focus on a more theoretical approach for the values that would be obtained if the engine was put through any loading tests. For this lab, the torque rating was chosen as the torque and the assuming that that peak torque is found at a certain RPM (Torque = 14.914 Nm, RPM=2700).

Now is the application of the motor to see if the theory lines up with measured values using a dynamometer, a tool used to measure certain aspects of the engine like torque, temperature, rpm, etc. The dynamometer is not the tool that actively measures these variables but it's the tool which puts the engine through specific scenarios so that the sensors which do record those variables can measure the values. Now, the fundamentals of how the dynamometer works, and its station will be explained as its relevance continues in further calculations.

The dynamometer that is used during the lab is a water brake. This water brake is the limiter to the engines' performance which is what creates the scenarios. The dynamometer is connected to the engines shaft, specifically to the rotating fins that spin inside the casing which is the red part shown in figure 5.

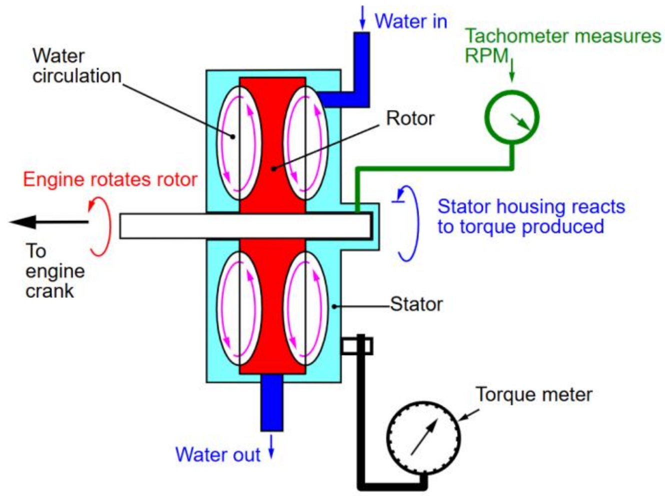

Figure 5:Diagram of Dynamometer Water Brake

First, imagine the system without water, the fins, seen in figure 6, will spin freely and would most likely just generate some heightened air. Keep in mind that the casing on the outside can spin also but independently of the fins. In this case, it's held in place, which is what will help generate torque readings but more on this later. Now imagine that there was an inflow of water into the system and the fins are moving as it's connected to the engine. The water that goes inside the casing will sort of swoop into the curved fin and come back up. This is ideal for the purpose of the water brake because little to no breaking would happen as the water is entering the fins. Now when the water is swooping up, it will go into the curved surface of the casing. The answer is no, remember that the fins are spinning also and do not stay in one place so while the water gets translated into a circular motion along one plane, in another plane, it gets translated, axially. So, as it gets translated axially while swooping up, the water hits the wall of one of the vanes from the casing. This causes a force on that wall to be generated but as stated before, the casing is grounded. This overall force on the walls from the water being moved by the fins, which is connected to the engine, is the component for the force in the torque measurement, the location of that force reading is then applied to measure the torque generated. These are both done by the setup and a reading is displaced on a screen.

Figure 6: Fins that are connected to motor shaft

Other devices in the setup are placed to measure temperature and pressure readings which will be used in calculations too like the air flow rate and heat loss but the torque reading actively applies engineering of the water brake to generate its value. So, unlike the theoretical approach to calculating the brake power, the dynamometer directly gives the torque for the specified RPM values instead of using ideal RPM and calculated torque for brake power which is shown in equation 3a.

$$BrakePower_{measured}(watts) = \frac{2\pi N}{60} * Torque \tag{3a}$$

Another value that was measured from this setup, before skipping over it, was the fuel flow rate. The way this was done was through a series of valves that was able to show fuel travel over a certain volume of fluid just like how fuel rate was explained before. This volume of fluid was measured over a period and recorded for what will later fill the graphs that are created. The formula for the fuel rate of gasoline is given by equation 3b.

$$\dot{m}_f = \frac{Volume_{fuel} * Density_{fuel}}{time} \tag{3b}$$

This fuel rate is important for calculations that consider efficiency and loss percentages since the fuel is part of what is considered as an energy input. However, fuel is not the only input that goes inside the engine. Air is also an important factor for the spark to ignite the mixture and considered in efficiency formulas since it’s an energy input. This air flow rate that goes into the engine is shown in equation 3c.

$$\dot{m}_a = \dot{m}_{a,chart} * \frac{P_{actual}}{P_{chart}} * \frac{T_{actual}+144}{T_{chart}+144} * \left(\frac{T_{chart}}{T_{actual}}\right)^{5/2} \tag{3c}$$

Now that the formulas for flow rates of both air and fuel have been derived to be used with, the values found in the dynamometer as well as the power found in the engines RPM range, efficiencies and losses can now be calculated to understand how the engine performed over the range of RPMs. Before showing the equations for the efficiencies and losses, a component regarding both the air and fuel must be calculated to both verify theory and make sure the engine is running with right air to fuel ratio. This ratio is important for engineers because the perfect amount of air to fuel is needed in combustion. A lower of higher one might lead to an engine that is either lean or rich. This is given in equation 3d.

$$AFR = \frac{\dot{m}_a}{\dot{m}_f} \tag{3d}$$

The efficiencies that will be calculated are volumetric efficiency and brake thermal efficiency. The volumetric efficiency that will be calculated is needed to understand how well the engine is taking in air and filling up the space of the displacement for the engine. Perfect efficiency would mean that the engine is taking in as much air as possible while a lower efficiency suggests the opposite and with better efficiency, as stated before, more air means more fuel, and as a result, more power. The brake thermal efficiency is an efficiency value used to calculate how well the energy from the fuel has been converted into mechanical power, so the brake power. A higher efficiency would suggest that the fuel that is being input into the engine is being turned into power while a lower efficiency would suggest that only a small portion of the fuel is being turned into power while the rest is lost to heat, friction, waste, etc. These are shown in equations 4a and 4b.

$$\eta_v = \frac{2*\dot{m}_a}{60N\rho_a V_s} \tag{4a}$$

$$\eta_b = \frac{Brake\ Power*3600}{\dot{m}_f*CV} \tag{4b}$$

*For equations 4a and 4b, the following variables are constants that were given to solve the equations: calorific value, displacement volume, density of air at ambient temperature

$$V_s = 230ml; \quad \rho_a = 101.325kPa; \quad CV = 44000\ kJ/kg$$

These efficiencies show how well the engine performs to its theoretical values, but they don't tell how bad the engine is performing. This is what the heat loss percentage is for. This value can tell us how much of the fuel's chemical energy is lost as heat during the combustion engine process. This is shown in equation 4c.

$$Heat\ loss\ \% = \frac{(\dot{m}_a+\dot{m}_f)*c_{p,exhuast}*(T_{exhuast}-T_{ambient})}{\dot{m}_f*CV} \tag{4c}$$

<u>Procedure</u>

The lab consists of 8 total stations with 7 stations being dedicated to the spark ignition engine, and the remaining station for the compression ignition engine. The compression ignition was done first followed by the 7 spark ignition stations. The stations can be done in any order, but it is important to follow the procedures within each station to successfully reproduce each experiment. It is also worth mentioning that the exhaust of these engines produces deadly fumes, so it is important to start these engines outdoors or in a well-ventilated area.

To start the procedure for the compression ignition station, station 8, pull the starter cord and allow the engine to warm up for 3 minutes. Once the engine has warmed up, the throttle is moved to its maximum position to ensure the engine receives an excess of fuel from the injector pump. With the throttle in this position the needle valve is adjusted to increase the flow of water. The increased flow of water simultaneously increases the load on the engine. The change in load from turning the needle valve is very extreme so it is important that the needle valve is adjusted slowly and in small increments. After the torque and speed reading briefly fluctuate then settles, record the exhaust temperature, pressure, torque engine speed, and time it takes for 8ml of fuel in seconds. To get the time reading for the 8ml of fuel, completely turn the fuel tap under the pipette to allow the engine to consume the fuel from the pipette. The pipette is marked when to start the timer and when to stop it, signifying 8ml of fuel.

For the first spark ignition station, station 1, the goal is to measure the bore and stroke of the Briggs and Straton cylinder to find the displacement volume. To find the bore, carefully measure the inner diameter of the cylinder using a pair of calipers. Since the piston's top dead center (TDC) is flush with the end of the cylinder measuring the stroke is simple. Rotate the crankshaft until the piston is at its lowest position and measure the distance from the piston head to the point where the piston would flush with the cylinder.

Station 2 involves finding the volume of the air between the piston at TDC and the valves or the clearance volume of the cylinder head. Due to the complicated geometry, playdough can be used to get a close to accurate measurement of the clearance volume. Start by filling the volume of the cylinder head with playdough. It is easier to add playdough than to remove so add playdough piece by piece until all gaps are thoroughly filled. After leveling the playdough with the cylinder head, remove the playdough and roll it into a ball, being careful not to excessively compress the playdough while rolling it. Gently measure the diameter of the ball without indenting the ball. Finally, using calipers, measure the diameter and thickness of the head gasket.

To find the flowrate of fluids exiting a fuel tank for station 3, start by filling the fuel tank with water being sure the valve is closed on the line. To get accurate measurements, make sure the gas cap is attached after filling the tank with water. Position fuel tank above a measuring cup and time how long it takes the cup to fill to a chosen level. Repeat this process 5 times ensuring the measuring cup gets filled to the same level. After calculating the flow rate for each run, calculate the average flowrate between them.

The air box assembly station, station 4, is important for understanding the air box component of an assembled engine. Start by locating the air box, valve cover, and exhaust on the engine. Unscrew the two fasteners from the airbox lid to observe the contents within. Analyzing the valve cover, observe how there is a valve within the cover. Finally, observe the hose connecting the valve cover to the air box.

Station 5 encompasses how the fuel and air intake of an engine is controlled. Identify the carburetor, throttle linkage, and governor. The governor can't be visibly identified as it requires the engine to be disassembled, but it is controlled through the revolutions of the crankshaft.

The spark and compression test station, station 6, highlights an engine's dependency on spark and compression for combustion to take place. To do the spark test, locate the spark tester connected to the engine and the switches on the corner of the cart the Briggs and Stratton engine is connected to. Flip the switches center, left, and right. Pull the start cord slowly and quickly to observe how the intensity of the spark differs between speeds. Change switch positions and speeds and notice how the intensity of the spark changes. For the compression test, locate the Briggs and Straton Engine with the compression gauge attached to the spark plug socket. Pull the start cord until the compression reading reaches a steady state and record that value in psi.

Station 7, the oil temperature test station provides a different technique for ensuring a Briggs and Stratton engine operates correctly. For this station, the tools required are a thermocouple to measure the oil temperature and a tachometer to measure the rotational speed of the crankshaft. First, turn the engine on allowing five minutes of idle time. Record the oil temperature reading once it has reached a steady state. Record the oil temperature at half throttle and full throttle ensuring the engine runs long enough for the temperature to reach a steady state at each position.

Results and Discussion

Section 4a

Stations 1 and 2 involved measuring the cylinder displacement and clearance volumes for the single cylinder Briggs and Stratton engine provided. The dimensions of the cylinder were taken (Table 1) and used to calculate the compression ratio of the engine. The compression ratio was calculated to be 8.75:1 using eq.1d. This result is consistent with typical compression ratios for lower powered engines such as the Honda GCV which has a compression ratio of 8.5:1 (Fig. 7).

Table 1: Calculated Cylinder and Clearance Volumes

$V_{Displacement}$ (mm^3)	V_{Gasket} (mm^3)	$V_{Play\text{-}Doh}$ (mm^3)	$V_{Clearance}$ (mm^3)	Compression Ratio (C_r)
247083.29	6075.09	25797.40	31872.50	8.75

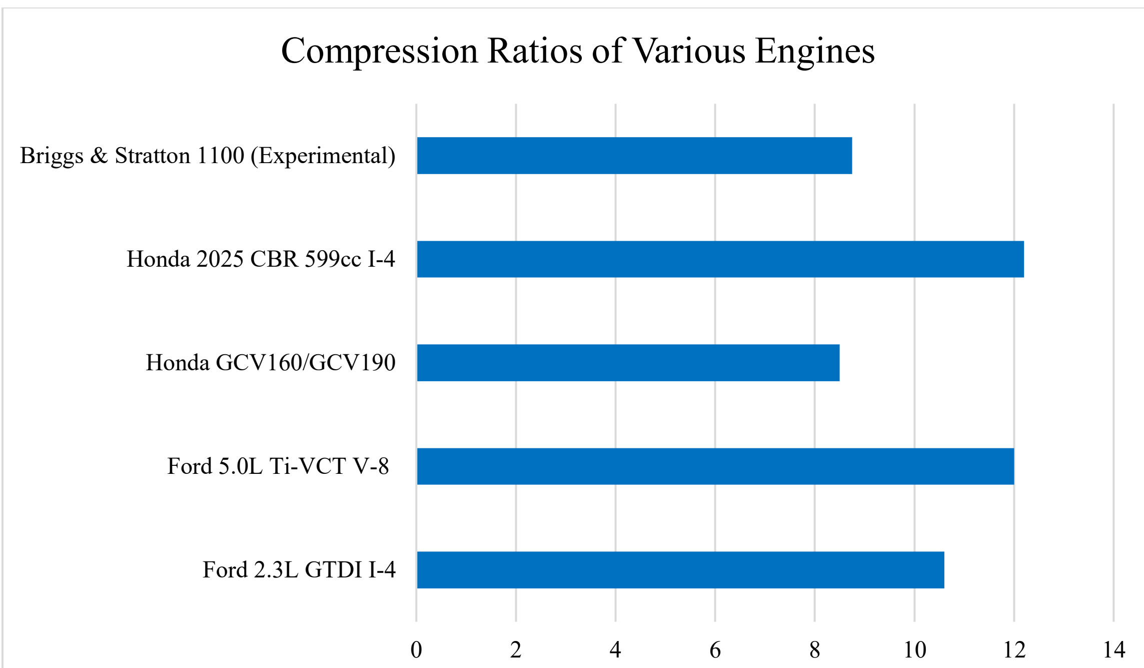

Figure 7: Typical Compression Ratios

Station 3 involved measuring the volume flow rate out of the fuel tank with water. The time it took for 100 ml of water to evacuate from the fuel tank was recorded five times. The mean time was recorded to be 10.196 seconds with a standard deviation of 0.572 seconds (Table 2). Realistically, gasoline would flow at a different rate from water due to density variations.

Table 2: Flow Rate Test Results

Time (s)	Water Volume (ml)	Mean Flow Rate (ml/s)	Mean (s)	Standard Deviation (s)
9.75	100	10.26	10.196	0.572
9.45	100	10.58		
10.6	100	9.43		
10.79	100	9.27		
10.39	100	9.62		

Station 4 and 5 involved analyzing multiple engine components. Photos and descriptions of the contents are in the introduction section (fig.3 & 4).

At station 6, spark and compression test were performed. The compression tests showed that the engine was able to build a maximum of 45 psi of pressure after 4 cranks with the pull chord (Table 3). Subsequent cranks did not build additional pressure. Observations showed that the harder the chord was pulled, the more pressure was generated. The measured 45 psi was well under the expected 110 psi noted by the lab manual. By this measure, the engine appears to need some gasket or cylinder ring repair to increase the ability to hold pressure. The spark test measured the intensity of the spark generated upon cranking the engine with the pull chord. This test examined whether the magneto transmitted sufficient voltage to the spark plug. When the switch on the tabletop was set to the side, no spark was observed. When the switch was set to the center, a spark occurred, and its intensity was proportional to how quickly the chord was pulled (Table 3). This trend is consistent with expectations, as the magneto transmits voltage based on the speed of the engine via electromagnetic induction. When the cord was pulled slowly and quickly, medium and high intensity sparks occurred, respectively.

Table 3: Results from Spark and Compression Tests

Compression (psi)	Spark Intensity		
		Slow	Quick
45	Switch At Center	Medium	High
	Switch At Side	No Spark	No Spark

At station 7 an oil temperature test was conducted. The engine was turned on and allowed to run for five minutes before any data was recorded. Fig.8 shows the inverse trend between oil temperature and engine speed. The data showed that as the engine speed increased, the oil temperature decreased. As an engine increases in temperature, oil temperature likewise decreases and reduces in viscosity due to the increase in average speed of the fluid particles. The circulation of the engine oil is also directly proportional to the speed of the engine as the oil pump, which is typically driven by the crankshaft, speeds up with the engine. For the Briggs and Stratton engine, it seems that the increased circulation of oil at higher engine speeds allowed it to cool quicker, reducing its average temperature as it passed the thermocouple.

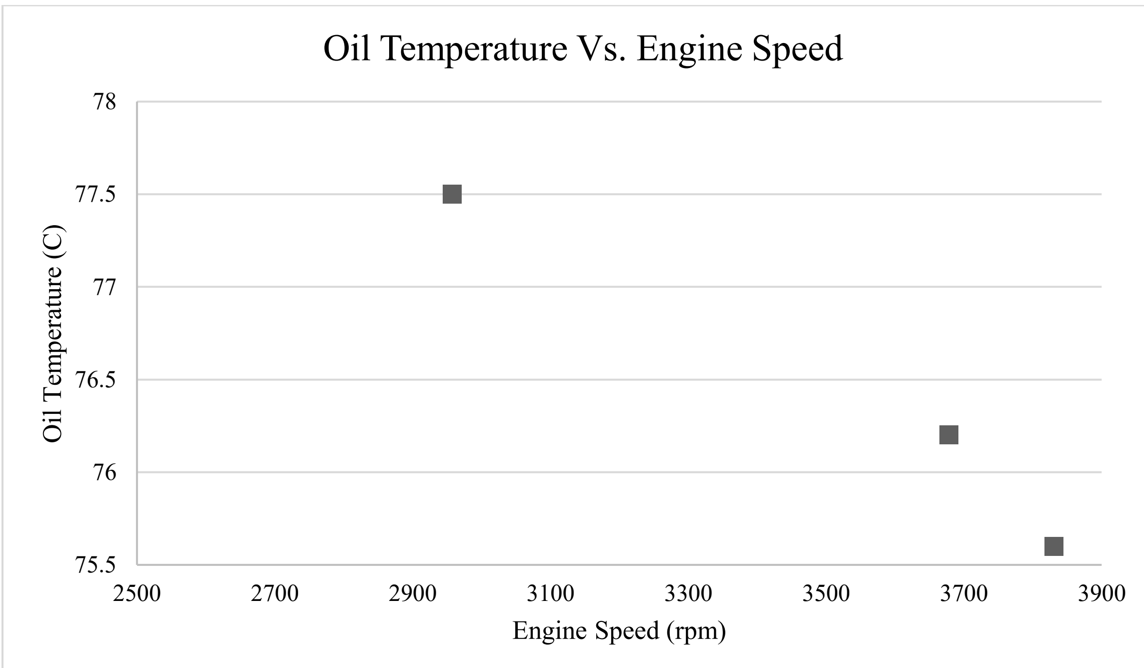

Figure 8: Oil Temperature (˚C) vs Engine Speed (rpm)

Lastly, the brake mean effective pressure (BMEP) and brake power were estimated for the engine using a torque rating of 14.914 Nm, and assuming that the engine achieves peak torque at 2700 rpm. The BMEP was estimated to be 758508.8 Pa and the brake power to be 4216.8 watts using eqs. 2a and 2b. The result makes sense as 4216.8 watts converts to approximately 5.655 HP, just over the expected value of 5.6 HP provided in the lab manual.

Table 4: Brake Mean Effective Pressure and Brake Power Calculation Results

$V_{Displacement}$ (mm^3)	Torque Rating (Nm)	BMEP (Pa)	Brake Power (Watts)	Brake Power (HP)
247083.29	14.914	758508.8148	4216.834	5.65486754

Section 4b

The engine bench testing at station 8 revealed correlations between many different variables such as torque, engine speed, brake specific fuel consumption (BSFC), brake power, brake thermal efficiency, and heat loss. The density of gasoline used the calculations below was 0.71 kg/liter. All data in figures 9-11 are either raw data from table 10 or calculated values which are located in table 5.

First, torque and power were compared to engine speed in fig.9. The scatter plot shows that both power and torque generally diminish with increased engine speeds between the measured bounds of 2683 and 2999 rpm. Torque and power and directly proportional to each other in eq.3a. Typically, engine performance curves show defined power and torque peaks, and they follow a parabolic path. For the tests performed, there is no such defined parabolic shape. According to the lab manual it can be assumed that the engine hits peak torque at approximately 2700 rpm, so the downward trend in the plot is reasonable. These results show that the engine was able to produce more torque and power at lower engine speeds.

Next, the BSFC was compared to the brake power. The plot (fig.10) shows that BSFC has an inverse exponential relationship to the brake power. As the brake power increased, so did the BSFC. This plot shows that the brake required a lower relative mass flow rate of water as the power increased, becoming more efficient.

Lastly, the brake thermal efficiency was compared to the percentage heat loss of the engine (fig.11). The brake thermal efficiency appears to follow a linear relationship with heat loss. This trend makes sense because we know that the brake power increases faster than the mass flow rate of fuel for this engine. Thus, as the engine is throttled up and the heat loss increases so should the brake thermal efficiency. This relationship is useful. The relationship indicates that one can take advantage of increased efficiency at an engine load by increasing the amount of heat rejected, which also directly correlates with its speed.

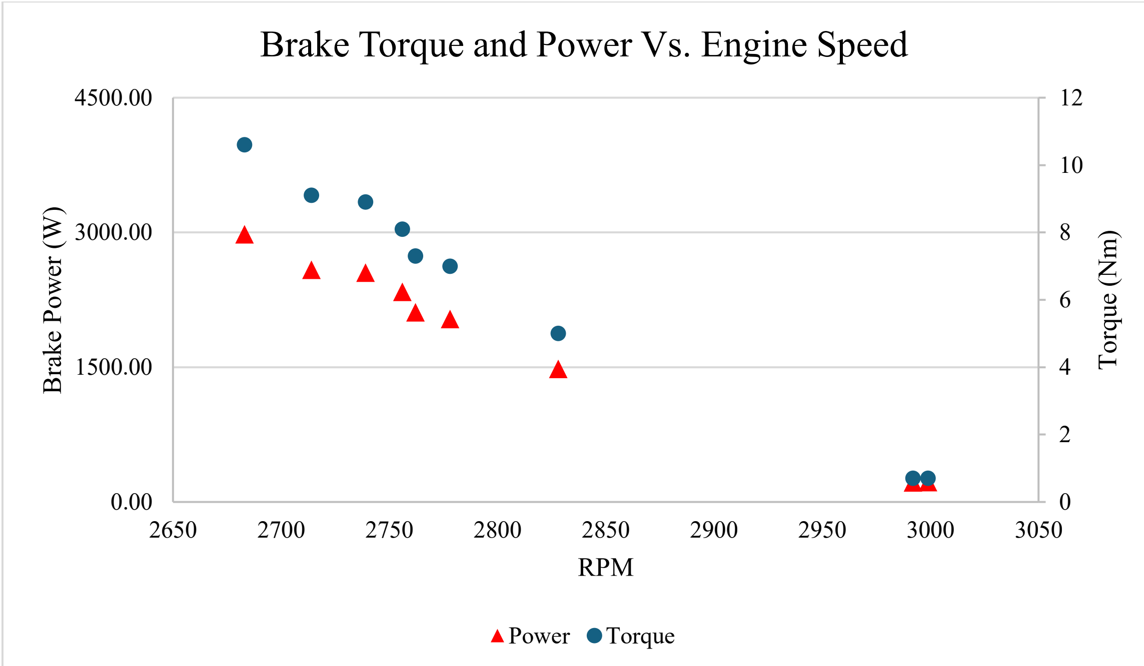

Figure 9: Torque (Nm) and Power (W) Vs. RPM

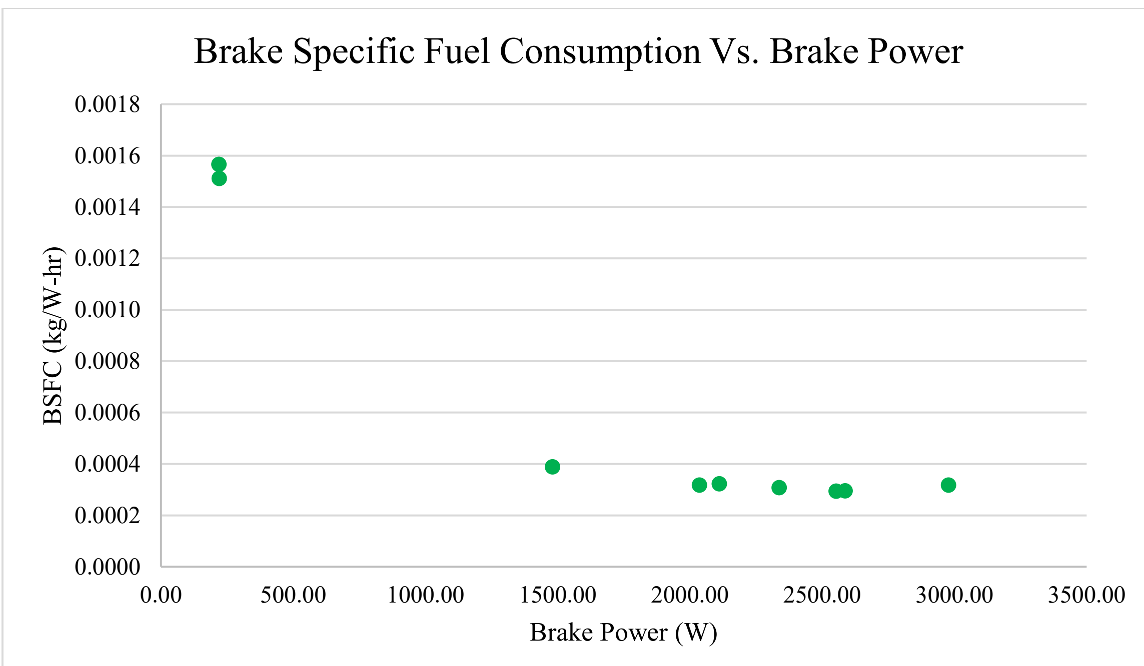

Figure 10: Brake Specific Fuel Consumption (kg/W-hr) Vs. Brake Power (W)

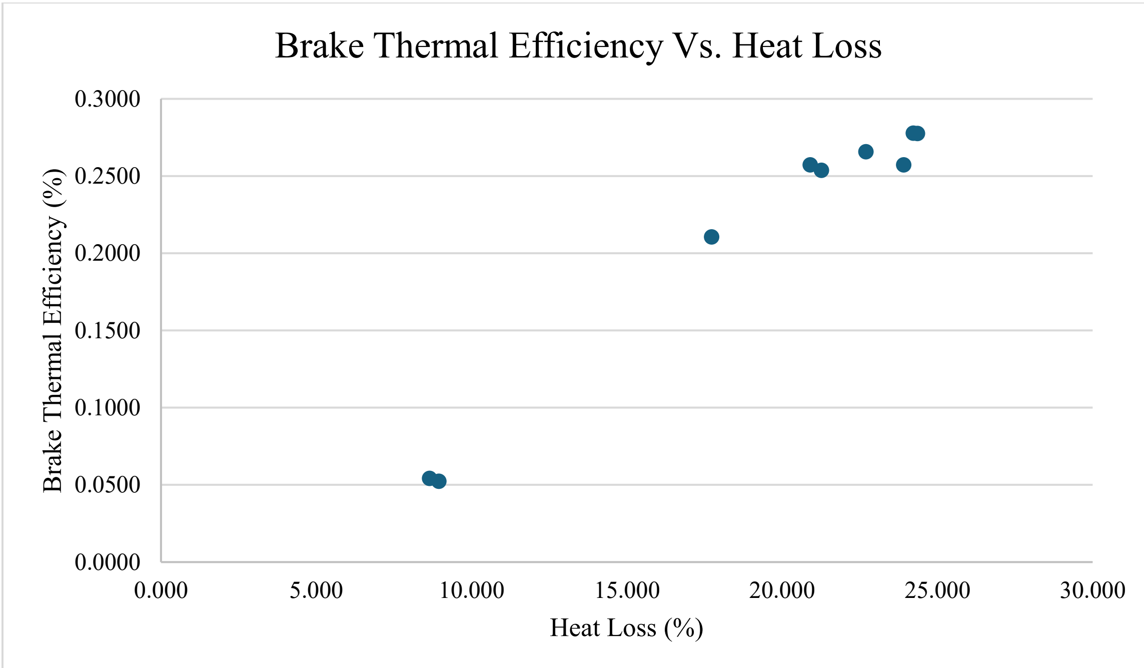

Figure 11: Brake Thermal Efficiency (%) Vs. Heat Loss (%)

Table 5: Engine Bench Testing Calculated Results

Brake Power (W)	Mass fuel Flow Rate (kg/hr)	BSFC (kg/Whr)	Mass Air Flow Rate (kg/hr)	AFR	Volumetric Efficiency	Brake Thermal Efficiency	Specific Heat	Heat Loss (%)
219.33	0.3435	0.001566	2.889	8.412	0.129	0.0522	1.0712	8.946
219.84	0.3322	0.001511	2.690	8.099	0.120	0.0542	1.0712	8.648
1480.74	0.5754	0.000389	7.174	12.469	0.338	0.2106	1.1065	17.729
2036.38	0.6477	0.000318	8.967	13.845	0.431	0.2572	1.1197	20.906
2111.42	0.6807	0.000322	9.465	13.906	0.457	0.2538	1.1224	21.270
2337.72	0.7197	0.000308	10.462	14.535	0.507	0.2657	1.1272	22.702
2552.76	0.7520	0.000295	11.558	15.369	0.563	0.2777	1.1299	24.228
2586.31	0.7624	0.000295	11.707	15.356	0.576	0.2775	1.1312	24.363
2978.21	0.9471	0.000318	14.099	14.886	0.701	0.2573	1.1334	23.914

Conclusion/References

Stations 1 and 2's compression ratio measured in the Briggs and Straton engine cylinder confirmed that it was most like the Honda GCV. The GCV is a low powered engine and when compared to the Ford 5.0L it can be inferred that the higher the compression ratio the more power required for an engine to work efficiently. At station 3, measuring the flowrate of water out of a fuel tank allowed for an approximate representation how quickly fuel can flow out of tank when connected to an engine. Due to the differing densities between water and fuel, the flow rate would be different but still merits a valuable observation. The harder the starting cord was pulled at the compression test at station 6, the more pressure was built up on the compression gauge. The experimental steady state psi was vastly under the expected psi which could have been due to a broken gasket or cylinder ring since typically the issue is an inability to maintain high pressures. The spark plug test exhibited a direct relation between the speed the starter plug is puled and the intensity of the spark in the magneto. The quicker the cord was pulled the more intense or brighter the lights the present light is. Contrary to intuition the increase in engine speed results in lower oil temperatures at station 7 while increasing engine temperature leads to a decrease the viscosity of the oil. Station 8 revealed coupled trends among torque, speed, power, BSFC, brake thermal efficiency, and heat loss. Between 2680–3000 rpm, torque and power declined with increasing speed, suggesting our points were past the engine's peak. Using 0.71 kg/L for gasoline, BSFC decreased as brake power rose, indicating better fuel-to-work conversion at higher load. Brake thermal efficiency increased alongside heat loss, so within our range the engine operated most efficiently at higher-load points.

Appendix/Questions

Table 6: Cylinder Measurements

Bore (mm)	Stroke (mm)
75.14	55.62

Sample Calculation - Displacement Volume

$$V_{Displacement} = \frac{\pi}{4}(Bore^2)(Stroke)(Number\ of\ Cylinders) = \frac{\pi}{4}(75.14mm)^2(55.62mm)(1)$$

$$= 247083.29mm^3$$

Table 7: Raw Data for Play-Doh Measurements

Diameter of Play-Doh sphere (mm)	Gasket (mm)
36.66	1.37

Sample Calculation - Volumes

$$V_{Gasket} = \pi\left(\frac{Bore}{2}\right)^2(Thickness\ of\ Gasket) = \pi\left(\frac{75.14mm}{2}\right)^2(1.37mm) = 6075.09mm^3$$

$$V_{Valve\ Vane} = \frac{4}{3}\pi\left(\frac{Diameter\ of\ play-doh\ ball}{2}\right)^2 = \frac{4}{3}\pi\left(\frac{36.66mm}{2}\right)^3 = 25797.4mm^3$$

Sample Calculation – Compression Ratio

$$C_r = \frac{V_{Displacement} + V_{Gasket} + V_{Valve\ Vane}}{V_{Gasket} + V_{Valve\ Vane}} = \frac{247083.29mm^3 + 6075.09mm^3 + 25797.4mm^3}{6075.09mm^3 + 25797.4mm^3}$$

$$= 8.75$$

Table 8: Raw Data for Flow Measurements

Elapsed time (s)	Volume of water (mL)
9.75	100
9.45	100
10.6	100
10.79	100
10.39	100

Table 9: Raw Data For Oil Temperature and Engine Speed

Oil Temp (˚C)	Engine Speed (RPM)
77.5	2957
76.2	3678
75.6	3831

Table 10: Engine Bench Testing Raw Data

Run Number	Exhaust Temp (C)	Pressure (Pa)	Manometer (mm H2O)	Mass Air Flow Rate (Chart)	Engine Speed (RPM)	Torque (Nm)	Fuel Time (s)
1	411	-15	-1.53	2.9	2992	0.7	59.53
2	411	-14	-1.43	2.7	2999	0.7	61.56
3	544	-59	-6.02	7.2	2828	5	35.54
4	574	-78	-7.95	9	2778	7	31.57
5	580	-79	-8.06	9.5	2762	7.3	30.04
6	591	-89	-9.08	10.5	2756	8.1	28.41
7	597	-100	-10.20	11.6	2739	8.9	27.19
8	600	-101	-10.30	11.75	2714	9.1	26.82
9	605	-125	-12.75	14.15	2683	10.6	21.59

<u>Sample Calculation – Theoretical and Measured Break Power</u>

$$BrakePower_{theoretical}\ (watts) = bmep(Pa) * V_{Displacement}(m^3)\frac{RPM}{2revs * 60}$$

$$= (758508.8148Pa)(247.08329m^3)\frac{2700RPM}{2revs * 60} = 4216.834155W$$

$$BrakePower_{measured}(watts) = \frac{2\pi N}{60} * Torque = \frac{2\pi(2992RPM)}{60} * 0.7Nm = 219.33W$$

<u>Sample Calculation – Mass Fuel Flow Rate</u>

$$\dot{m}_f = \frac{Volume_{fuel} * Density_{fuel}}{time} = \frac{0.008L * 0.71\frac{kg}{L}}{59.53s} = 0.3435\frac{kg}{hr}$$

Sample Calculation – Mass Air Flow Rate

$$\dot{m}_a = \dot{m}_{a,chart} * \frac{P_{actual}}{P_{chart}} * \frac{T_{actual} + 144}{T_{chart} + 144} * \left(\frac{T_{chart}}{T_{actual}}\right)^{\frac{5}{2}}$$

$$= 2.9\frac{kg}{hr} * \frac{101300\frac{b}{Pa}}{101300\frac{b}{Pa}} * \frac{293.75K + 144}{293.15K + 144} * \left(\frac{293.15K}{293.75K}\right)^{\frac{5}{2}} = 2.889\frac{kg}{hr}$$

Sample Calculation – Air to Fuel Ratio

$$AFR = \frac{\dot{m}_a}{\dot{m}_f} = \frac{2.889\frac{kg}{hr}}{0.3435\frac{kg}{hr}} = 8.412$$

Sample Calculation – Volumetric Efficiency

$$\eta_v = \frac{2 * \dot{m}_a}{60N\rho_a V_s} = \frac{2 * \frac{2.889\frac{kg}{hr}}{3600s}}{60(2992RPM)(208 \times 10^{-6}\frac{kg}{m^3})(1.201L)} = 0.129$$

Sample Calculation – Brake Thermal Efficiency

$$\eta_b = \frac{Brake\ Power * 3600}{\dot{m}_f * CV} = \frac{219.33W * 3600}{0.3435\frac{kg}{hr} * 440 \times 10^5} = 0.0522$$

Sample Calculation – Heat Loss Percentage

$$Heat\ loss\ \% = \frac{\left(\dot{m}_a + \dot{m}_f\right) * c_{p,exhuast} * (T_{exhuast} - T_{ambient})}{\dot{m}_f * CV} * 100$$

$$= \frac{\left(2.889\frac{kg}{hr} + 0.3435\frac{kg}{hr}\right) * 1.0712 * (684.15K - 293.75)}{0.3435\frac{kg}{hr} * 44000} * 100 = 8.964\%$$