THESIS

INSTALLATION AND TESTING OF A CUMMINS QSK19

LEAN BURN NATURAL GAS ENGINE

Submitted by

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ABSTRACT

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The goal for a more efficient engine will never disappear. Over the years many different techniques have been explored within the common goal of higher efficiency. Lean combustion has proven to be effective at increasing efficiencies as well as reducing emissions. The purpose of this thesis is to install a modern Cummins QSK19G and perform certain test that will explore the lean combustion limits and other methods that could possibly increase efficiency even more. The entire installation and instrumentation process is documented within this thesis.

The engine was installed in the Engines and Energy Conversion Laboratory at Colorado State University. The engine was installed with the hopes of instilling the desire for endless future tests from Cummins as well as other companies seeking this type of research engine. The lean limit was explored in the most detail. Cummins supplied a test plan that satisfied their desired stopping at a lean limit when the coefficient of variance of indicated mean effective pressure reached 5%. For the curiosity of others involved and this thesis, the lean limit was explored further until the engine could no longer ignite the ultra-lean combustion mixture.

Friction accounts for a significant loss in a modern internal combustion engine. One role of the engine oil is to reduce these frictional losses as much as possible without causing increased wear. A test was conducted on the QSK19G to explore the effects of varying the engine oil viscosity. Frictional losses of two different viscosity oils were compared to the stock engine oil losses. The fact that reducing oil viscosity reduces frictional losses was proven in the test.

ACKNOWLEDGMENTS

I first want to thank my parents for everything they have done for me throughout my entire life. They have provided me with a life that I will be eternally grateful for. When I was making the decision to leave Alabama and begin my graduate career at Colorado State University, they were the ones to push me and make it possible to embark on such a journey. I have never looked back on that life changing decision. Thank you Mom and Dad!

Dr. Daniel Olsen has given me an opportunity that I could only dream of throughout my earlier schooling. I am so thankful that he viewed my resume as suitable for the project I was assigned to when I began here at Colorado State University in August of 2011. The project I began proved to be a great challenge that would not have been possible without the help of three others here at the Engines and Energy Conversion Laboratory. Phillip Bacon proved to be an irreplaceable source of knowledge on anything I could think of. Kirk Evans suffered through all of my intelligent and the not so intelligent questions to help me learn and produce a functioning test engine. Many of the tasks were not manageable for one person which leads me to Corey Degroot. Corey was essential in many of the early installation steps.

Thank you to my friends Paris Amy, Jake Doyle, Matt Ludeman, and Elaina Jennings for their support along the way, mainly keeping me sane in my free time. I could not have done it without such a great group of friends.

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EPA	Environmental Protection Agency
CSU	Colorado State University
ϕ	Equivalence Ratio
λ	Lambda
NO_x	Mono-nitrogen oxides
LFL	Lean Flammability Limit
LIL	Lean Ignition Limit
LML	Lean Misfire Limit
PP	Peak Pressure
THC	Total Hydrocarbons
COV	Coefficient of Variance
IMEP	Indicated Mean Effective Pressure
FMEP	Friction Mean Effective Pressure
BMEP	Brake Mean Effective Pressure
NMEP	Net Mean Effective Pressure
NPT	National Pipe Thread
ECM	Engine Control Module
IR	Infrared Radiation
CO	Carbon Monoxide
CO_2	Carbon Dioxide

FID	Flame Ionization Detection
NO	Nitrous Oxide
NO_2	Nitrogen Dioxide
O_2	Diatomic Oxygen
FTIR	Fourier Transform Infrared
HAP	Hazardous Air Pollutants
MCT	Mercury cadmium telluride
Ge-on-KBr	Germanium-on-Potassium Bromide
FFT	Fast Fourier Transform
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
MN	Methane Number

Chapter 1 – Background and Introduction

1.1 Overview

The demand for internal combustion engines is still present and will be for many years to come. The focus now is doing everything possible to reduce emissions and increase the efficiency of the engines of tomorrow. The Environmental Protection Agency (EPA) passes stricter and stricter regulations on heavy duty engines every few years. The focus of this thesis is on stationary natural gas engines used primarily for power generation. Using natural gas instead of other petroleum products has many benefits. Natural gas is a great alternative fuel because of its large supply, low cost, and the ability to adapt it as an engine fuel [1]. Using a fuel in the gaseous state provides benefits such as reduced wall wetting effects on the intake manifold and cylinder walls particularly in cold conditions [2]. This property of natural gas drastically aids in cold starting ability in cold climates that are common for stationary power generation. Natural gas also has relatively broad flammability limits [3] which allow the engine to run at high air to fuel ratios. Natural gas engines as a whole operate with lower pollutant emissions and increased efficiency [4].

This thesis deals with the installation and testing of a Cummins QSK19G lean burn natural gas engine. Chapter 2 presents the entire installation process of the engine in the lab test facility at Colorado State University (CSU). Chapter 3 presents a set of baseline data. This test was necessary to make sure the engine was preforming consistently data published by the manufacturer. Chapter 4 contains data and analysis of 4 equivalence ratio sweeps to explore the lean limit of the engine. The final chapter deals with a lube oil test. Two different oils were used in the engine and performance data was then compared to the stock engine oil. The purpose of this test was to quantify the effects of varying the viscosity of the engine oil.

1.2 Lean Engine Operation

Traditionally engines are operated at what is known as stoichiometric conditions. This refers to the point where chemically there is exactly the right amount of air to react with the fuel. In order to increase efficiency and reduce emissions, lean engine operation has been explored for many years. Lean engine operation or lean combustion describes a condition where there is excess air present in the combustion process. There are many benefits associated with lean combustion. Two terms that are commonly used to describe the air to fuel ratio are the equivalence ratio (ϕ) and lambda (λ). Lambda is the inverse of the equivalence ratio and Equation 1 one gives the equation for the equivalence ratio [3].

$$\phi = \frac{actual\ fuel{-}air\ ratio}{stoichiometric\ fuel{-}ratio} \tag{1}$$

1.2.1 Advantages and Disadvantages

The advantages of lean combustion focus on two areas: increased efficiency and decreased emissions [5,6]. Most of the benefits are due to lower combustion temperatures. Engine efficiency increases due to lower heat transfer losses [3]. At lower combustion temperature the specific heats are more linear resulting in lower heat transfer losses. One disadvantage is that the power density of a typical naturally aspirated engine will decrease as the combustion mixture is made more and more lean. A means of boosted intake manifold pressure is possible due to lower temperature which lowers the tendency of knock [3]. Most lean burn engines will incorporate a turbocharger or supercharger to maintain comparable or even higher power densities. Pumping losses become a smaller portion of shaft power when utilizing a supercharger or turbocharger which can further increase efficiency. The lower combustion temperature has an effect on engine emissions as well. NO_x emissions drop significantly due to lower combustion temperature [7]. As the combustion mixture is made even leaner, some disadvantages become significant. The lean mixture reduces the flame speed [8] and requires more energy to ignite. These two problems can cause misfire, flame quenching, and incomplete flame propagation before the exhaust valve opens in the expansion stroke leading to increased unburned hydrocarbons in the exhaust stream [9]. Overall, there exists a point that balances the advantages and disadvantages of lean combustion.

1.2.2 Lean Limit

A unanimous definition of the lean limit does not exist among various sources [1]. Three definitions exist in literature: lean flammability limit (LFL) is an inherent fuel property independent of engine design [10], lean ignition limit (LIL) describes the leanest mixture that an engine's ignition system can produce a flame kernel [11], and lean misfire limit (LML) can be described in many ways [11]. The third definition has been broken down into many different interpretations of the LML. One way to describe the LML is the air to fuel ratio at which the first misfire is experienced [6]. A frequency of total misfires is sometimes established to characterize the lean limit [12,13,14]. Similar to the frequency of total misfires, a selected threshold frequency of cylinder Peak Pressure (PP) can be used to define the lean limit [15]. Because incomplete combustion usually increases total hydrocarbons (THC's), certain quantities of THC's present in the exhaust stream is another way to quantify the lean limit [16,17]. The last way to characterize the lean limit is by selecting a value of the coefficient of variance (COV) of indicated mean effective pressure (IMEP) or peak pressure (PP) [18]. Cummins specified the lean limit to be the point where the COV of IMEP reaches 5%.

The lean limit can be tested in two ways. The first method is to start from stoichiometric conditions and slowly increase the air to fuel ratio until the first complete misfire trace is seen [1]. This method corresponds with the LML [13]. The other way is to motor the engine and slowly decrease the air to fuel ratio until the first ignition cycle is viewed [1]. The LIL is commonly tested with this method [13].

Optimal efficiency does not occur at the lean limit. The air to fuel mixture is bounded on the rich side by the onset of knock and by misfire on the lean side [8]. As the combustion mixture is made leaner from stoichiometric conditions, the efficiency increases and the combustion stability declines. An efficiency peak is reached when combustion instability overcomes the increasing efficiency. For one case the equivalence ratio was measured to be 0.625 [19]. The lean limit equivalence ratio is dependent on engine design and operating parameters such as speed and intake manifold pressure. Beyond this point, efficiency falls due to increased combustion duration which increases heat transfer to cylinder walls [20]. The reason the optimal operating point occurs at a richer point than predicted because of the onset of combustion instability and misfire [21], which also acts to reduce efficiency due to poor fuel utilization. The cyclic variations also become too large for the engine to run smoothly due to misfire and/or deplenished flame speed [12,22]. The combustion process is commonly broken down into two sections, the 0-10% and 10-90% burn durations. The 0-10% duration is generally characteristic of ignition energy and laminar flame speed while the 10-90% duration is usually attributed to the flame propagation and turbulence [19]. The level of cyclic variations is quantified in two ways: COV of IMEP and PP [3]. The parameter used to describe the lean limit in this thesis, COV of IMEP can be decreased by increasing turbulence in the combustion chamber [23]. The reason for this lies in the correlation between the 10-90% burn duration and the COV of IMEP. Because the 10-

90% burn duration dominates the combustion process, a decrease of burn duration will give a decrease in COV of IMEP [19]. Figure 1 demonstrates the relationship between efficiency and COV of IMEP. Clearly, as the mixture becomes leaner past the point of peak efficiency, a drastic decline in combustion stability is evidenced by a spike in COV of IMEP.

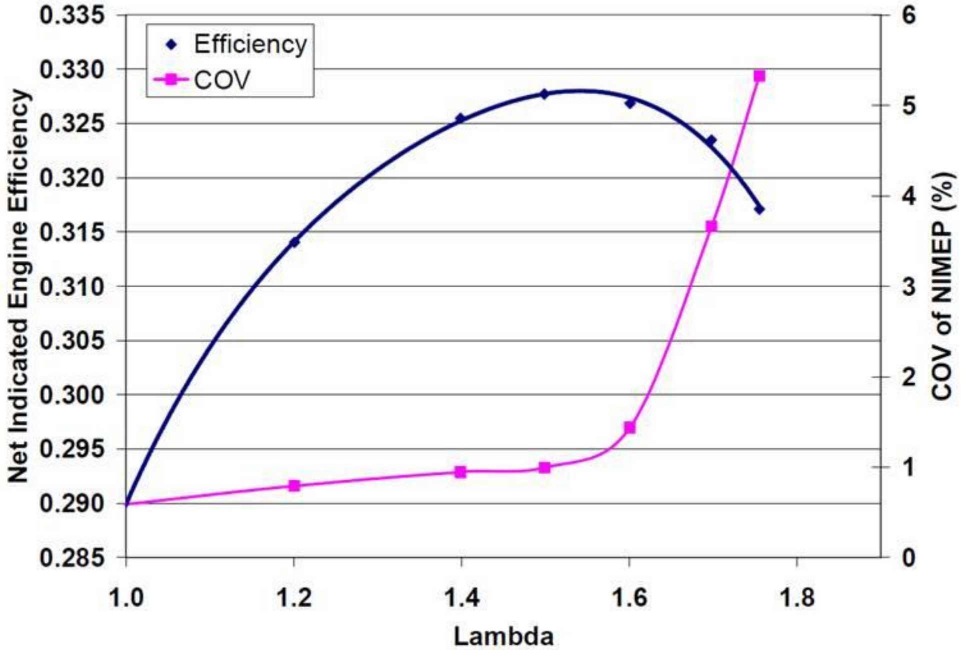

Figure 1. Effect of air-fuel ratio on efficiency and coefficient of variation in NIMEP [23].

1.3 Lube Oil Viscosity Effects

With rising demand for more fuel efficient engines, reducing mechanical losses due to friction becomes more and more important. Mechanical friction usually accounts for 10-15% of the total energy in a current internal combustion engine [24]. Figure 2 shows the energy distribution in a fired engine.

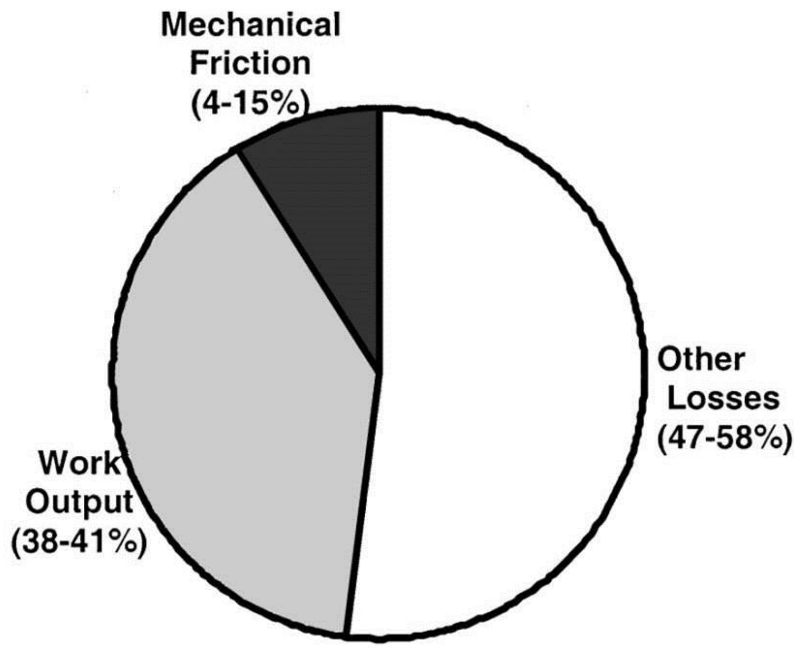

Figure 2. Distribution of total energy in a fired engine [24].

All of the moving parts in an engine contribute to the friction losses. One function of the engine oil is to reduce the friction in moving parts. As oil viscosity decreases, frictional losses also decrease [24]. The other function of the engine oil is to reduce wear on components and increase life. Although less viscous oils reduce friction, the oil must not be made to thin and introduce more wear [24]. Optimizing engine oil is one method to reducing frictional engine losses but creating the optimal oil can be costly and must be explored to determine if it is the economical decision [25]. Common engine oil ratings (15W-30) contain two parameters. The first number is the friction modifier and it helps to keep the oil thinner at lower temperature for cold operation. The second number is the base oil viscosity and describes the oil viscosity at normal operating temperatures (100°C). Changes in the base oil viscosity have larger effects on friction than changes in the friction modifier [26].

There are many ways to measure the frictional losses in an internal combustion engine. The method selected for this project is to calculate the friction mean effective pressure (FMEP). This method was selected because it can be used on a stock engine under full load. In this thesis, FMEP is calculated by subtracting the brake mean effective pressure (BMEP) from the net mean effective pressure (NMEP), as shown in Equation 1. Equation 2 through Equation 4 [27] show how the NMEP is calculated from pressure traces of each cylinder. BMEP is calculated using the measured brake power and the engine geometry, as shown in Equation 3 [24].

$$FMEP = NMEP - BMEP \tag{2}$$

$$NMEP = -\frac{\frac{2*\pi}{360}\int_{-360}^{360} P*dV}{V_d} \tag{3}$$

Where *P* is the instantaneous cylinder pressure

dV is the incremental change in volume

and V_d is the displacement volume.

$$V_d = \frac{\pi*B^2}{4} * L \tag{4}$$

Where *B* is the cylinder bore diameter

and L is the stroke length.

$$dV = \frac{\pi*B^2}{4}\left\{a * \sin\theta\left[1 + \frac{a*\cos\theta}{\sqrt{L^2 - a^2*sin^2\theta}}\right]\right\} d\theta \tag{5}$$

Where *a* is the crank radius

and θ is the crank position relative to top dead center (TDC).

$$BMEP = \frac{BP*nr}{V_d*rpm} \tag{6}$$

Where *BP* is the measured brake power

nr is the number of revolutions per cycle

and *rpm* is the engine speed

Because FMEP is a measure of total mechanical friction in an engine, it provides an effective way to characterize the effects of varying oil viscosity on total engine friction.

Chapter 2 – Engine Installation and Test Setup

2.1 Three Dimensional Test Cell Model

When the project began in August of 2011, there was an engine still occupying the test cell dedicated to the Cummins QSK19. In order to make the transition smoother during the engine swap, a three dimensional model of the test cell was created. It contains all existing connections that would need to be made such as engine mounting locations, jacket water coolant, and dynamometer shaft position. After the test skid had been modeled, the critical engine dimensions were extracted from an engine model provided by Cummins. With fixed dimensions of both the test skid and the engine established, the engine could be located on the test skid. The mounting brackets were designed to support the engine where it had been placed in the 3-D model. All hard plumbing lines were routed to their specific connection location allowing a bill of materials to be created and materials purchased to facilitate the transition from the Waukesha to the Cummins. Figure 3 shows the complete 3-D model.

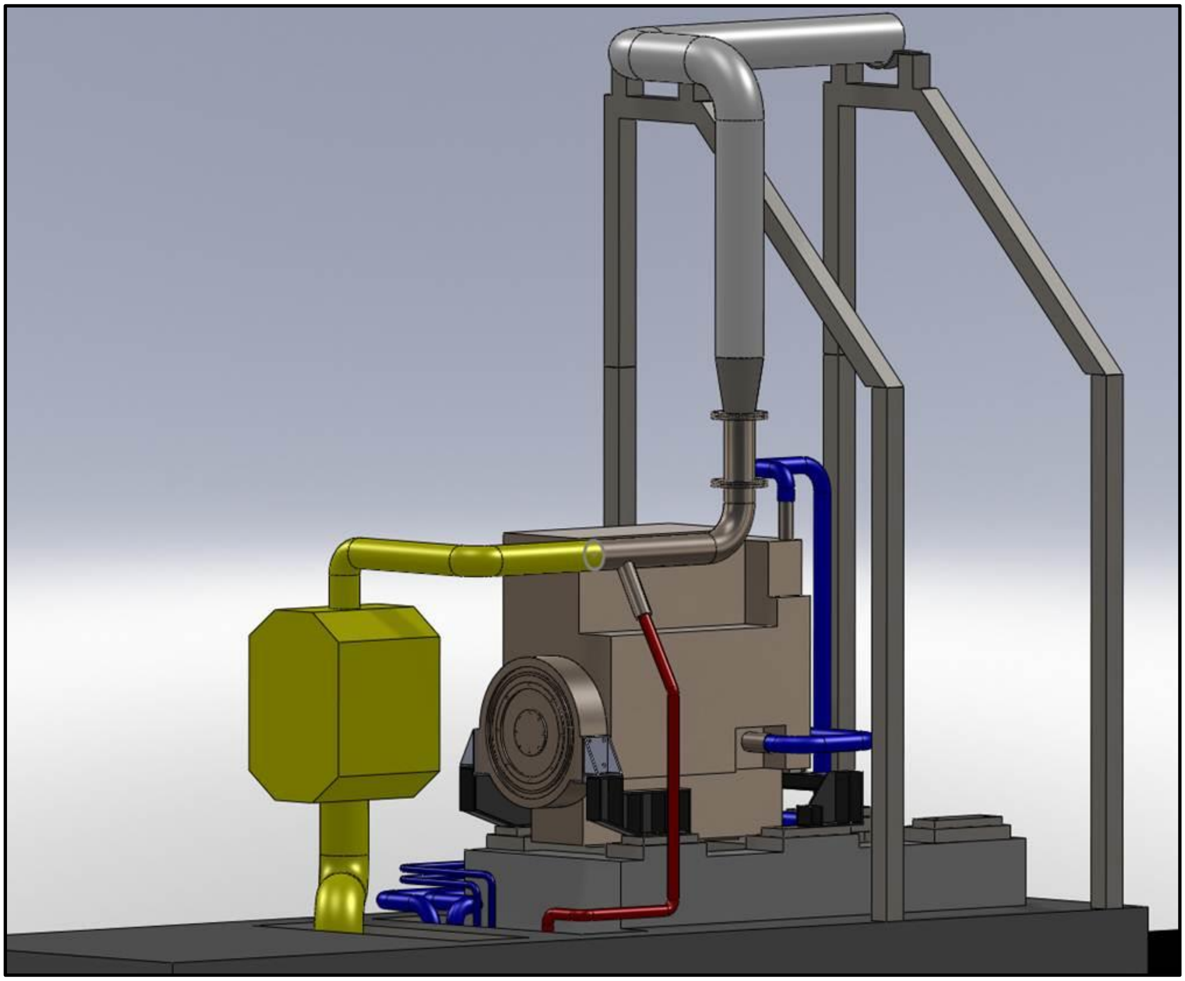

Figure 3. Complete SolidWorks 3-D Model.

2.2 Mounting Brackets

The 3-D model was used to determine all measurements for the mounting brackets. The rear brackets were built using 3/8in (9.53mm) thick steel plate. The left and right brackets are mirror images of each other. The engine was shipped with brackets attached to the rear mounting locations. The rear brackets were initially designed to work with the brackets that were attached to the engine. The strength of the shipping brackets was concerning so they were replaced with stronger brackets that utilize two more mounting holes on the engine. Figure 4 compares the old shipping bracket with the reinforced bracket that is currently in use. The front bracket was designed with a similar pattern. The only difference is the engine has a central mounting location on the front rather than both sides like the rear. The front mounting bracket consists of a 3in (76.2mm) square tube with 3/8in (9.53mm) wall thickness connected to two feet on each end that are built from 3/8in (9.53mm) steel plate. All pieces for the mounting brackets were either cut with a horizontal band saw or water jet cutter. After all the pieces were cut to size, they were welded together to form the brackets. The final brackets were sand blasted and painted with black semi-gloss paint.

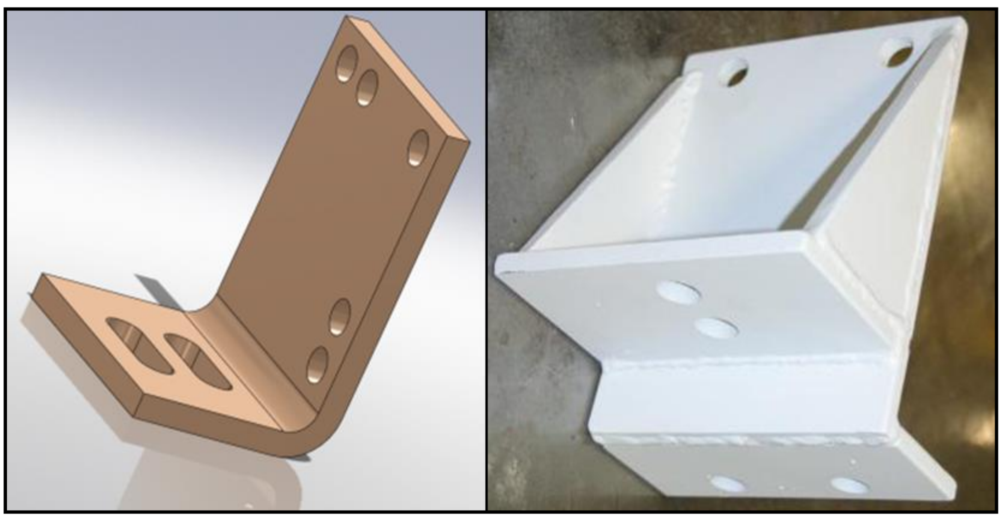

Figure 4. Shipping Bracket (left), Stronger Redesigned Bracket (right).

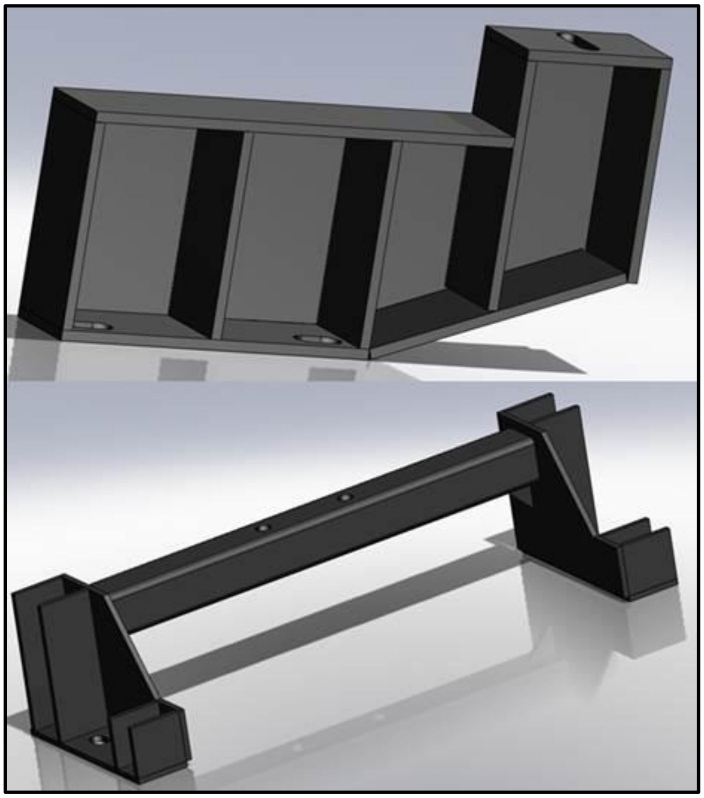

Figure 5. Finished Mounting Brackets.

2.3 Plumbing Systems

2.3.1 Jacket Water Coolant Plumbing

The Cummins QSK19 was placed on the test skid in January 2012. The first plumbing system installed was the jacket water coolant. The old jacket water lines from the Waukesha engine terminated at a flange connection on the test skid. The coolant lines for the QSK19G were routed from the flange locations (Figure 6) to the appropriate locations on the engine. The existing lines were 3” schedule 40 pipe. This was perfect for the 3in (76.2mm) jacket water inlet on the engine. The jacket water outlet on the engine is two 2.5in (63.5mm) connections. The jacket water return line was split with a tee fitting and reduced to 2.5in (63.5mm) (Figure 7). The entire pipe used for the jacket water is welded to together. Engine connections are made with sections of the appropriate size hose and hose clamps. The onboard engine thermostats were blocked completely open to allow the engine temperature to be regulated by the lab temperature controlled cooling water system. The thermostats were left in the engine so that the total flow restriction remains similar to the stock configuration. The engine coolant bypass was removed because it serves no purpose with the thermostats blocked open. The engine is sometimes used for slipstream catalyst testing. The catalyst testing unit requires a coolant supply. Coolant supply and return connections (Figure 8) were added to the existing jacket water lines during installation.

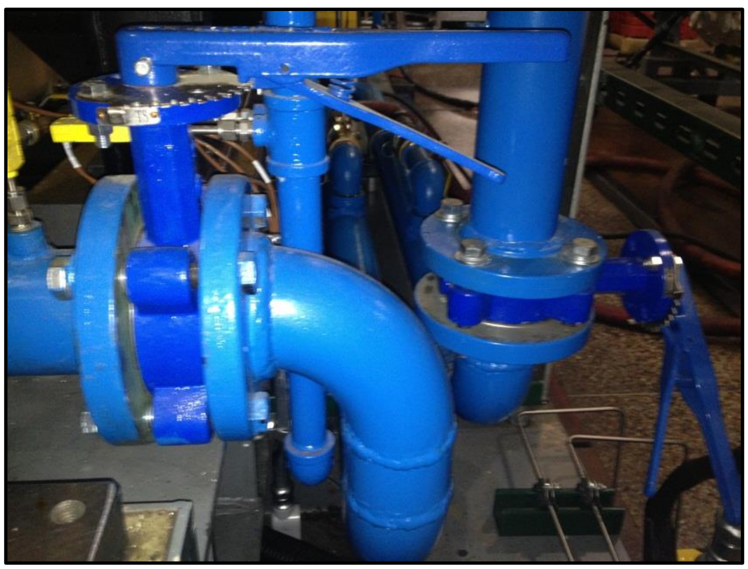

Figure 6. Jacket Water Flange Connections.

Figure 7. Engine Coolant Return Connections.

Figure 8. Catalyst Testing Unit Coolant Connections.

2.3.2 Intake Air Plumbing

The intake air plumbing only required slight modification. The current pipe needed to be lowered 17.8” (453.39 mm). The intake pipe has a flange connection before it makes the connection to the engine. The piece from the flange connection to the engine was rebuilt to include various instrumentation ports. A rubber connector was obtained from Cummins to make the connection to the engine. The pipe used for the intake line is 5” schedule 40, which has the same outside diameter as the engine connection. Figure 9 shows the air intake connection to the engine.

Figure 9. Air Intake Connection.

2.3.3 Intercooler Coolant Plumbing

The oil cooler coolant lines from the Waukesha installation were repurposed for the QSK19G. The old lines were 2” threaded pipe. These lines were replaced at valves below the test skid with 1” threaded pipe. The lines parallel the jacket water coolant lines towards the front of the engine. At the front corner of the engine, the intercooler coolant lines turn vertical and connect to the intercooler with hose connections. The intercooler coolant lines are connected to the lab cooling water system via an external pump, negating the need for an onboard pump. The intercooler coolant pump was removed from the engine.

Figure 10. Intercooler Coolant Connections.

2.3.4 Natural Gas Plumbing

The natural gas plumbing required more work than the other plumbing systems. The natural gas plumbing was re-routed from the supply and vent locations below the test skid. The supply line is 2” threaded pipe and the vent line is 1” threaded pipe. The supply line first is connected to an electric solenoid ball valve (Figure 11). This is the block valve that can isolate the engine from the building’s natural gas supply. From the block valve the plumbing continues through a pressure regulator and then connects to the engine. The on engine fuel connection is a 2” female NPT. A 24in (0.61m) flex line (Figure 12) was connected to this port to make necessary transition from the vertical pipe to orientation of the engine connection. A fuel vent line is also included in the system. This allows the fuel between the block valve and the engine to be bled in the event of an unsuccessful start.

Figure 11. Natural Gas Block Valve.

Figure 12. Natural Gas Flex Line.

2.3.5 Exhaust Plumbing

The exhaust was run from the engine to the common header along the west wall of the laboratory. The connection to the engine is a 5” flange. From the flange on the engine, a reducer was used to get to the 8” pipe for the rest of the plumbing. A tee with 8” inline connections and a 4” intersecting connection was used after the reducer. A similar tee was placed after the back pressure valve. The two tees supply exhaust to the slipstream test apparatus. An 8” pneumatic butterfly valve (Figure 13) is used to control the back pressure of the engine. This is necessary to simulate altitudes lower than Fort Collins, CO.

Figure 13. Exhaust Back Pressure Valve.

2.3.6 Oil Drain Plumbing

One of the ports on the oil pan was removed to make room for a remote oil drain location. ¾” threaded pipe was run from the oil pan to the edge of the test skid to simplify the oil changing process.

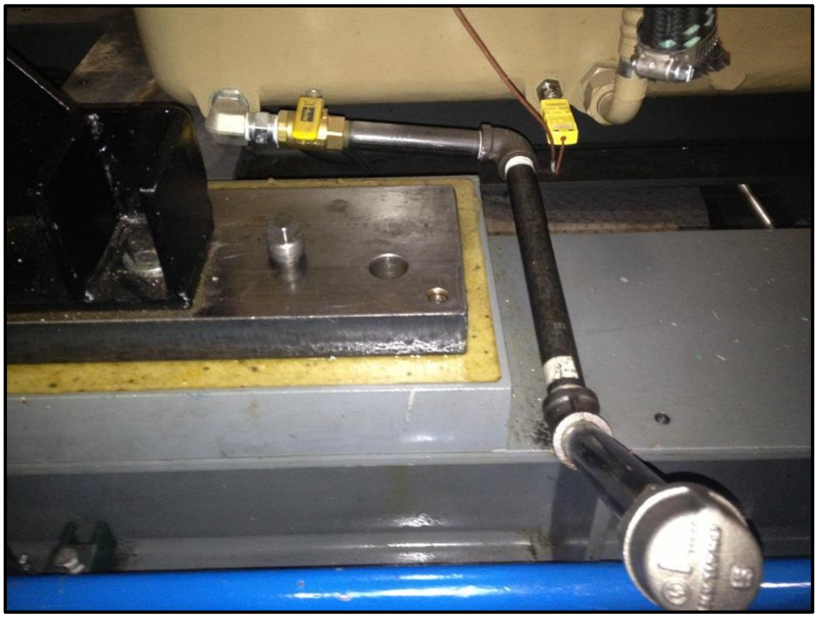

Figure 14. Remote Oil Drain.

2.3.7 Crank-Case Blow-by Connections and Flow Meter

The engine was equipped with a coalescing filter on the crank case blow-by gases. It was located on the rear end of the intercooler. To better fit the test skid, the filter was relocated to the front end of the intercooler. This allowed the plumbing from the filter to connect easier and cleaner. The blow-by gases are routed through a flow meter and out to the ambient air outside the building.

2.4 Other Installation Tasks

2.4.1 Driveshaft Installation

The dynamometer on the test skid was not moved for the QSK19G installation. The engine was placed in a position so that the current dynamometer and driveshaft could be used without relocating. The engine crankshaft and dynamometer shaft are parallel separated by a 3in

(76.2mm) height difference. A 36in (914.4mm) driveshaft results in a driveline angle of 4.75°. The maximum angle is specified as 7° for parallel shafts operating at a maximum of 2500 RPM. Based on this specification, the driveline angle is within the safe operating limits. A flywheel adapter plate had to be designed to join the driveshaft with the QSK19G flywheel. The piece was manufactured out of a 1" thick piece of steel. The rough shape and holes were cut with the water jet cutter. The piece was then sent to a private machine shop for final machining. Figure 15 is the engineering drawing that was sent to the private machine shop.

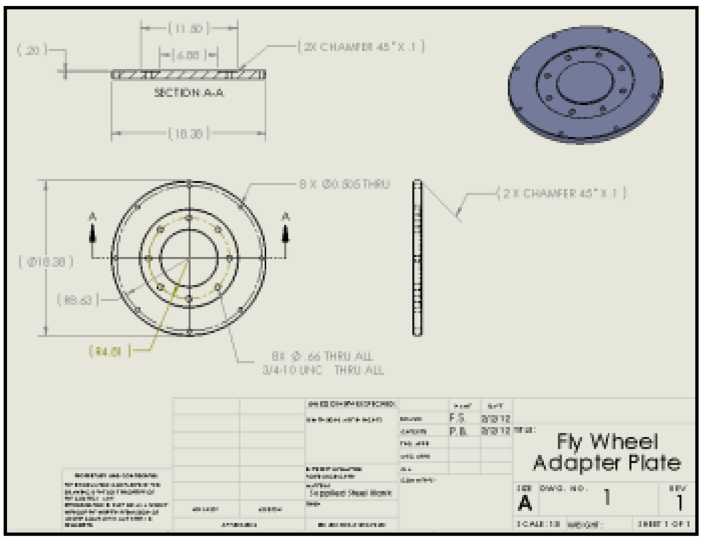

Figure 15. Flywheel Adapter Plate Drawing.

2.4.2 Encoder Bracket Installation

The high speed data acquisition system requires a high resolution encoder to provide precise crankshaft position. This encoder shaft is connected to the crankshaft with a fabricated adapter plate that is bolted to the balancer on the front of the engine. The encoder stand was fabricated and integrated with the front engine mount. Figure 16 shows the adapter plate mounted on the engine balancer and the mounting bracket for the encoder.

Figure 16. Encoder Mounting System.

2.4.3 24 Volt Battery Installation

Both the Cummins and CSU control panels require a 24 volt power supply. The electric starter also requires a 24 volt power supply. In order to satisfy these needs, two large 12 volt batteries wired in series were installed underneath the test skid (Figure 17). The batteries are maintained with a low current battery charger at all times.

2.4.4 Moving Parts Covers

The engine test skid is open to the lab environment around it. To ensure safe operation, covers were built to conceal all pinch points near rotating engine parts. The driveshaft cover was re-used from the previous engine. New covers for the driveshaft/fly wheel interface and for the balancer on the front of the engine were fabricated out of a combination of sheet metal and expanded metal.

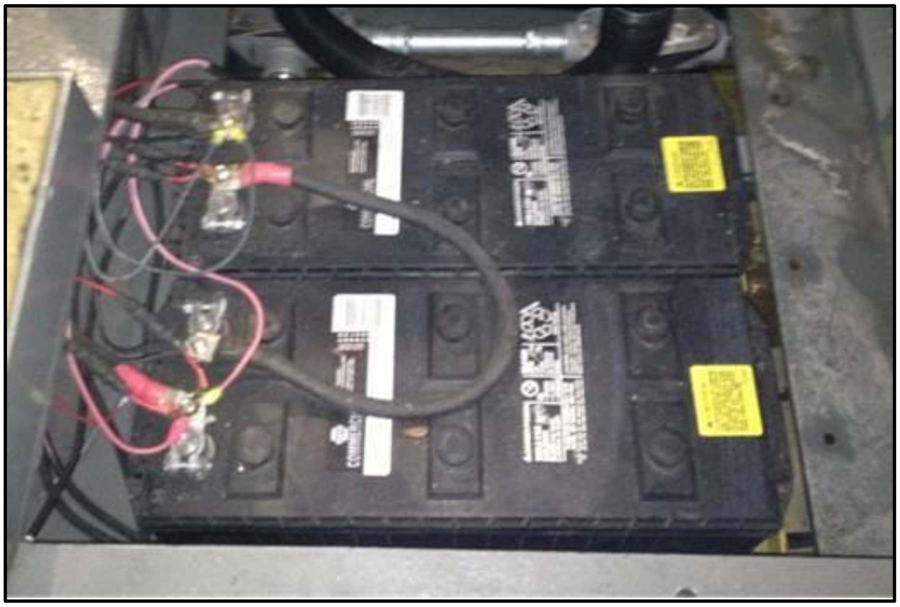

Figure 17. 12 Volt Batteries.

Figure 18. Driveshaft/Fly Wheel Interface Cover (left), Balancer Cover (right).

2.5 Engine Instrumentation

The engine was delivered in its standard configuration generator set configuration. In order to record the desired data during testing, the engine had to be instrumented further. The project proposal includes a list of parameters that had been agreed upon. This list was used as a guide for the instrumentation plan. A total of 18 temperature and 14 pressure measurements were added to the engine system.

2.5.1 Engine Disassembly

The first step for instrumenting the engine was to disassemble part of the engine. Engine disassembly started from the top and moved downward. The carburetor assembly was removed first. The turbocharger assembly was removed next. After the turbocharger was out of the way, the 3 part exhaust manifold was taken off. Removal of the throttle assembly and intercooler followed. All of these parts needed to be machined to install the necessary sensor or pressure line. Depending on the location and material, the ports were either drilled and tapped or a weldolet was welded to the instrument location. All temperatures are measured with Omega k-type thermocouples. The turbocharger support bracket had to be modified to allow clearance of the cylinder 2 exhaust port thermocouple. Figure 19 shows the modified part. The pressure measurement technique varies. Most are routed with 3/8in (9.53mm) stainless tubing from the measurement location on the engine back to a Rosemount pressure transducer. Some pressures are measured with unique devices depending on the specific need. For example, oil rifle pressure is measured with a small Omega pressure transducer mounted directly to a port on the oil rifle volume. This prevents the need for a supply line that would essentially be filled with a dead volume of engine oil. Another special pressure measurement location is the in-cylinder combustion pressure. This parameter is measured independently for each of the 6 cylinders. 6 AVL-QC34C pressure transducers were provided by Cummins for these measurements. The in-cylinder pressure transducers are installed into a precisely machined cylinder head. The engine was shipped with only one cylinder head machined for an in-cylinder pressure transducer. Five machined heads were shipped separately. The new heads needed to be installed leading to further disassembly of the engine. The head swap was done while the rest of the engine was disassembled to save time. After all work had been completed on the engine parts, everything was reassembled following the owner's manual procedure with new gaskets.

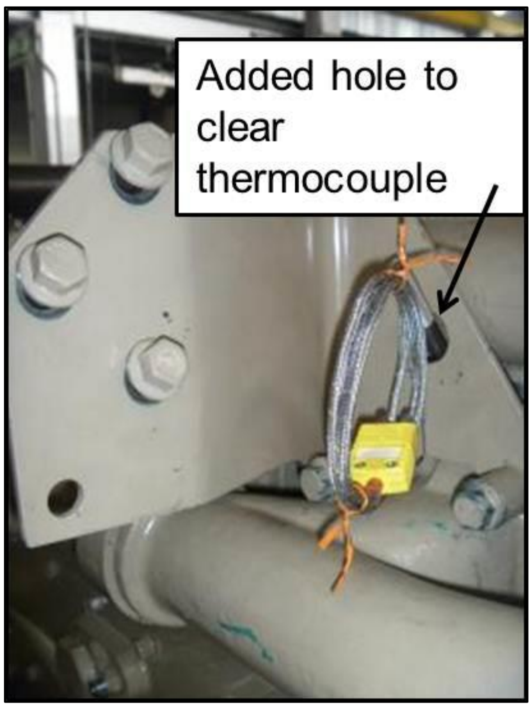

Figure 19. Modified Turbocharger Support Bracket.

2.5.2 Conduit Installation and Engine Wiring

The wiring system for all of the instrumentation and engine controls is very complex. A comprehensive wiring diagram is included in the appendix. All data acquisition sensors are connected to a main control box on the test skid (Figure 20). The main control box contains a National Instruments (NI) Compact RIO chassis. The NI chassis contains 7 modules that handle varying signal types to process all of the data coming from the on engine instrumentation. The chassis can also send signals to control certain devices on the test skid such and fuel valves. Table 1 lists all of the NI modules and their individual functions.

Table 1. NI Modules.

Module Function	Model Number	Qty
Thermocouples	9213	2
24 Volt Sink	9425	1
24 Volt Source	9476	1
Analog Input ± 20 mA	9208	1
Analog Input ± 10 mA	9205	1
Analog Output ± 20 mA	9265	1

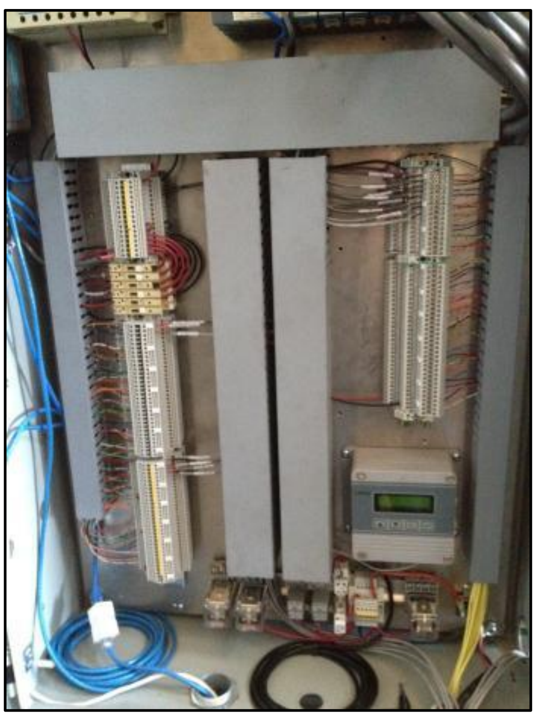

Figure 20. CSU Control Panel.

Other output signals are sent to the control panel attached to the engine ECM. The field wiring travels from the control box to each individual sensor through a network of electrical conduit. The conduit keeps the wires safe and protected from vibration and chemical spills. The field wiring enters the control box either from the above wire trays, or from the conduit network below the test skid. A direct conduit path is also present from the CSU control box to the Cummins control box. The path is necessary to establish communication between the two control systems.

2.5.3 Pressure Line Installation

All of the Rosemount pressure transducers are mounted in a row on the west side of the test cell. Each transducer is plumbed to its appropriate measurement location with 3/8in (9.53mm) stainless steel tubing. All of the lines are routed to a common bulkhead and from there the lines split off and are routed to the appropriate location on the engine.

2.5.4 Starter Wiring / Solenoid

The engine came equipped with a 24 volt electric starter. The current required to engage the solenoid on the starter is greater than what the relay in the control box can provide, therefore an intermediate relay was added that could handle the starter solenoid as well as be activated by the relay in the CSU control panel. The relay (Figure 21) is mounted on the bottom of the carburetor bracket just above the engine starter.

Figure 21. Engine Starter Relay.

2.5.5 Pressure Transducer Calibration / Installation

The in-cylinder pressure transducers provide by Cummins had to be calibrated before they could be installed for testing. In order to calibrate the transducers, a mounting vessel had to be fabricated to interface the pressure transducer with the dead weight tester used in the calibration process. The adapter vessel was designed to mimic the technique used inside each of the engine cylinder heads. After the part had been fabricated it was attached to the dead weight tester. Next the transducer was connected to the combustion analyzer to record its output. The gains on the Kistler charge amplifiers were adjusted until each transducer produced accurate output signals. Each transducer was calibrated using its own signal cable and charge amplifier. After calibration each transducer was installed into its appropriate cylinder head.

2.5.6 Cummins Control Box Overview

The engine was shipped with its own control cabinet similar to the test skid control panel. The supplied control panel contains the parent engine control module (ECM), throttle controller, circuit breakers, relay, and all the necessary terminal blocks. When the engine was first brought online, several connections inside the control panel were found to be inconsistent. These inconsistent connections made troubleshooting the wiring very difficult. The entire control panel was re-wired with new terminal blocks to ensure proper connections. Other communication with the test skid control panel is necessary and was added during installation. Table 2 lists the signals sent and received from the test skid control panel.

Table 2. Shared Signals between Lab Control Room and Cummins Control Panels.

Signal Name	Signal Description	Source
Idle / Rated	Commands the engine to operate at idle speed or rated speed	CSU
TOB	Torque over boost feedback used for equivalence ratio control	CSU
Start / Stop	Commands the engine to either be in start or stop state	CSU
Key Switch	Gives control system power	CSU
PLC Input for Gas	Tells plant that the engine is ready for fuel	Cummins

2.6 Testing Analyzers

2.6.1 Rosemount 5-gas Emissions Bench

A summary table for the analyzers within the bench is provided in Table 3. A Peltier-type condenser removes water from the exhaust sample before the gas enters the analyzers. Infrared radiation (IR) adsorption is used by the analyzer to determine relative CO concentrations. IR detection is also used to measure CO_2 concentrations in the exhaust. Total hydrocarbon compounds (THC's) are detected using a flame ionization detection (FID) method. A regulated flow of sample gas passes through a flame sustained by regulated flows of fuel gas and air. Within the flame, the hydrocarbon sample stream undergoes a complex ionization that produces electrons and positive ions, which are collected by an electrode, causing a measurable current flow. The ionization current is proportional to the rate at which carbon atoms enter the burner and is therefore a measure of the concentration of hydrocarbons in the sample. The NGA 2000

CLD uses the chemiluminescence method of detection for NO_x. All NO_2 is reduced to NO over a catalyst. The NO is reacted with internally generated ozone (O_3) to form NO_2 in an electronically excited state. The excited molecule immediately reverts to the ground state emitting photons (red light), which is measured by a photodiode. The intensity of the chemiluminescence is directly proportional to the NO_x concentration. The determination of O_2 concentration is based on measurement of the magnetic susceptibility of the sample gas. O_2 is strongly paramagnetic, meaning its molecules have permanent magnetic moments even in the absence of an applied field, while other common gases are weakly diamagnetic.

Table 3. 5-Gas measurement technique

	Device	***Measurement Technology***	***Minimum Concentration Range***	***Maximum Concentration Range***	***Linearity***
CO	Ultramat 6	IR	0 – 10.0 ppm	0 – 10000 ppm	< 0.5% of full-scale value
CO_2	Ultramat 6	IR	0 – 5.0 ppm	0 – 30 %	< 0.5% of full-scale value
THC	Fidamat 6	FID	0 – 10 ppm	0 – 99999 ppm	< +/- 1% of full scale
NO_x	NOx MAT 600	Chemiluminescence	0 – 1.0 ppm	0 – 3000 ppm	< 0.5% of full-scale value
O_2	NGA 2000, PMD	Paramagnetic	0 – 1.0 ppm	0 – 100 %	+/- 1% of full scale

Figure 22. 5-Gas analyzer rack with a combination of Rosemount and Siemens instruments.

2.6.2 Fourier Transform Infra Red (FTIR) spectrometer

Hazardous Air Pollutants (HAP's) are measured using our Fourier Transform Infra Red (FTIR) spectrometer (Figure 23). The primary HAP's of interest are formaldehyde, acrolein, and acetaldehyde. Ammonia and hydrogen cyanide can also be measured. THC (up to C3) and NOx speciation are performed with the FTIR. The most important aspects of the Nicolet 6700 FTIR spectrometer include the mercury cadmium telluride (MCT) detector, germanium-on-potassium bromide (Ge-on-KBr) beamsplitter, and an instrument resolution limit of 0.125 cm^{-1} (after apodization). The instrument uses a 10 meter gas cell, which has a volume of 2 liters and utilizes zinc selenide windows.

Figure 23. Nicolet 6700 Fourier Transform Infra Red spectrometer for measuring HAPS and other constituents.

2.6.3 Fuel Gas Chromatograph

The composition of the fuel gas is measured with a Varian CP – 4900. This analyzer utilizes a split-sample technique to achieve very fast analysis times (~1 minute). Gas species are separated with packed columns and detected using a thermal conductivity detector. Typically the analysis is set up to determine fuel gas composition up through C6. The instrument is shown in Figure 24

Figure 24. Varian CP – 4900 gas chromatograph for measuring fuel gas composition.

2.6.4 Combustion Analyzer

The device used to record high speed combustion data is separate from the rest of the data acquisition system. We utilize a portable system that connects to the in-cylinder pressure transducers on any engine in the laboratory. The cart contains several components that work together to provide the necessary data. The brain of the system is a National Instruments PXI-

1002. This computer is connected to 6 Kistler Type 5010 charge amplifiers. The in-cylinder pressure transducers are connected to the charge amplifiers during engine testing. The transducers are also connected to an ITW Cooling system to maintain a safe operating temperature. An incremental encoder is connected to the crankshaft on the engine to provide crankshaft position as well as instantaneous engine RPM. The software for the system was written by Kirk Evans. IMEP is calculated with a trapezoidal integration at the recorded encoder resolution. Heat release is a traditional single-zone 1^{st} law calculation. Knock analysis is done by fast Fourier transform (FFT) method and an area of knock trace method is available. The complete system is shown in Figure 25.

Figure 25. CSU Combustion Analyzer Cart.

2.7 Software Design

The main software designed for the project was a LabView control system. The program was written to carry out engine control and data collection. The ECM performs the primary engine control functions of speed, air/fuel ratio, ignition timing, and boost control. The program also handles all of the facility controls, including coolant pumps and cooling towers. When the start command is given to the Labview program, all of the necessary steps are completed automatically to ensure a proper, safe engine start. Figure 26 is a block diagram showing the relative timing of the steps required for a safe start.

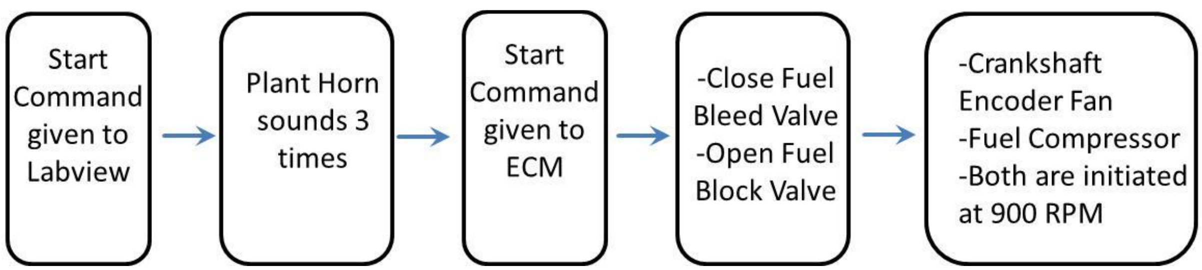

Figure 26. Safe Start Flow Chart.

Aside from controlling all equipment within the test cell, the program also sends the necessary signals to the Cummins ECM's. Communication with the Cummins ECM and data collection is achieved with the use of a National Instrument's CompactRIO chassis. The chassis contains different modules to handle a variety of sensor output. The program Calterm was provided by Cummins to communicate with the engine's ECM's. In order to have proper communication between the test computer and the Cummins's ECM's, an Inline 6 adapter was installed. Calterm communicates with the ECM's through this adapter. Calterm is necessary to adjust engine parameters such as ignition timing, air to fuel ratio, etc. Also the entire configuration file can be downloaded to change between engine operating speed. Data acquisition is achieved through the same LabView program that controls the engine. The output from all of the sensors as well as the output from our emissions analyzers is recorded while a data point is in progress. Figure 27 is a simplified representation of the signal flow throughout the controls and data acquisition system.

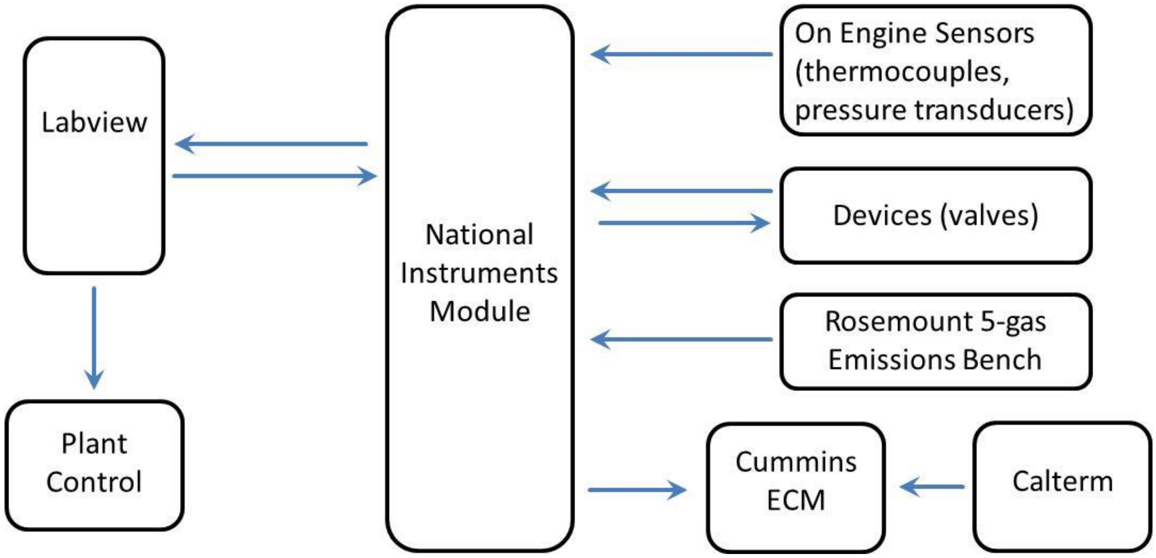

Figure 27. Controls and Data Acquisition System Signal Flow Diagram.

The high speed combustion data is recorded from a separate location. Each pressure transducer is connected to a charge amplifier and then travels to a National Instruments PXI-1002. The PXI receives engine speed and crank position through an incremental encoder mounted to the crankshaft.

2.8 Engine Start Up and Commissioning Test

Engine start was a joint effort between the employees here at the EECL and Cummins. The engine test plan had to be modified during the testing due to difficulty with engine communication and engine tuning. The initial plan was one day for engine start up and then 2 days for commissioning testing. Upon start up, there were many problems within the Cummins control panel. Several inconsistent connections were found in the terminal blocks making troubleshooting difficult. The final solution was to re-wire the entire panel. This solved the communication problems and allowed for successful startup. The next problem occurred with engine tuning. It took several days to adjust the closed loop NO_x control to the right set points for both 1500 and 1800 RPM. The exact tuning process was supplied by Cummins during the time that we were starting to run the engine. The document is included in the appendix. The first step of the tuning process is to slowly bring the engine to rated load and run for 30 minutes allowing everything to stabilize. The engine is first tuned in open loop control tuning providing a rough tune, NO_x values of +/- 0.4 ppm. Once stable, the NO_x reading is compared to the set point given in the tuning document. If the reading is low, the engine is made richer by applying a negative offset to the ECM parameter C_LMDOFF. If the reading is high, the engine is made leaner by applying a positive offset to the parameter. This becomes an iterative process to get the NO_x level as close to the set point as possible. To achieve a more precise tune, the closed loop control tuning was carried out next, capable of reaching +/- 0.05 ppm. The process is similar to the open loop control tuning. The precise procedure is provided in the appendix. The parameter C_TBGM must be changed to 1 to begin the tuning process. Figure 28 outlines the parameters that must be changed in Calterm to complete both open and closed loop control tuning.

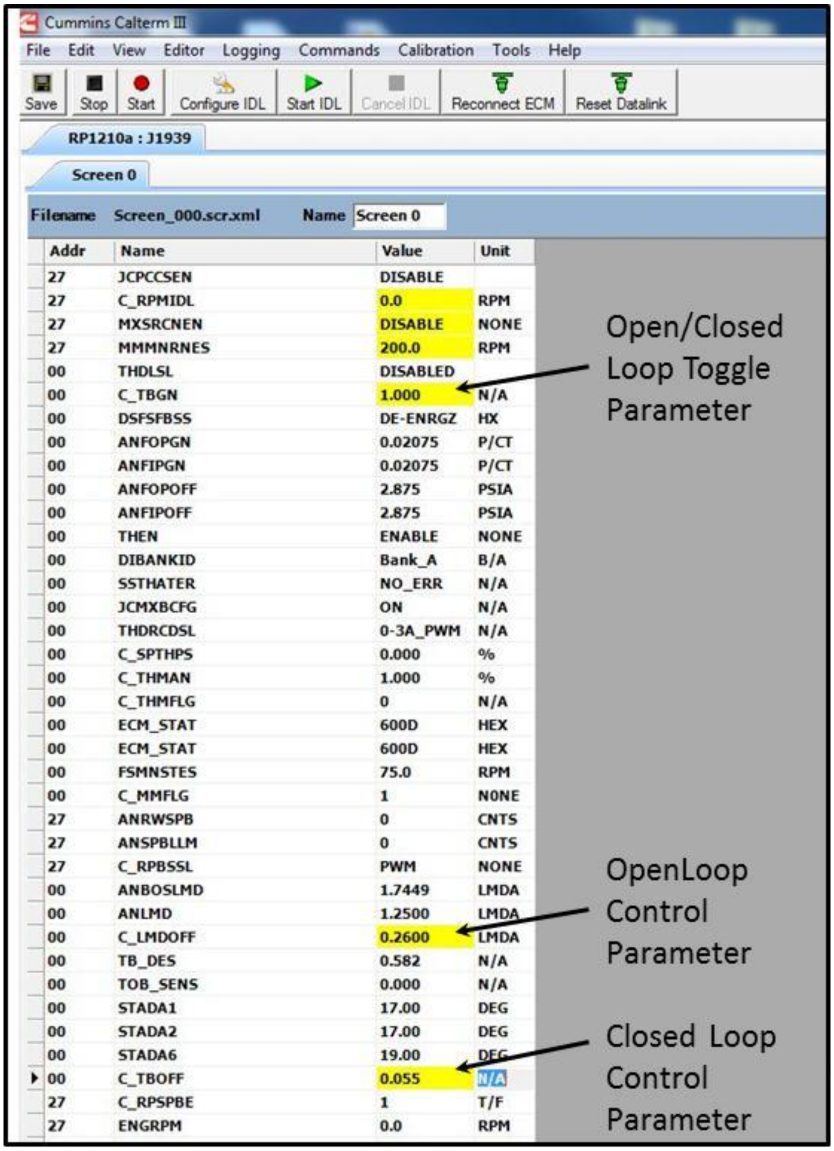

Figure 28. Calterm screen shot during NO_x tuning.

After the engine was running consistently within the emissions margins, the commissioning testing was carried out. The revised engine test plan was as follows. The first step was to take the engine to full load at rated speed and carry out the closed loop NO_x tuning. After the tuning process, a ten minute data point was recorded. A 75% load and a 50% load point followed the 100% point. This process was carried out for both 1800 and 1500 RPM. The data was then compared with the published test cell data from Cummins to verify the test readiness of the engine. Table 4 provides a comparison between the supplied set points from Cummins and the CSU test data. The set points are a combination of specifically supplied values and values taken from the engine data sheets. All of the engine data sheets are included in the appendix. Figure 29 is a plot of brake specific fuel consumption (BSFC) versus engine shaft power. Both the 1800 and 1500 RPM data is plotted together including the test data from CSU and from the Cummins test cell.

Table 4. Cummins Set Points compared with CSU Data.

Parameter	Cummins Set Points		CSU Data	
RPM	1500	1800	1500	1800
Power [hp]	450	471	451	472
Torque [ft-lb]	1576	1374	1579	1376
Fuel Consumption [BTU/hp-hr]	7232	7720	7641	8155
NO_x [ppm]	163	136	135	127
Jacket Water Temp [°F]	200	200	200	200
Intake Manifold Temp [°F]	145	145	146	146
Oil Pressure [psi]	50-70	50-70	65.5	70.8

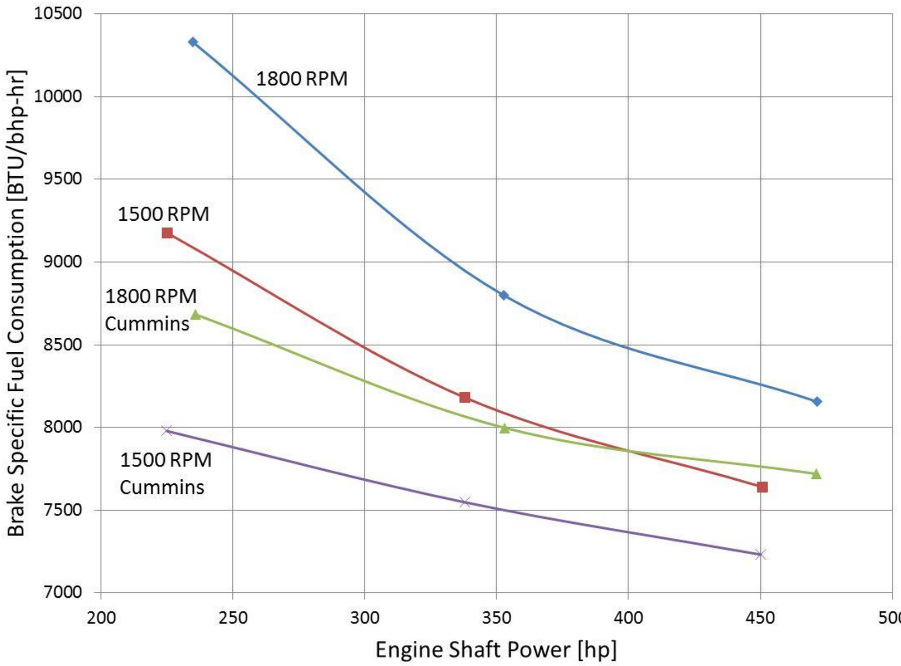

Figure 29. Brake Specific Fuel Consumption vs. Engine Shaft Power.

Brake thermal efficiency (BTE) is shown in Figure 30. The values for the CSU data are calculated from measured fuel flow and shaft power. The efficiencies are calculated with the same method for the Cummins data with the exception of fuel flow. The fuel flow was calculated from BSFC because actual fuel flow was not included in the supplied data sheet. However, this should make no difference since BSFC is calculated directly from fuel consumption and BTE is proportional to the inverse of BSFC.

The closed loop NO_x tuning process was carried out for both the 1500 and 1800 RPM load sweeps. The tuning document listed precise set points for NO_x levels throughout the load range of testing. Figure 31 shows how NO_x varied with load in testing and compares it to the set points provided in the tuning document. The blue and red curves represent the data collected in the lab under closed loop control. The closed loop control method did not increase the air to fuel ratio enough to maintain the desired NO_x values.

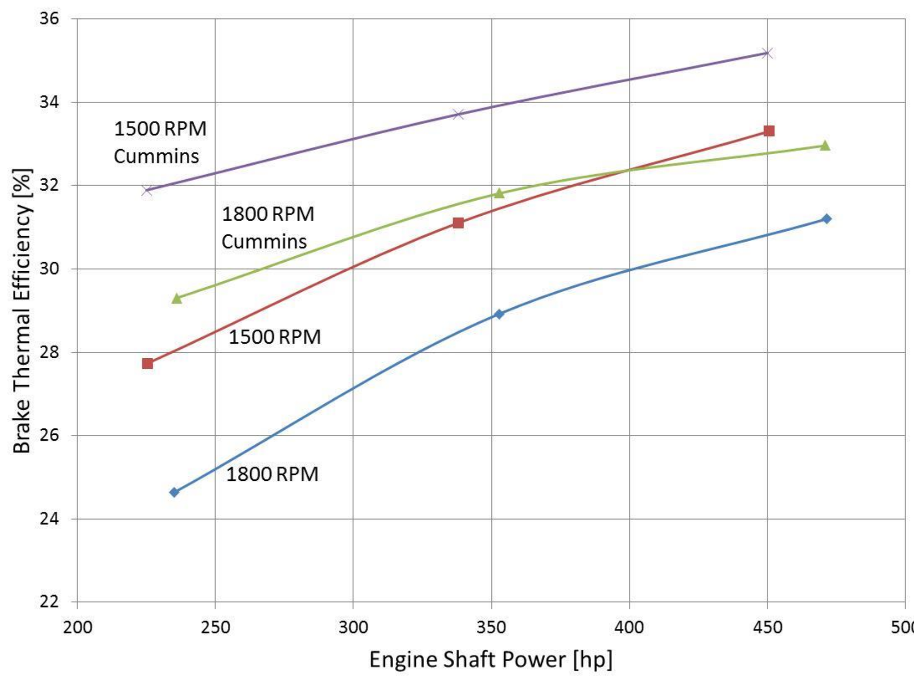

Figure 30. Brake Thermal Efficiency vs. Engine Shaft Power.

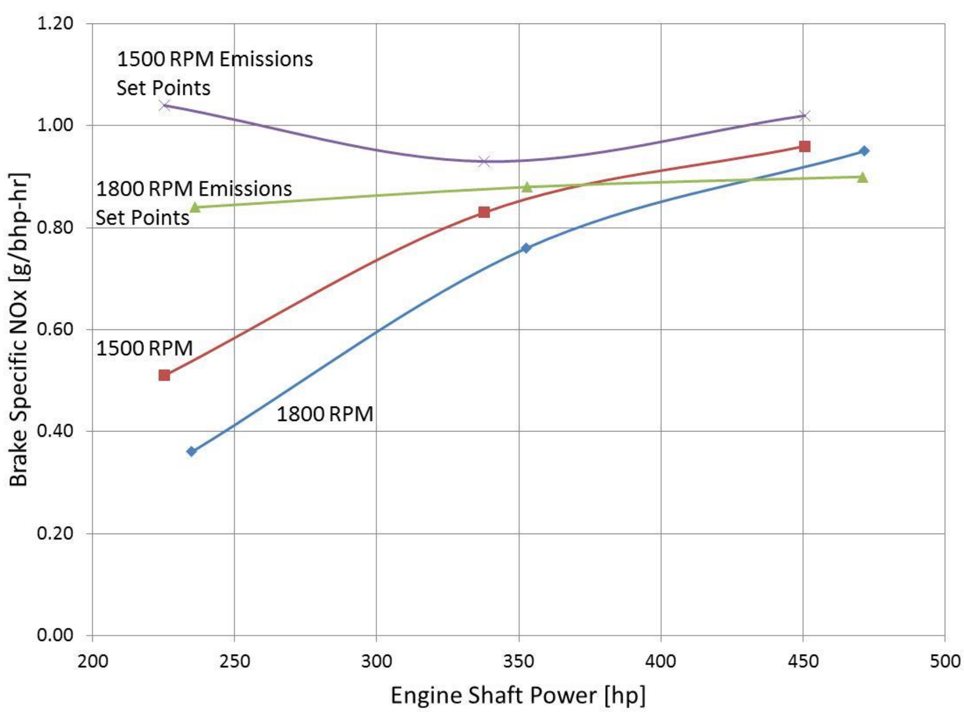

Figure 31. Brake Specific NO_x vs. Engine Shaft Power.

The BSFC values calculated here at CSU are much higher than the values provided in the engine performance data sheets. The two things that could have caused this are different intake manifold temperature and different air to fuel ratio. The target intake manifold temperature for the engine performance data is not given. Therefore the only thing was to target the set point given as 145 degrees Fahrenheit. This could have caused a small discrepancy but not account for the total difference. Based on the BSFC curves, as load is removed, the difference in BSFC grows. The main cause of this is due to a lower air to fuel ratio than test data. The NO_x plot shows that as the load decreases, the NO_x values fall much lower than the set points. In this region of operation, a lower NO_x value is proportional to equivalence ratio. The overall efficiency decreases as equivalence ratio drops explaining higher BSFC lower BTE values.

Chapter 3 – Baseline Test Data

3.1 Summary

The Baseline testing included two different test types. The first test was a load sweep at both 1500 and 1800 RPM. The load was varied from 100% down to 25% in 25% increments. A 90% load point was added to both sweeps to eliminate the need for a similar load sweep with the coming low viscosity oil test plan. The second test included was an equivalence ratio sweep at 100% load for both 1500 and 1800 RPM. Chapter 3 contains the results from the load sweep at both 1500 and 1800 RPM.

3.2 Test Plan

The baseline testing began on August 28 2012, and was concluded on August 30, 2012. The 1800 RPM data was collected first. The engine was started and taken to rated speed and full load. Here, the NO_x level was tuned to the set point in closed loop control. The load sweep began at 100% load with a ten minute data point. From there, load was removed and ten minute data points were recorded at 90%, 75%, 50%, and 25%.

3.3 Test Results and Discussion

The Baseline load sweep data is summarized for both 1500 and 1800 RPM in Figure 32- Figure 43. The Figures include brake specific emission, average burn locations and durations for cylinders 1-5, average burn locations and durations for cylinder 6, BTE BSFC, and COV's of IMEP and peak pressure. All parameters are plotted versus engine load. The combustion data from cylinders 1-5 was averaged together because all share the same ignition timing. Cylinder 6 combustion data was kept separate because the timing is advance by 2 degrees for knock detection. Figure 32 - Figure 37 are for 1500 RPM and Figure 38-Figure 43 are for 1800 RPM.

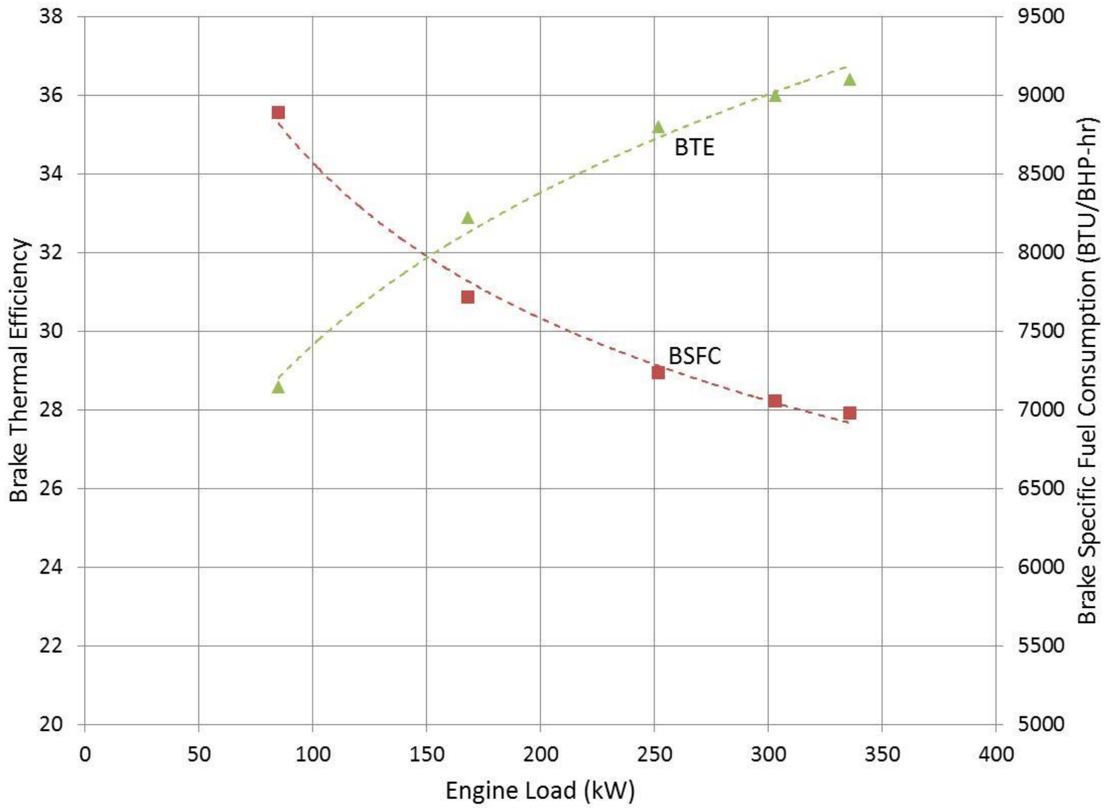

Figure 32. BTE and BSFC vs. Engine Load @ 1500 RPM.

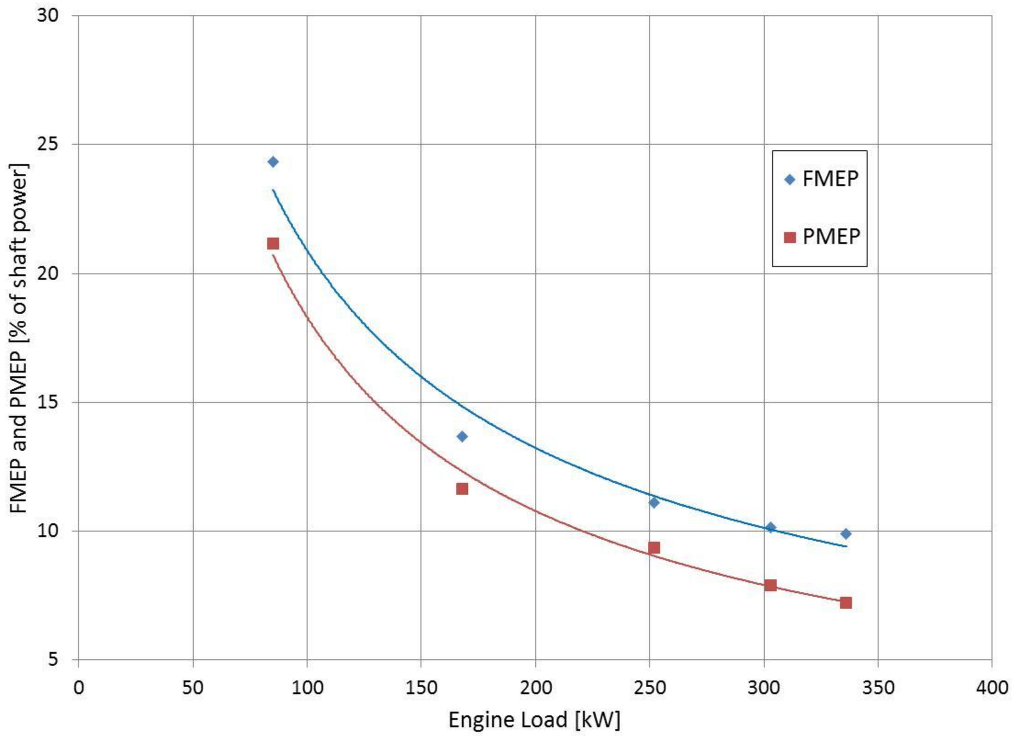

Figure 33. FMEP and PMEP vs. Engine Load @ 1500 RPM.

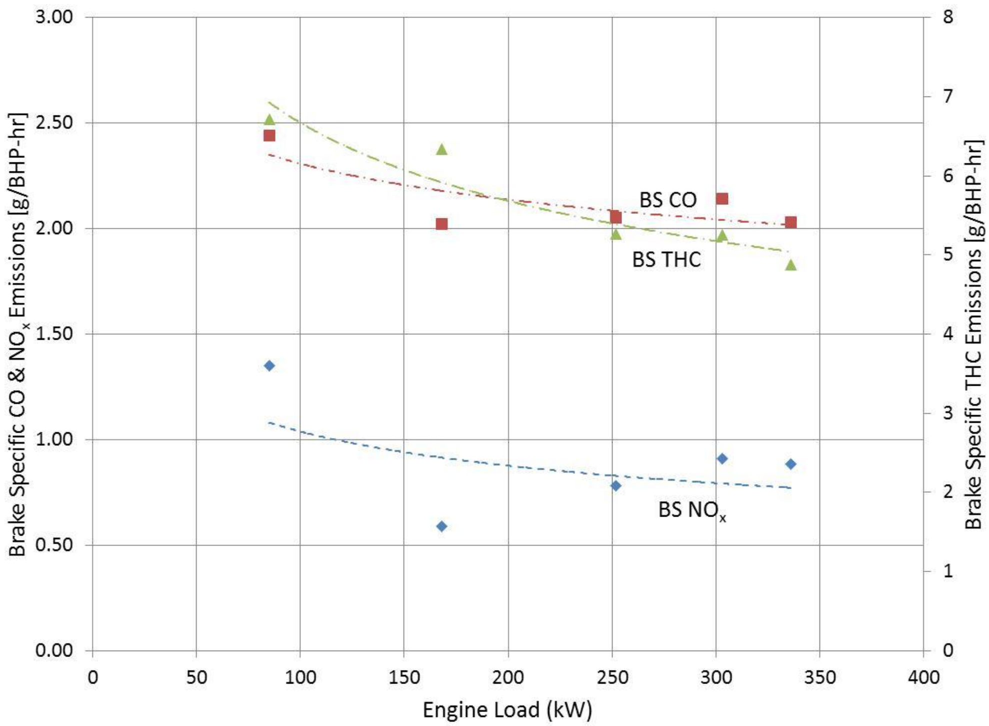

Figure 34. Brake Specific Emissions vs. Engine Load @ 1500 RPM.

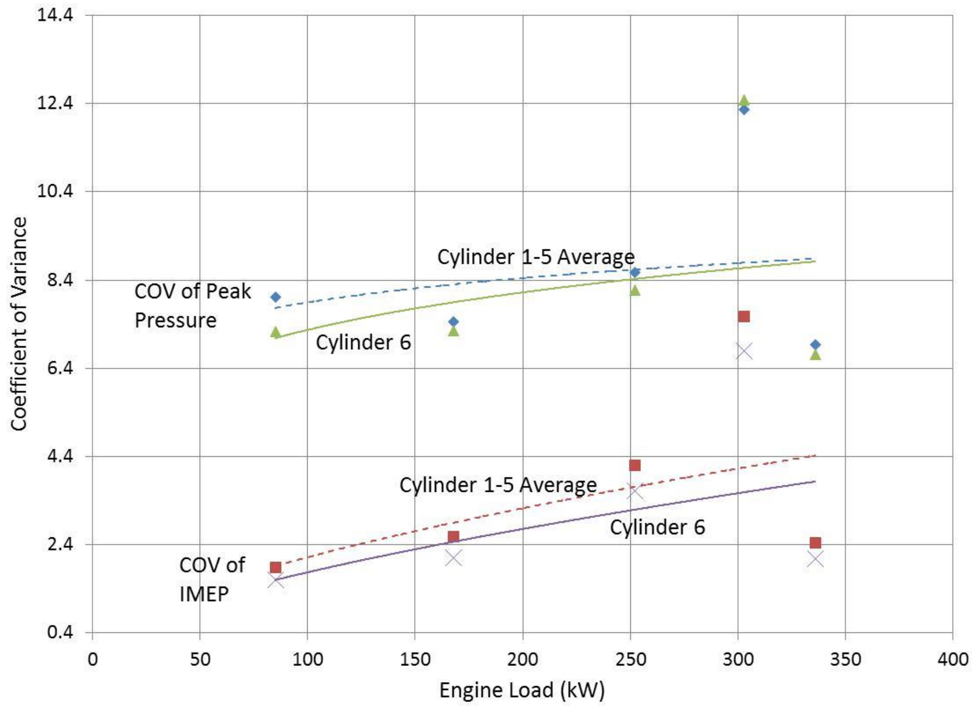

Figure 35. COV’s of IMEP and Peak Pressure vs. Engine Load @ 1500 RPM.

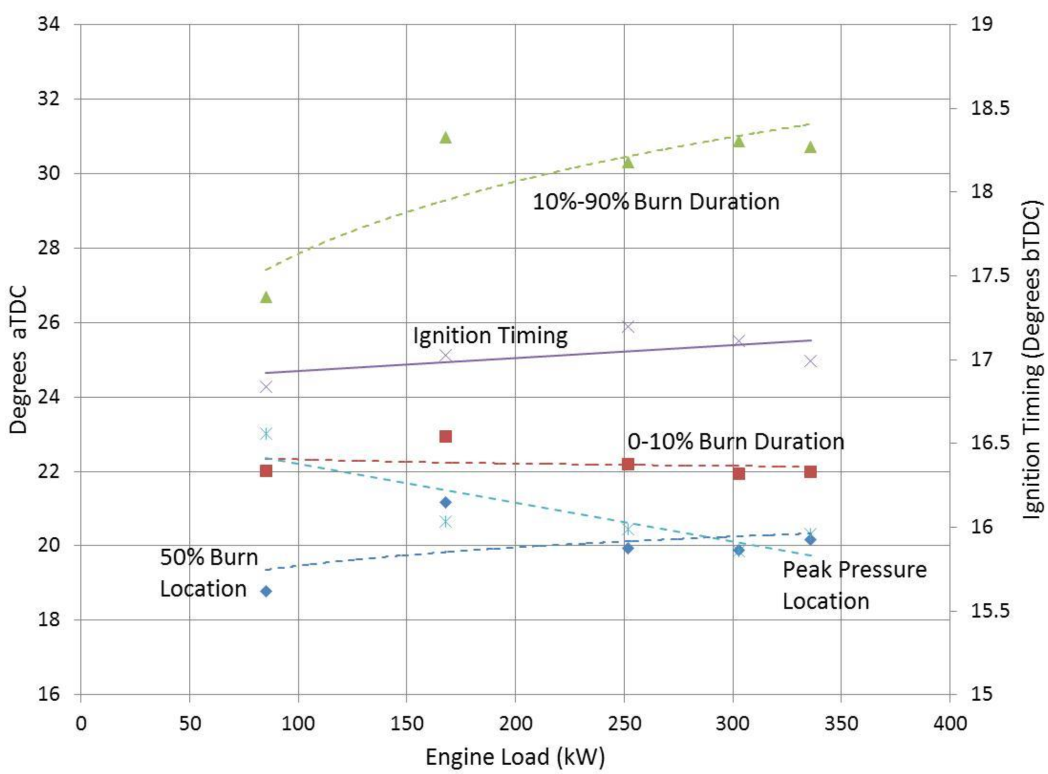

Figure 36. Cylinders 1-5 Average Combustion Data vs. Engine Load @ 1500 RPM.

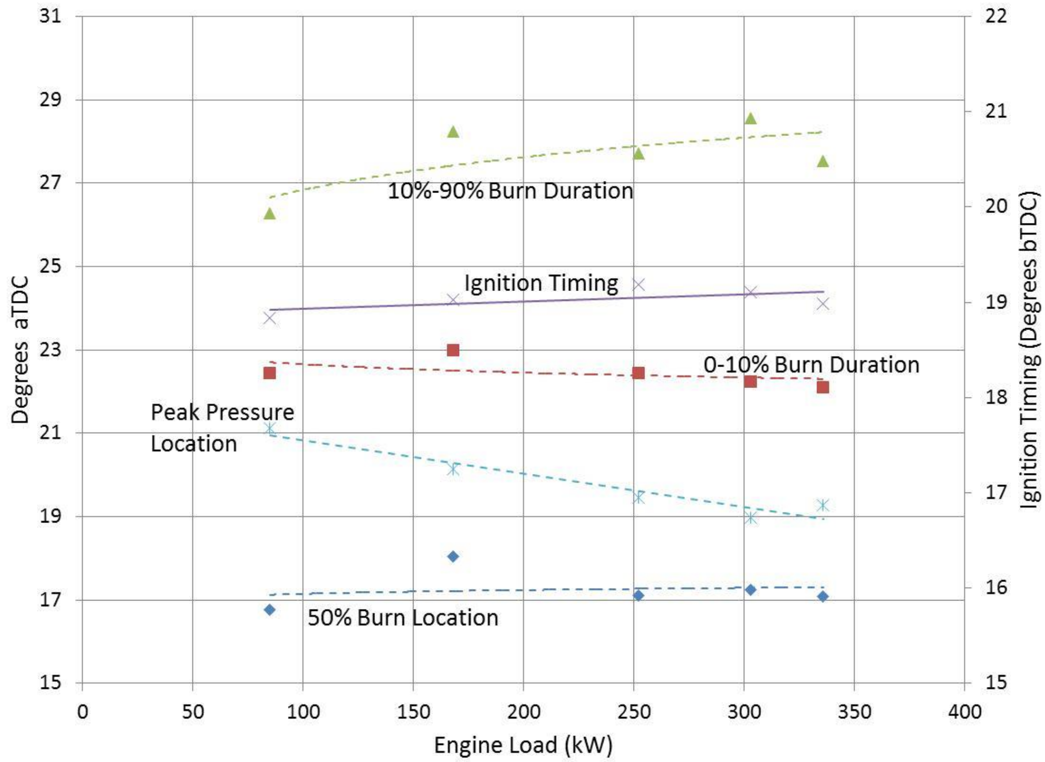

Figure 37. Cylinder 6 Combustion Data vs. Engine Load @ 1500 RPM.

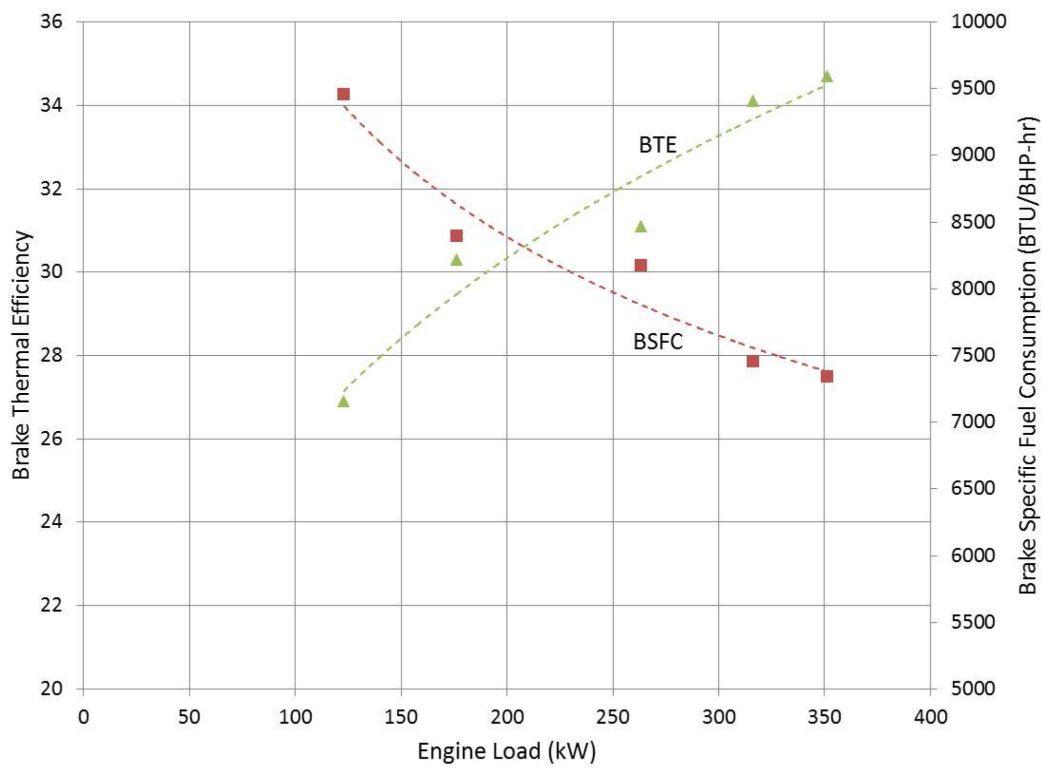

Figure 38. BTE and BSFC vs. Engine Load @ 1800 RPM.

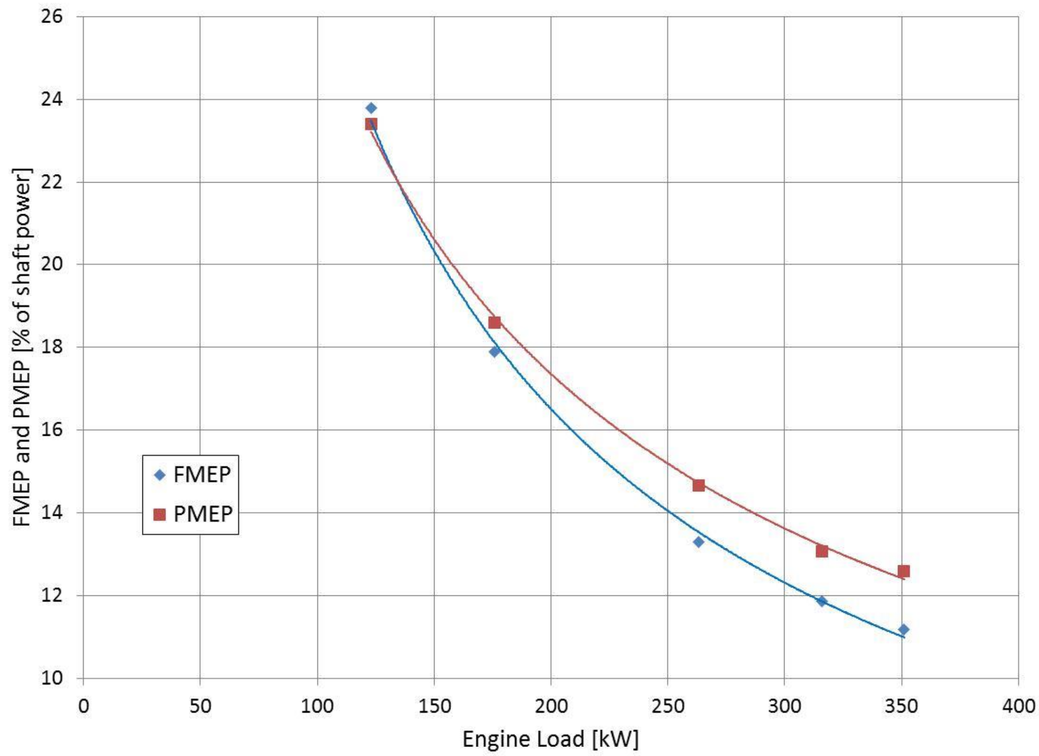

Figure 39. FMEP and PMEP vs. Engine Load @ 1800 RPM.

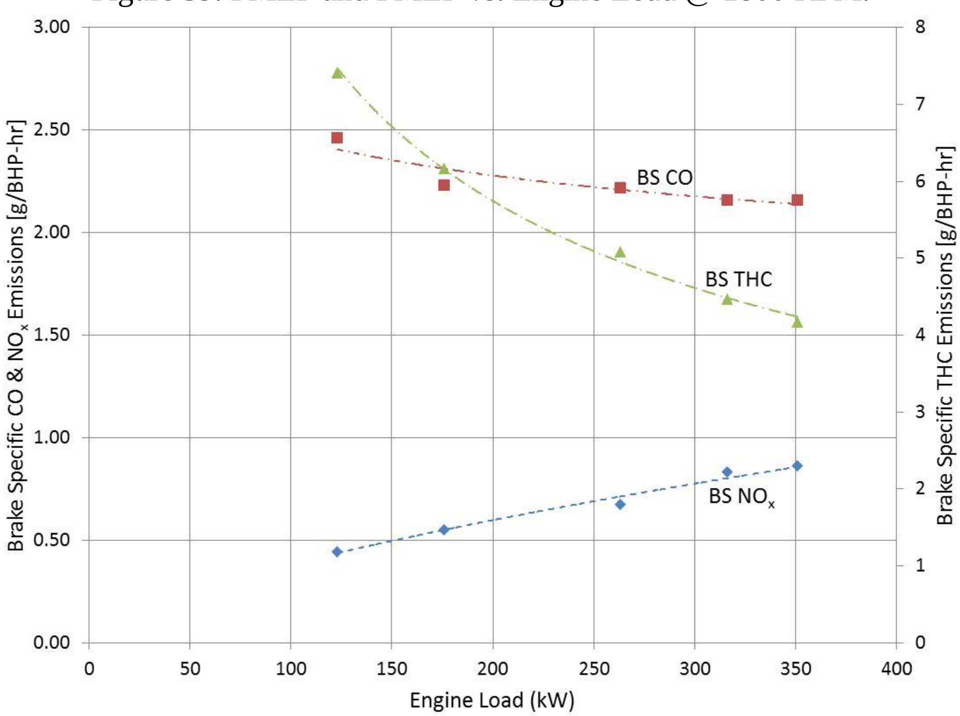

Figure 40. Brake Specific Emissions vs. Engine Load @ 1800 RPM.

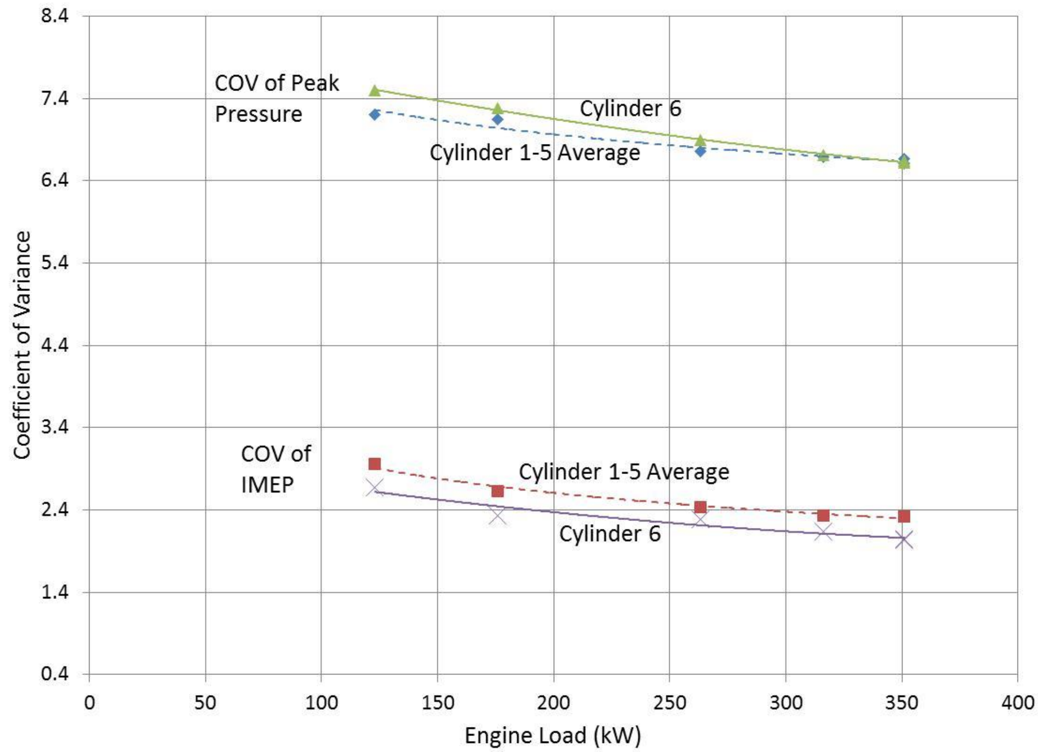

Figure 41. COV's of IMEP and Peak Pressure vs. Engine Load @ 1800 RPM.

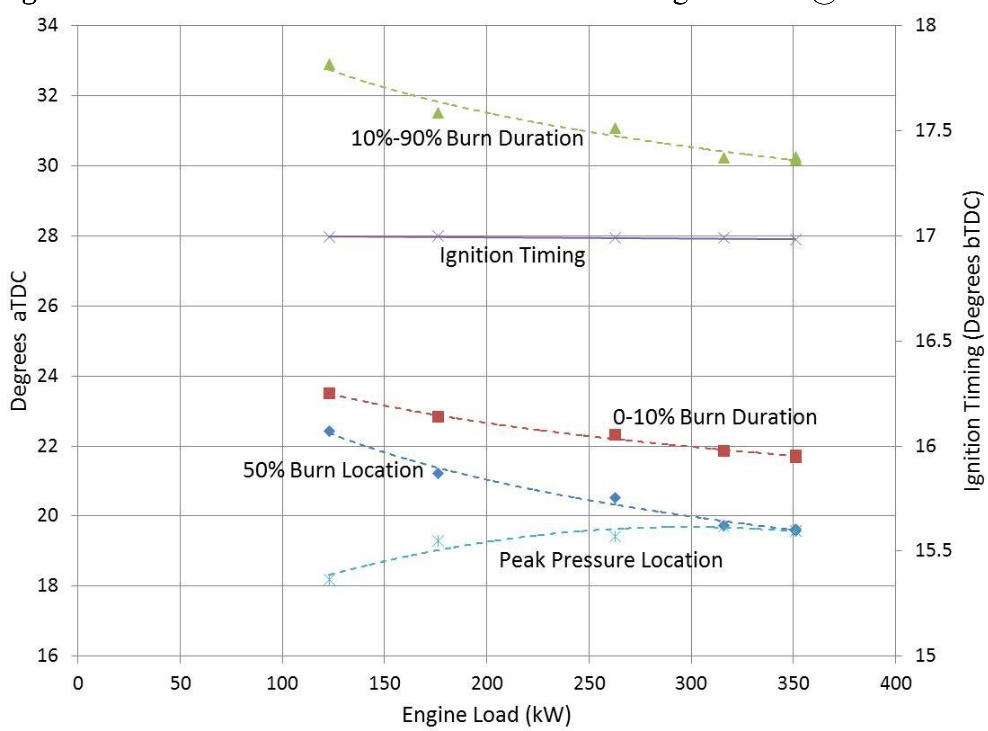

Figure 42. Cylinders 1-5 Average Combustion Data vs. Engine Load @ 1800 RPM.

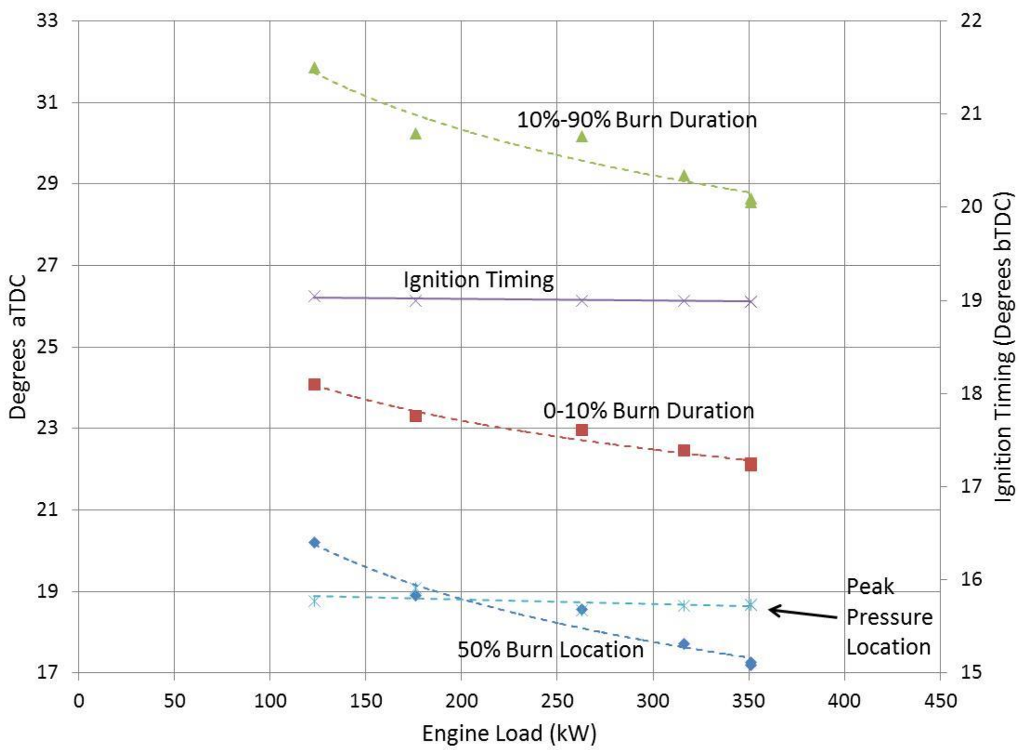

Figure 43. Cylinder 6 Combustion Data vs. Engine Load @ 1800 RPM.

Figure 32 and Figure 38 show the trends of brake thermal efficiency and brake specific fuel consumption for 1500 and 1800 RPM respectively. These trends are consisted with normal engine performance. As the engine load is increased the thermal efficiency increases and BSFC decreases. The reason for this is explained by the power loss parameters FMEP and PMEP. At low engine load FMEP and PMEP are larger fractions of shaft power than at high load. Figure Figure 33 and Figure 39 highlight the changes in FMEP and PMEP. At full load FMEP and PMEP are approximately 10% of shaft power while closer to 25% at low engine load. Another trend that is seen is increasing combustion stability with increasing engine load. The burn durations decrease as engine load increase which decreases the COV of IMEP and PP. The decrease in THC emissions also indicates more complete combustion. More effective combustion helps increase the thermal efficiency at high loads as well. The engine was tested in closed loop air to fuel ratio control to maintain a NO_x set point of 1 g/BHP-hr. Figure 34 and

Figure 40 shows that the closed loop control does not decrease the air to fuel ratio enough to hold the NO_x level constant at lower loads.

Chapter 4 – Lean Limit Test Data

4.1 Summary

The goal of the lean limit engine test was to investigate how the engine operates when the air to fuel ratio is increased beyond the normal operating point of the engine. The first test was conducted in September of 2012 which included both 1500 RPM and 1800 RPM equivalence ratio sweeps at 100% load. The second test was a few months later in December of 2012 and included two equivalence ratio sweeps at 50% load for two different fuel compositions with a controlled methane number and without methane number control.

4.2 Test Plan

The initial test plan consisted of an equivalence ratio sweep at 100% load at 1800 RPM. In order to change the equivalence ratio, the parameter C_LMDOFF in Calterm was adjusted. Before the parameter could be changed, the ECM was switched to open loop control. Once in open control, the parameter C_LMDOFF was increased by the specified value in the test plan. When C_LMDOFF is increased, the equivalence ratio decreases and takes the engine closer to the lean limit. The lean limit was described by Cummins as the point where COV IMEP becomes greater than 5% or the engine cannot maintain speed and load. In this test procedure, the engine was unable to maintain speed before achieving a COV of IMEP greater than 5%. Six complete data points were recorded during the equivalence ratio sweep with equal steps in varying C_LMDOFF.

The 1500 RPM testing was conducted using the same process. The engine was started and taken to rated speed and load. Next, the NO_x was tuned in closed loop control. Following NO_x tuning, the load sweep was performed with the same data point length and load increments as the 1800

RPM test. The only difference between the equivalence ratio sweep for the 1500 RPM test was how the equivalence ratio was varied. The engine would not maintain stability when adjusting C_LMDOFF in open loop control. The engine was switched back to closed loop control and the parameter C_TBOFF was used to vary equivalence ratio. This parameter has an opposite effect on equivalence ratio; when C_TBOFF is decreased, the equivalence ratio also decreases moving towards the lean limit. The 1500 RPM test also reached a point where the engine speed could not be maintained before the COV of IMEP became greater than 5%. Six complete data points were recorded during the 1500 RPM equivalence ratio sweep with equal steps of C_TBOFF.

Because the engine was unable to maintain load at leaner conditions, the equivalence ratio sweep was repeated at 50% load. The secondary test was only carried out at 1800 RPM. The test procedure was identical to the first sweep.

4.3 Results and Discussion

The 100% load equivalence ratio sweep data is summarized for both 1500 and 1800 RPM in Figure 44-Figure 53. The Figures include brake specific emission, average burn locations and durations for cylinders 1-5, average burn locations and durations for cylinder 6, BTE, BSFC, and COV's of IMEP and peak pressure. All parameters are plotted versus equivalence ratio. The combustion data from cylinders 1-5 was averaged together because all share the same ignition timing. Cylinder 6 combustion data was kept separate because the timing is advance by 2 degrees for knock detection. Figure 44 - Figure 48 are for 1500 RPM and Figure 49 - Figure 53 are for 1800 RPM.

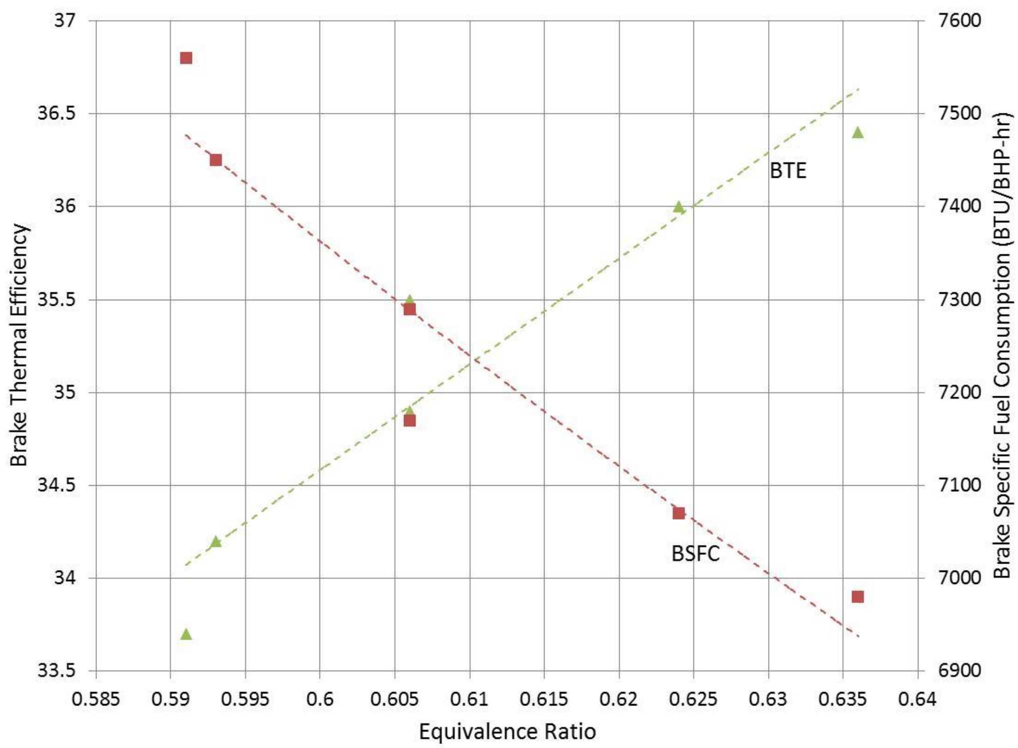

Figure 44. BTE and BSFC vs. Equivalence Ratio @ 1500 RPM.

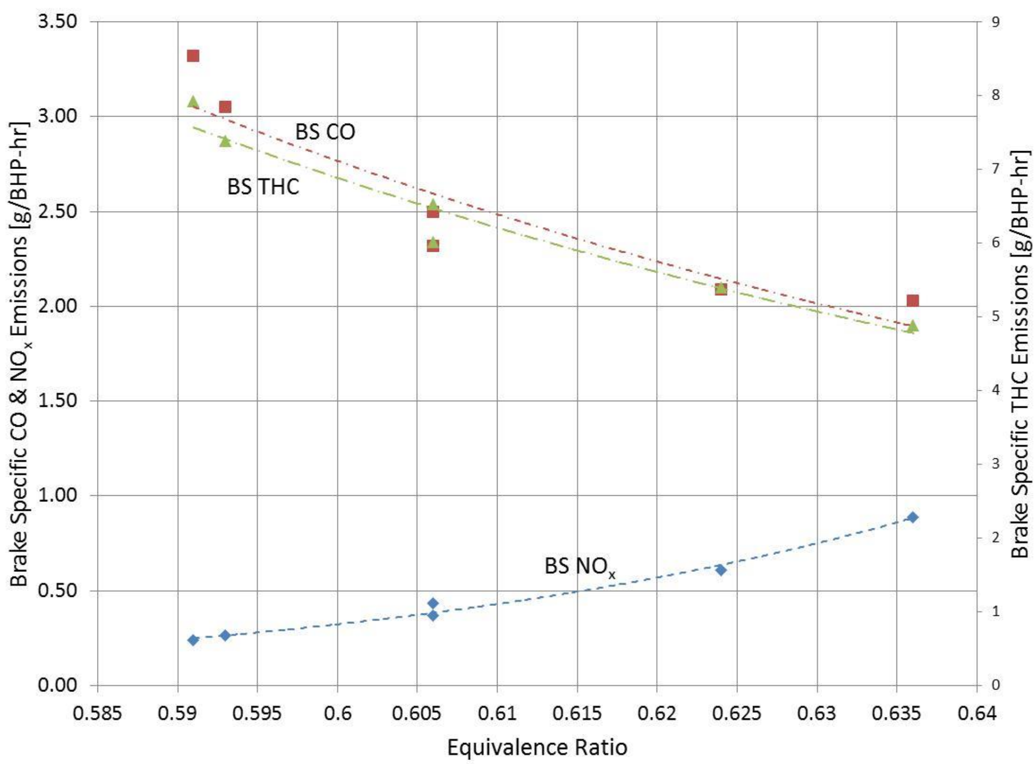

Figure 45. Brake Specific Emissions vs. Equivalence Ratio @ 1500 RPM.

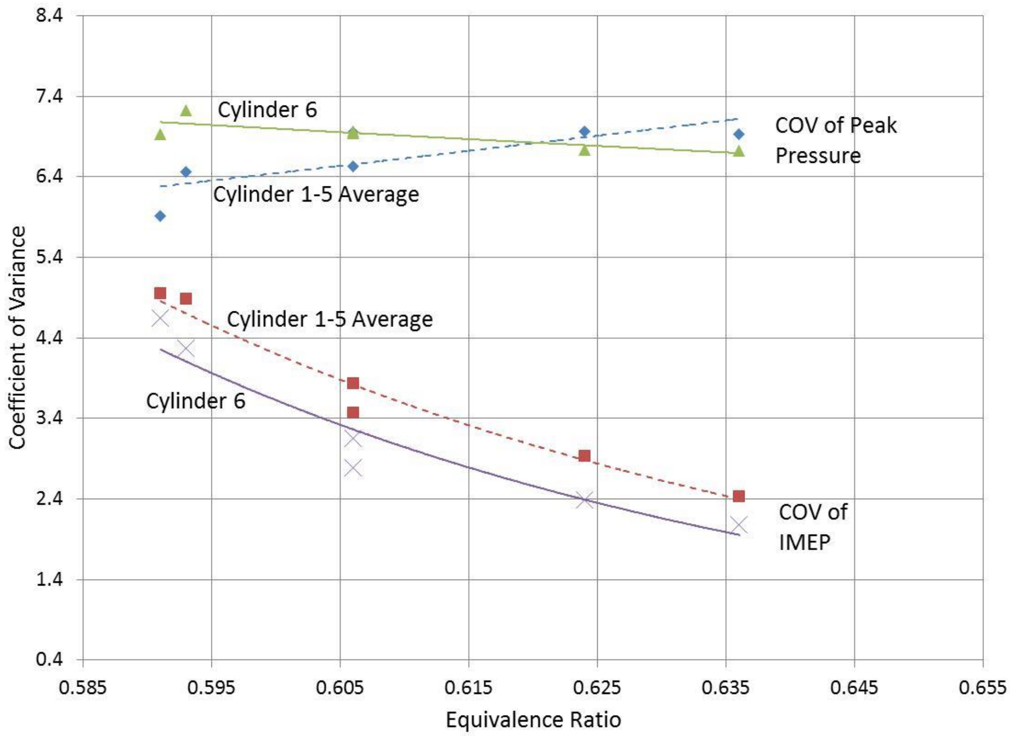

Figure 46. COV's of IMEP and Peak Pressure vs. Equivalence Ratio @ 1500 RPM.

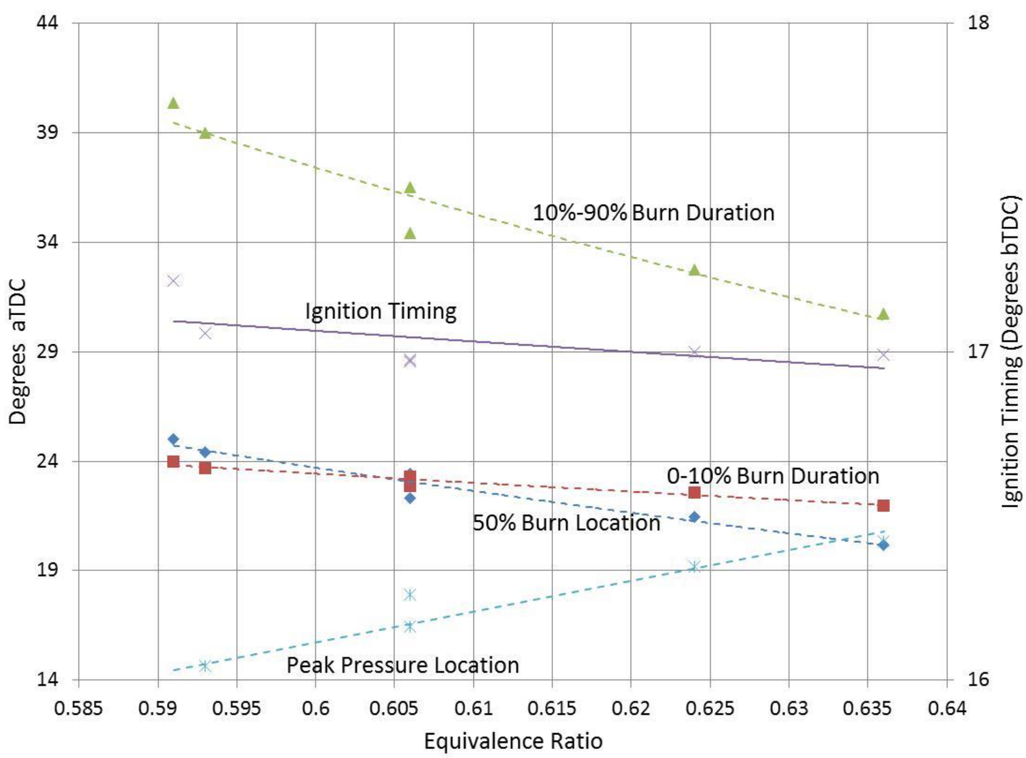

Figure 47. Cylinders 1-5 Average Combustion Data vs. Equivalence Ratio @ 1500 RPM.

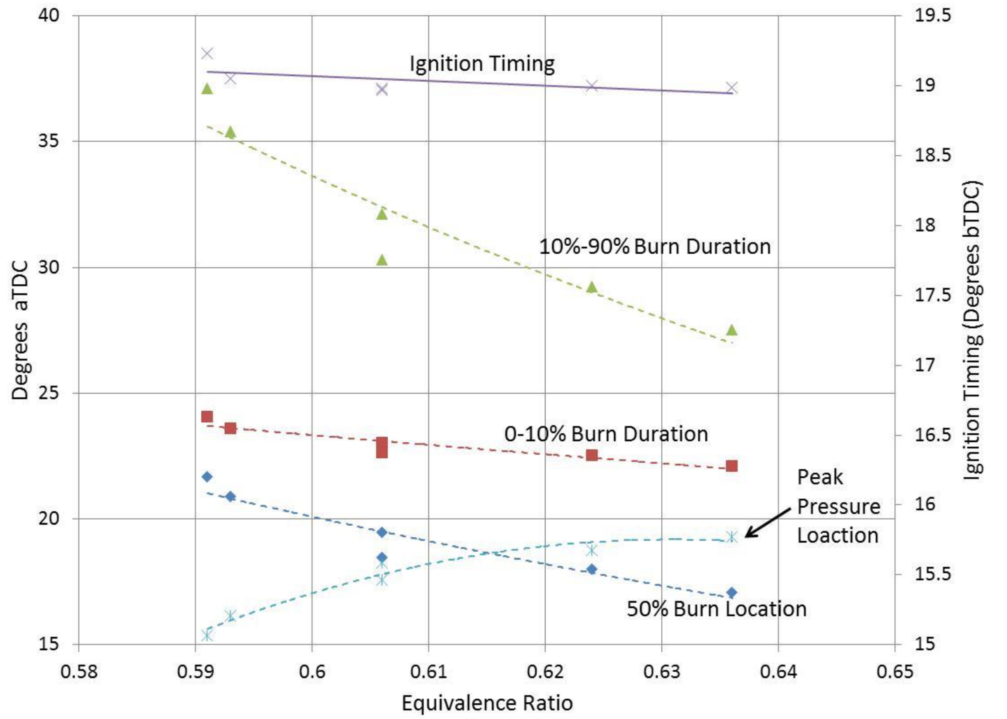

Figure 48. Cylinder 6 Combustion Data vs. Equivalence Ratio @ 1500 RPM.

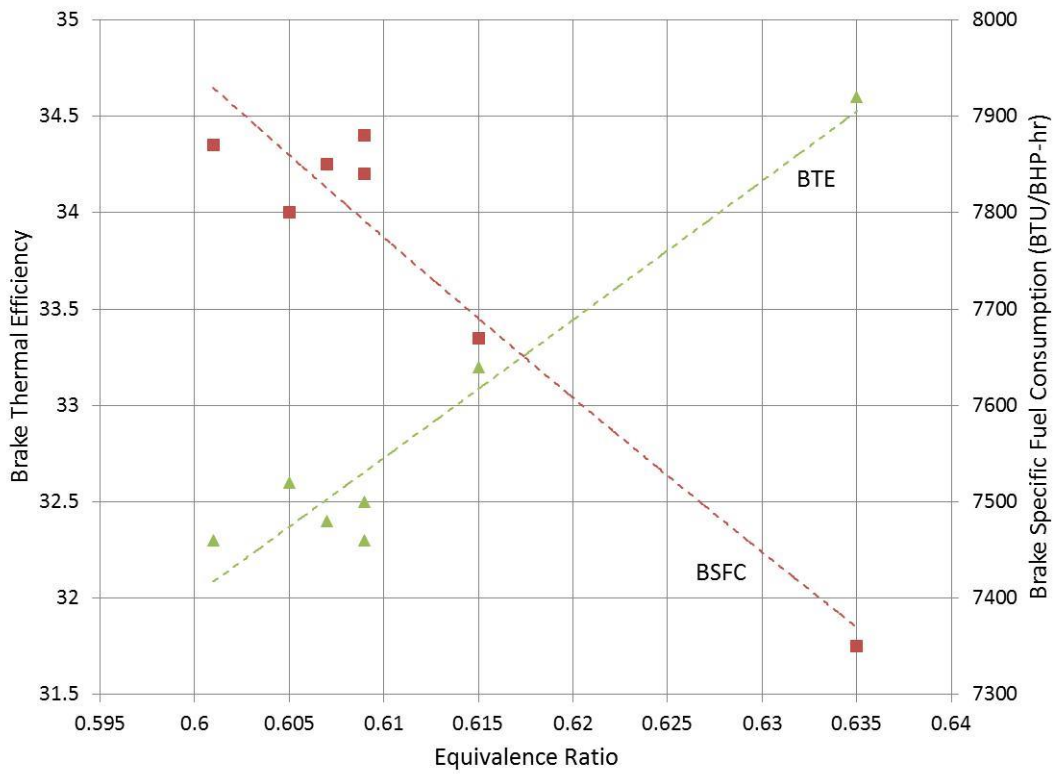

Figure 49. BTE and BSFC vs. Equivalence Ratio @ 1800 RPM.

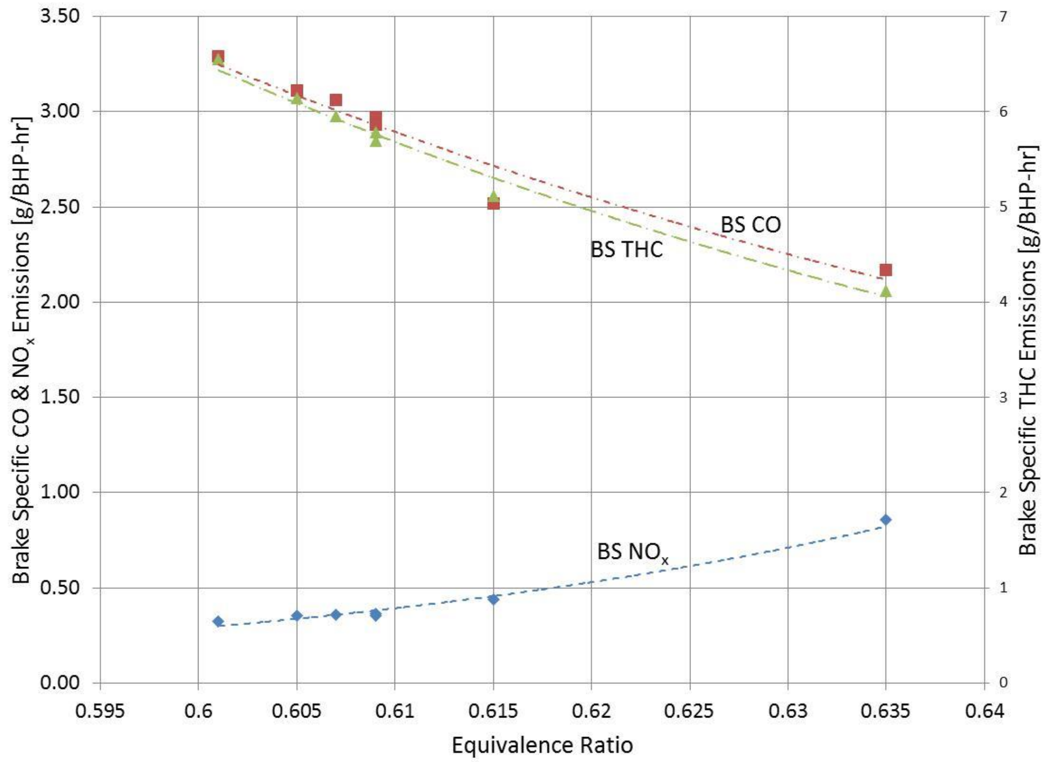

Figure 50. Brake Specific Emissions vs. Equivalence Ratio @ 1800 RPM.

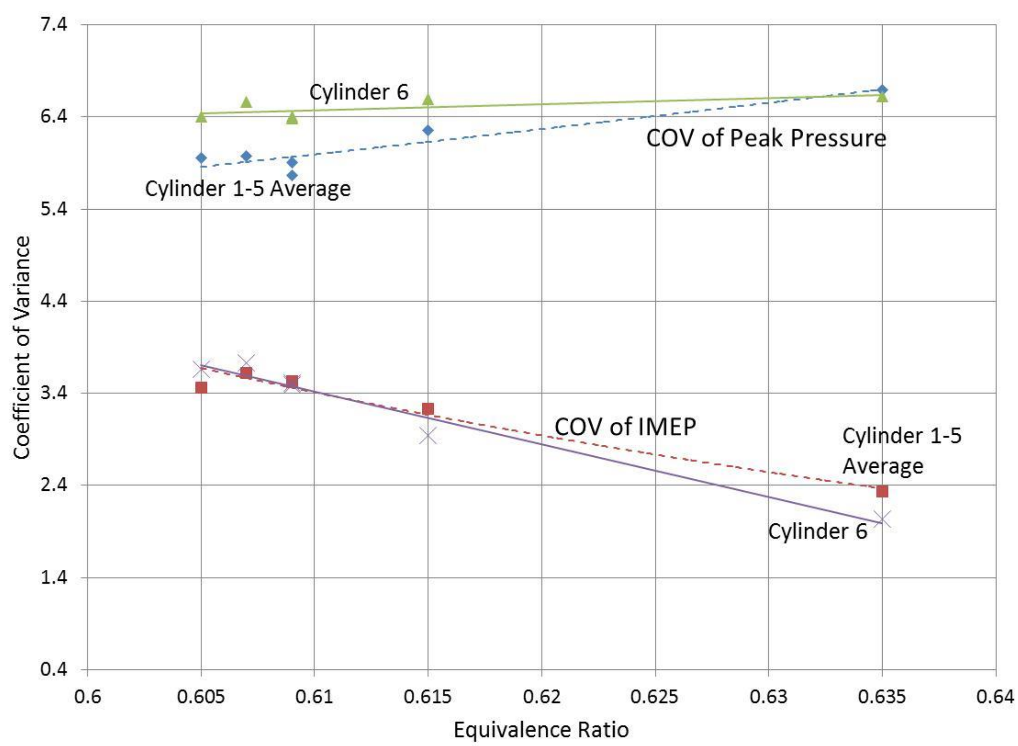

Figure 51. COV's of IMEP and Peak Pressure vs. Equivalence Ratio @ 1800 RPM.

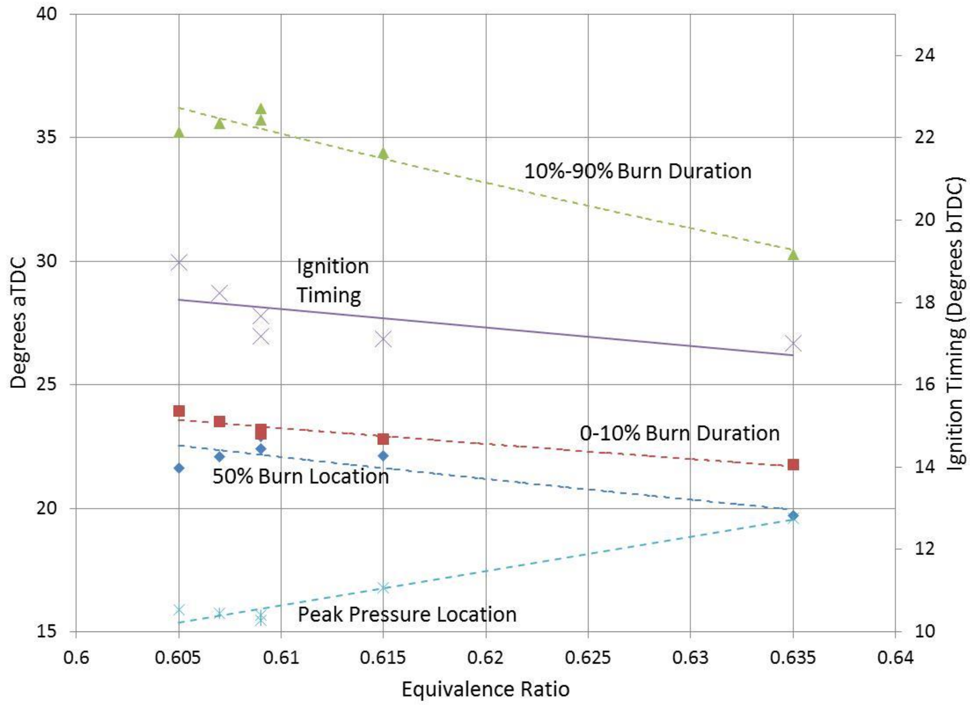

Figure 52. Cylinders 1-5 Average Combustion Data vs. Equivalence Ratio @ 1800 RPM.

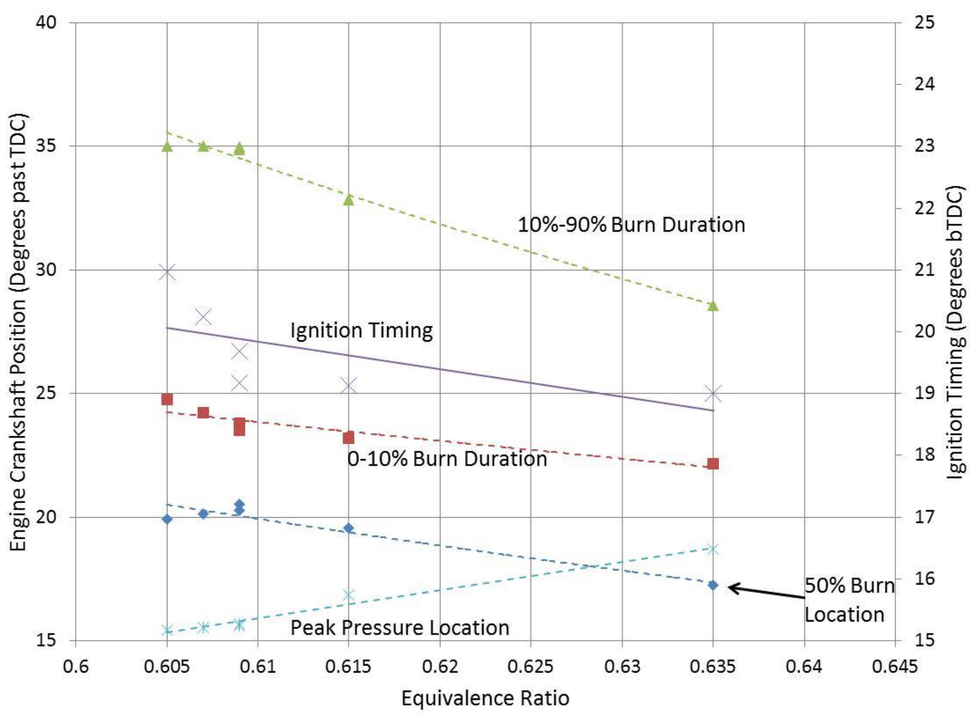

Figure 53. Cylinder 6 Combustion Data vs. Equivalence Ratio @ 1800 RPM.

As stated in the test plan section, at very lean operating conditions, the engine was unable to maintain speed for both 1500 RPM and 1800 RPM. The reason for the engine losing speed is due to insufficient air flow. As the equivalence ratio was decreased, the only way to maintain the same power output was to increase the mass flow of air into the engine. Once the throttle was completely open and the turbocharger was performing at its maximum capacity, the only way to continue to decrease equivalence ratio was to decrease the mass flow rate of fuel. Figure 54 clearly shows that the throttle is 100% open at the leanest point in the test (when the equivalence ratio was 0.605). The combination of decreased thermal efficiency and burning less fuel caused the power output of the engine to decrease. Because the dynamometer maintains a constant torque the engine speed decreased to follow the decrease of engine power output. One thing that may have allowed for leaner operating conditions would be referencing the waste gate to the inlet air pressure. The inlet air pressure is higher than ambient conditions causing the wategate, which is referenced to ambient conditions, to open sooner than it would at sea level. If the wategate was referenced to the inlet air conditions, intake manifold pressure would have been able to reach slightly higher values.

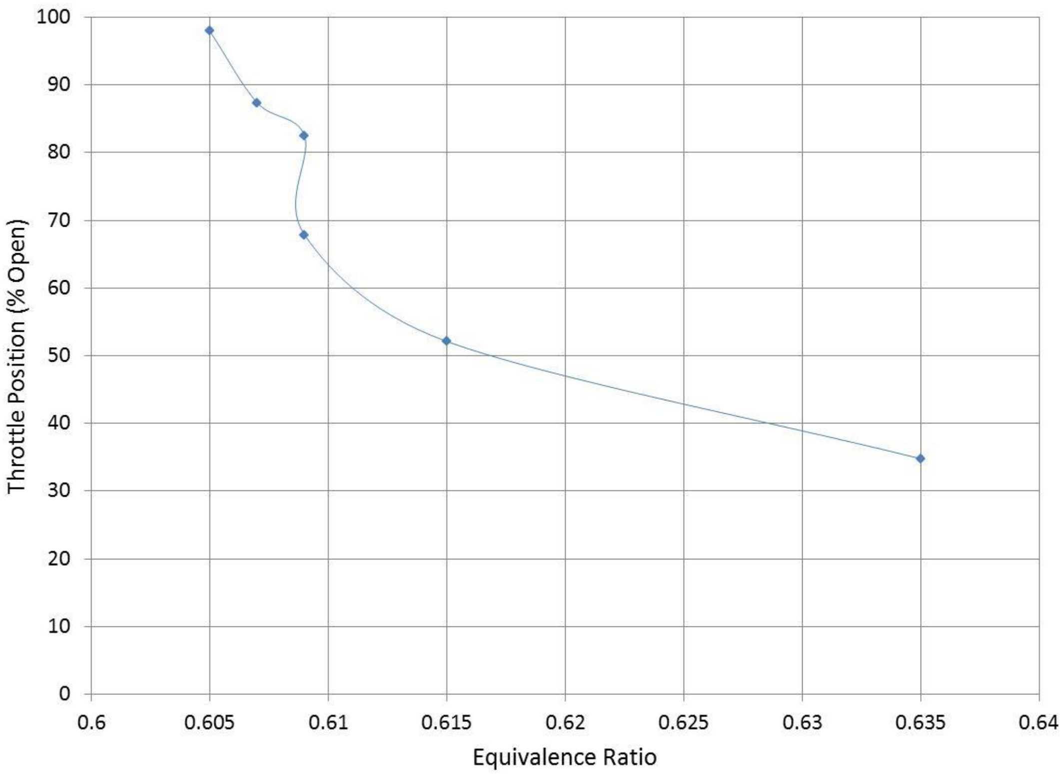

Figure 54. Throttle Position vs. Equivalence Ratio at 1800 RPM.

The emissions trends for both 1500 and 1800 RPM show the effects of equivalence ratio on combustion temperature and stability. As equivalence ratio is increased, NO_x increases due to increased combustion temperature, and THC and CO emissions decrease because combustion stability increases. One point in the 1500 RPM data does not follow the overall trend of the data. This point is the 170 kW point in the 1500 RPM load sweep. For this point, the BSCO and $BSNO_x$ are both low and the BSTHC is high. Also, the COV of IMEP and PP are lower for this point than where the trend would predict the values. All of the burn durations and locations occur later than the trend except for the location of peak pressure. The cause of this point varying from the overall trends is unclear.

The 1500 RPM, 300 kW point in the load sweep has much higher COV values than the rest of the data points. This was most likely caused by speed surging in the engine. The speed surging issue also caused the COV's for all of the 1500RPM data to be greater than the 1800 RPM overall. The engine is runs much more stable at 1800 RPM.

It was believed that due to cylinder 6 having 2 degree advanced timing that it would display higher COV values because flame propagation is slower and less likely in cooler mixture, but the values were shown to actually be lower in cylinder 6 than the cylinder 1-5 average. This may be caused by better "breathing" so the residual fraction and turbulence is better.

The 50% load equivalence ratio sweep data is summarized for 1800 RPM in Figure 55-Figure 64. The Figures include brake specific emission, average burn locations and durations for cylinders 1-5, average burn locations and durations for cylinder 6, BTE, BSFC, and COV's of IMEP and peak pressure. All parameters are plotted versus equivalence ratio. The combustion data from cylinders 1-5 was averaged together because all share the same ignition timing. Cylinder 6 combustion data was kept separate because the timing is advance by 2 degrees for knock detection. The first five figures are for closed loop methane number (MN) fuel control and Figure 60-Figure 64 are for pipeline natural gas. The closed loop MN fuel control resulted in an average MN of 64.4 with a standard deviation of 1.39. The pipeline natural gas had amuch higher average MN of 89.5 with a standard deviation of 2.83.

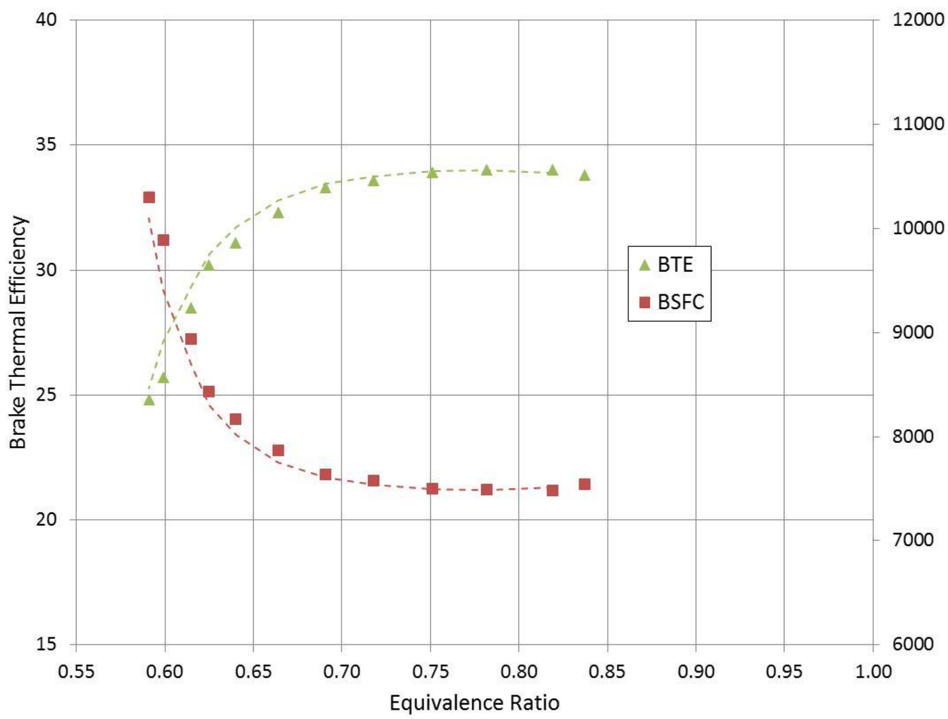

Figure 55. BTE and BSFC vs. Equivalence Ratio with MN Control.

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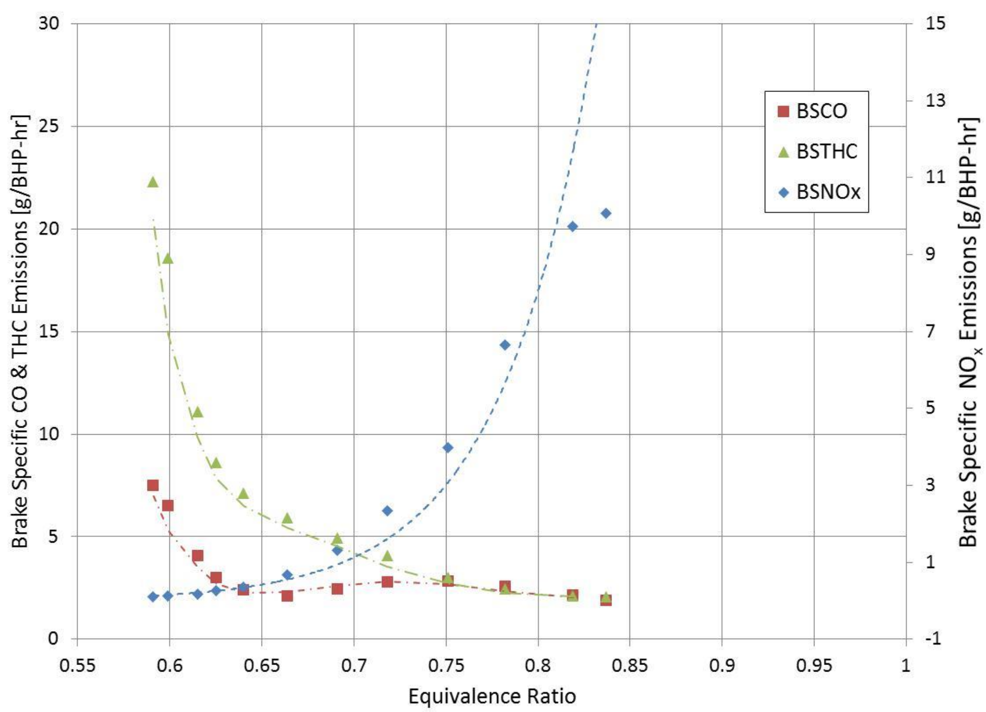

Figure 56. Brake Specific Emissions vs. Equivalence Ratio with MN Control.

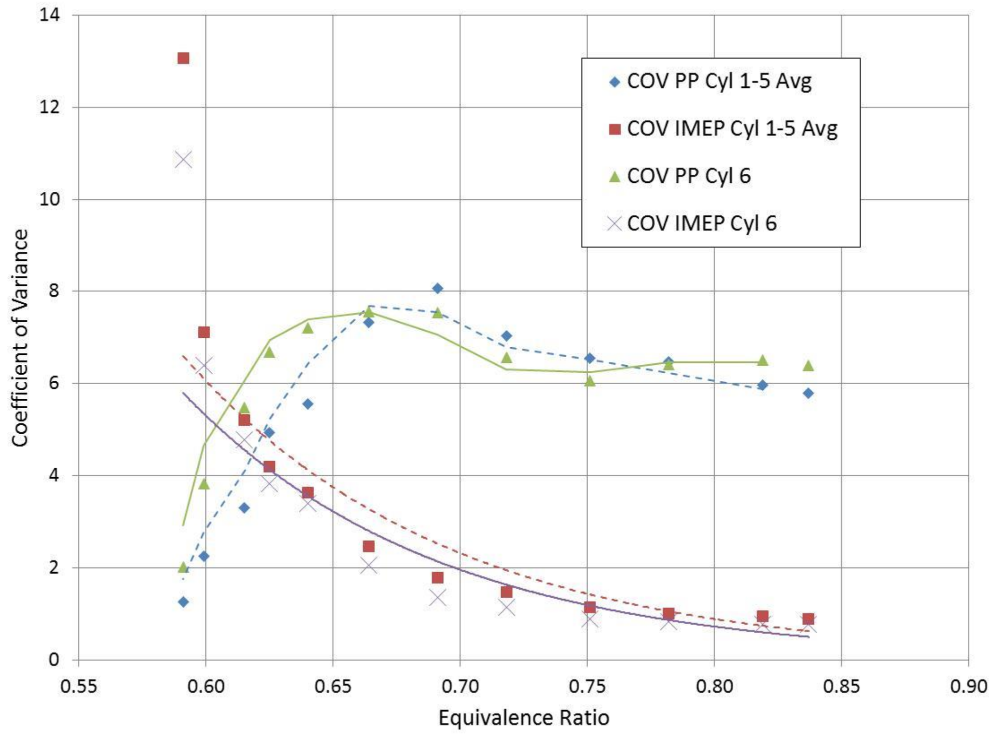

Figure 57. COV's of IMEP and Peak Pressure vs. Equivalence Ratio with MN Control.

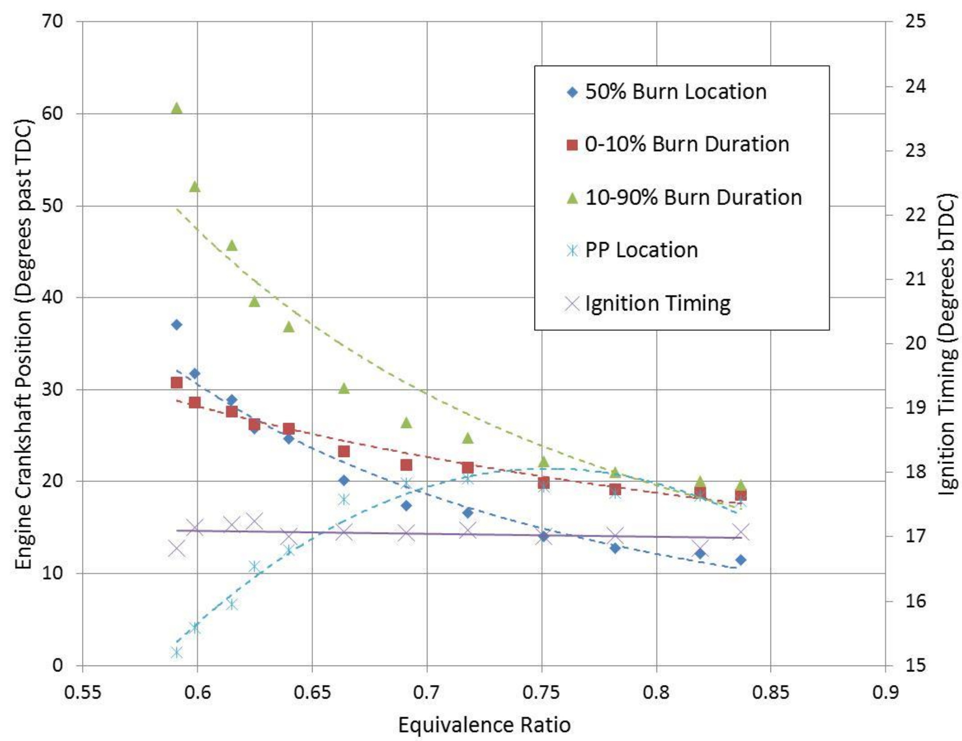

Figure 58. Cylinders 1-5 Average Combustion Data vs. Equivalence Ratio with MN Control.

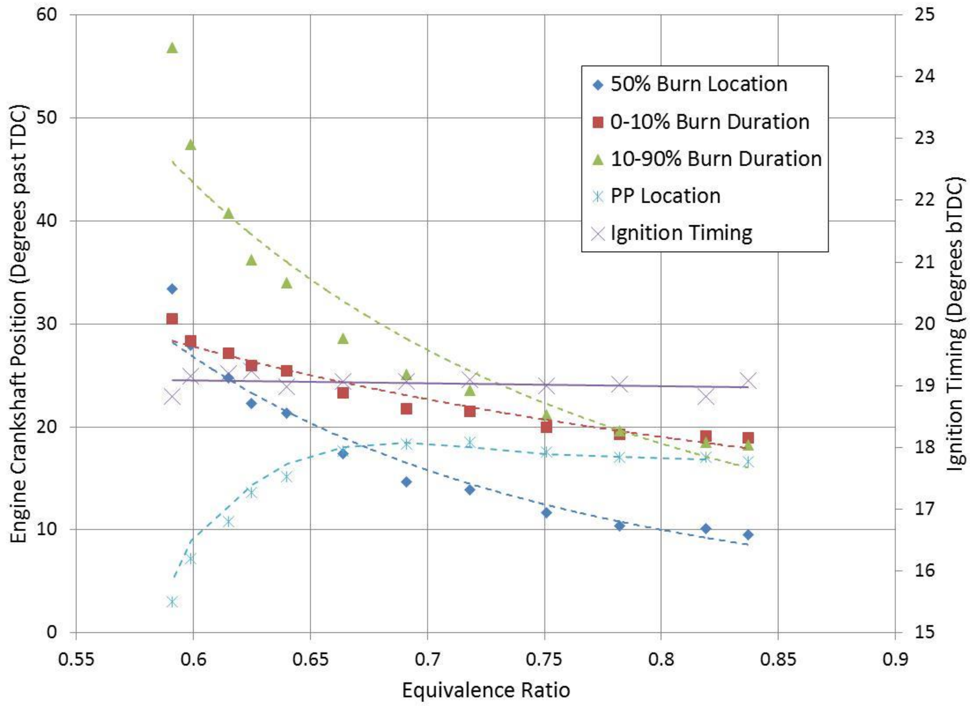

Figure 59. Cylinder 6 Combustion Data vs. Equivalence Ratio with MN Control.

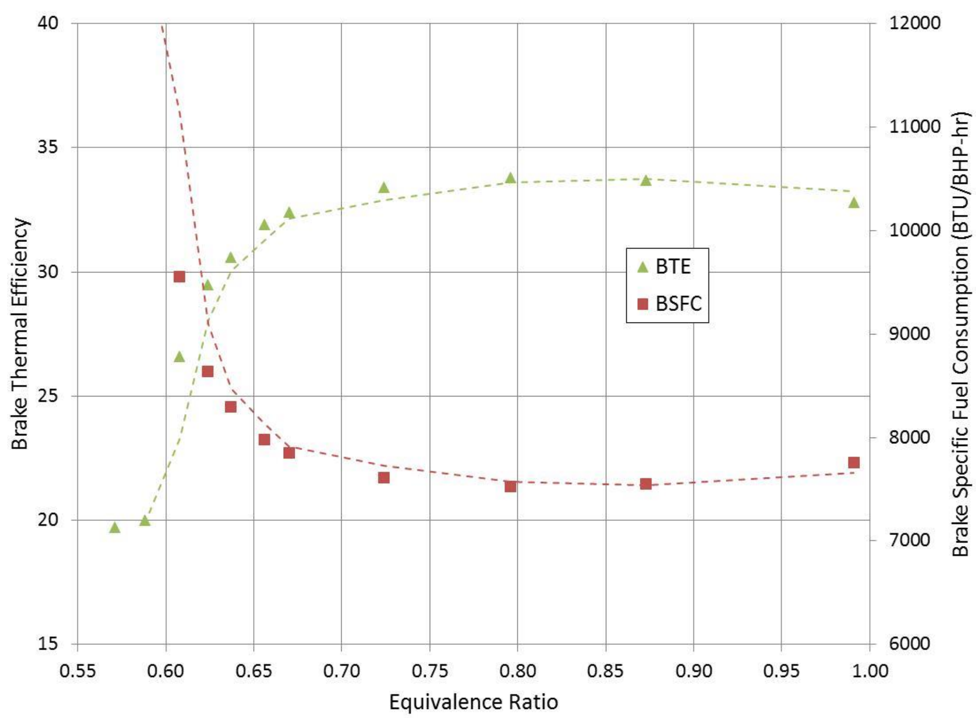

Figure 60. BTE and BSFC vs. Equivalence Ratio without MN Control.

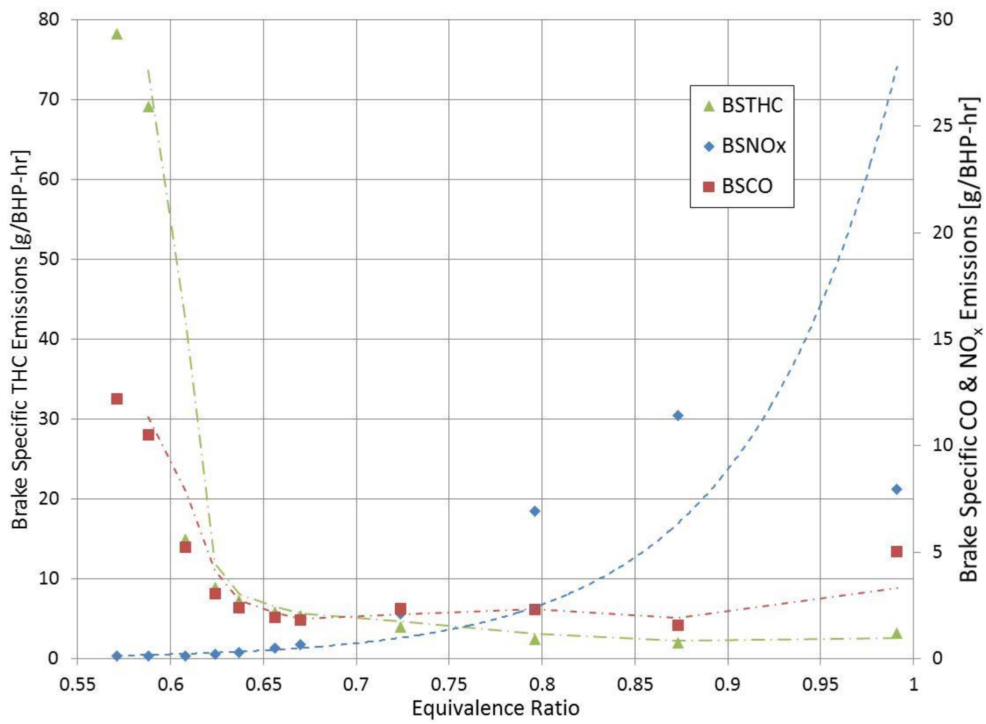

Figure 61. Brake Specific Emissions vs. Equivalence Ratio without MN Control.

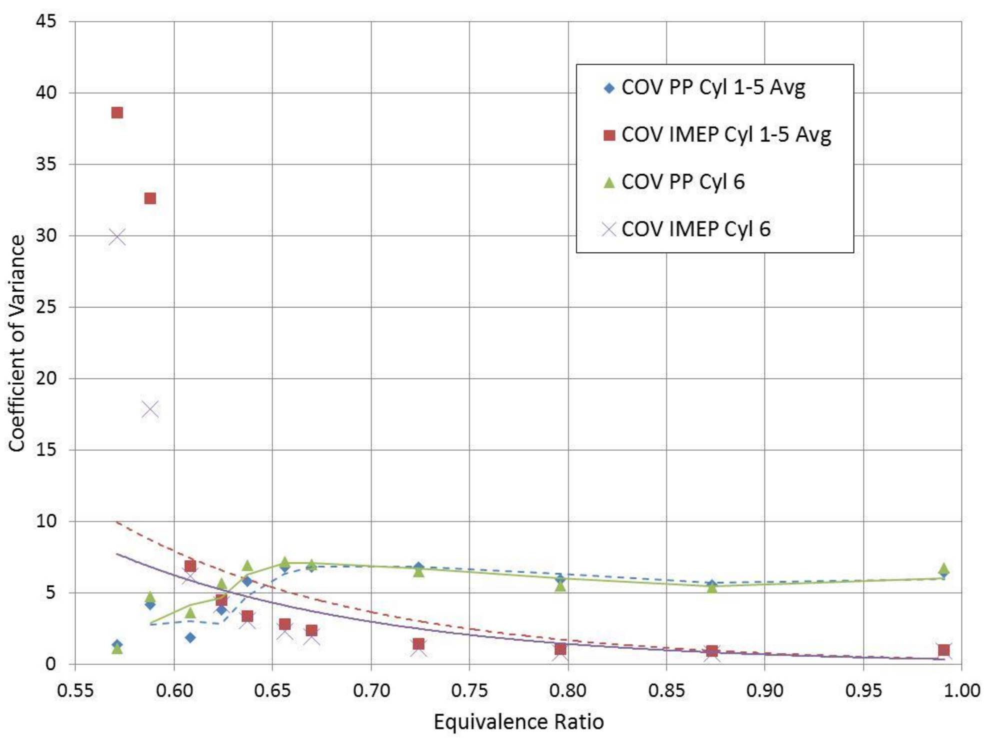

Figure 62. COV's of IMEP and Peak Pressure vs. Equivalence Ratio without MN Control.

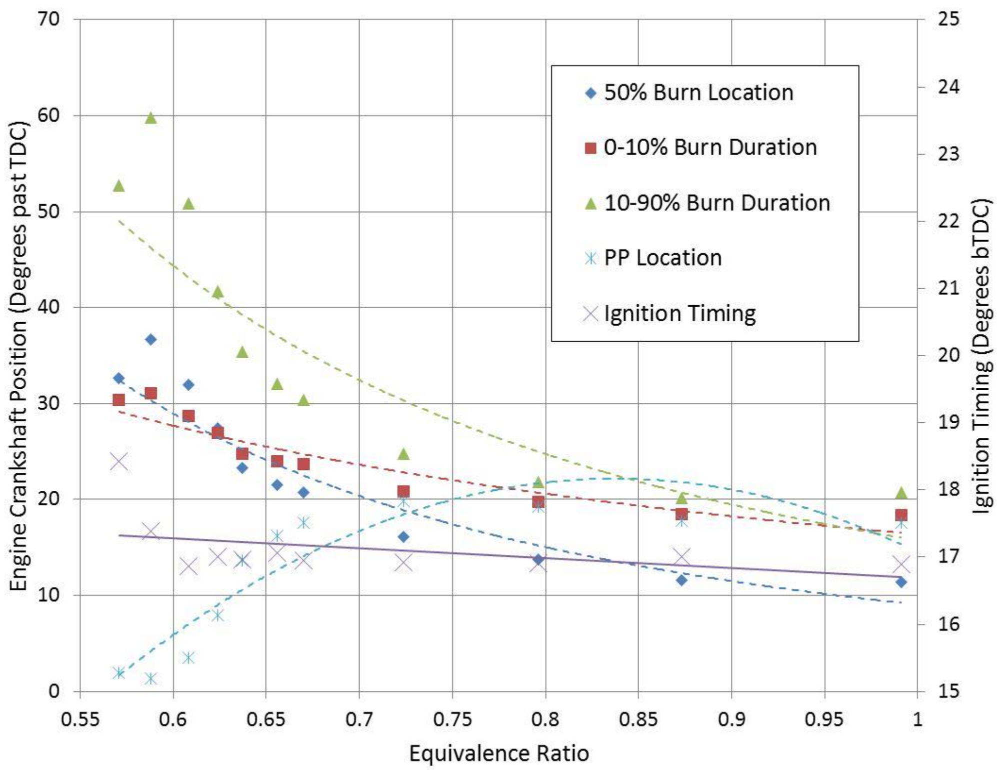

Figure 63. Cylinders 1-5 Average Combustion Data vs. Equivalence Ratio without MN Control.

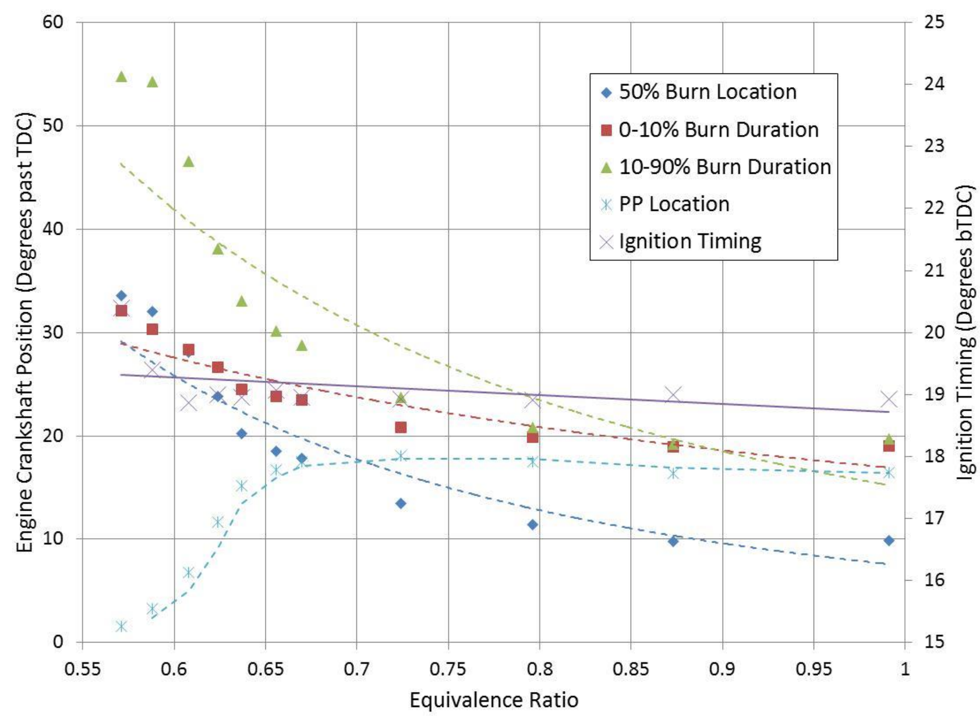

Figure 64. Cylinder 6 Combustion Data vs. Equivalence Ratio without MN Control.

Because the load was reduced to 50% for the third and fourth equivalence ratio sweeps, the problem of insufficient air flow causing speed to drop was not experienced. The equivalence ratio range was much larger for the final two sweeps as well, ranging from 0.571 to 0.991. The rich side of the sweep is limited by increasing exhaust port temperature and the onset on knock. The equivalence ratio was not increased to levels that cause those problems. The area of interest was exploring the lean limit of the engine as well as showing that the engine has an optimum air to fuel ratio that results in the maximum thermal efficiency. The highest thermal efficiency occurred at an equivalence ratio of approximately 0.8 for both sweeps. There is a gradual decrease as phi moves towards stoichiometric due to higher combustion temperatures. There is a dramatic decrease in BTE as phi moves lean and COV of IMEP increases. The sweep using a controlled methane number reported a maximum thermal efficiency of 34%, just higher than the pipeline test at 33.8%.

With the extra air capacity at 50% load, the lean combustion area was explored much deeper than at 100% load. The lean limit as defined by a COV of IMEP greater than 5% was shown to occur at a phi equal to 0.615 for methane number control and 0.625 for uncontrolled methane number. The equivalence ratio was lowered until COV's of IMEP were much higher than the previous threshold of 5%. COV's of IMEP went as high as 39%. This was an extreme value experienced at the leanest point in the sweep without methane number control. The reason for the high COV is due to misfires mainly in cylinder 5. Cylinder 5 was firing sporadically. Figure 65 summarizes the event of cylinder 5's performance. At an equivalence ratio of approximately 0.608 the exhaust port temperature of cylinder 2 drops off significantly. Another parameter that identifies severe misfire of the engine is the rapid spike in THC. More un-burned fuel passed through the engine explaining the increase in THC. Also at this same point, the COV's of IMEP and throttle position spike upward. All three changes are related to the loss of Cylinder 5. When Cylinder 5 quit firing, the remaining 5 cylinders had to produce the required power to maintain load which explains the rapid increase in throttle position.

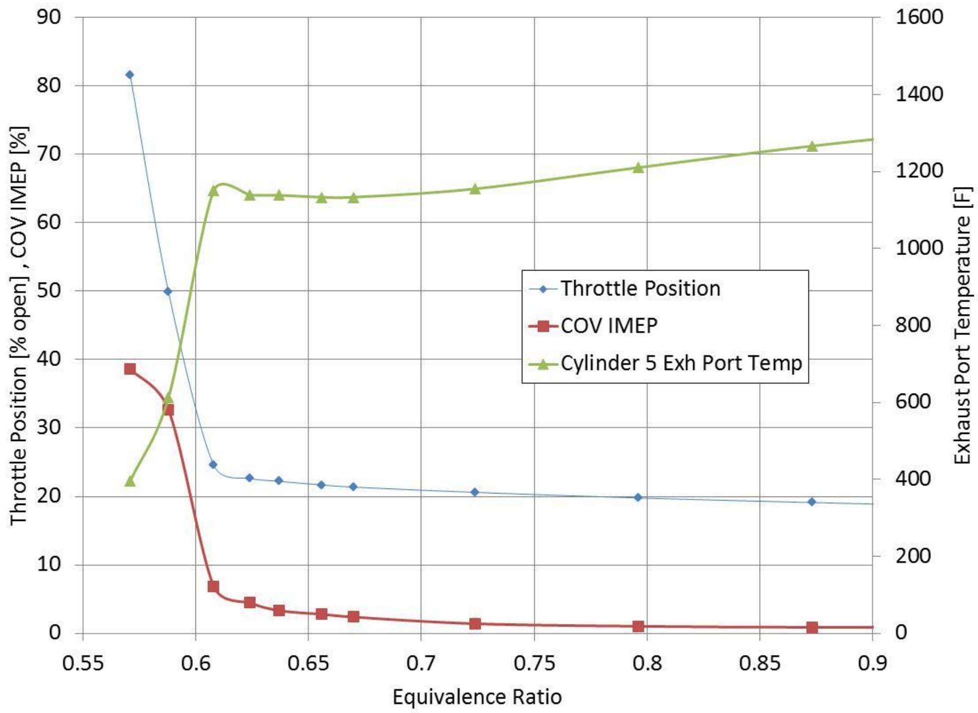

Figure 65. Cylinder 5 Event Summary under strong misfire.

Another trend shown in the data is a common minimum of exhaust port temperatures around an equivalence ratio of 0.65. As equivalence ratio decreases from stoichiometric, exhaust port temperature decrease due to excess combustion air. The combustion stability is also declining shown by a gradual increase in COV of IMEP. An equivalence ratio of 0.65 represents the point where the decline in combustion stability overcomes the benefit of excess air and actually causes exhaust port temperature to increase slightly before the lean limit is reached. The average burn locations are occurring so late at these lean conditions that the port temperatures rise. Figure 66 and Figure 67 show the exhaust port temperatures for both sweeps with and without methane number fuel control.

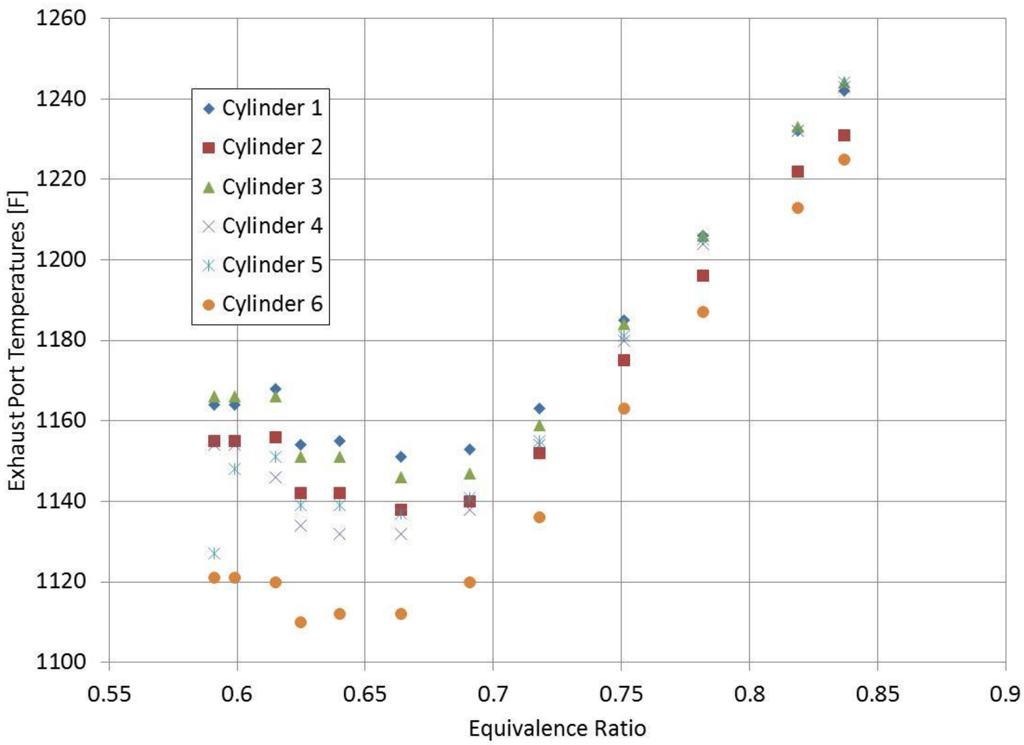

Figure 66. Exhaust Port Temperatures vs. Equivalence Ratio with MN Control.

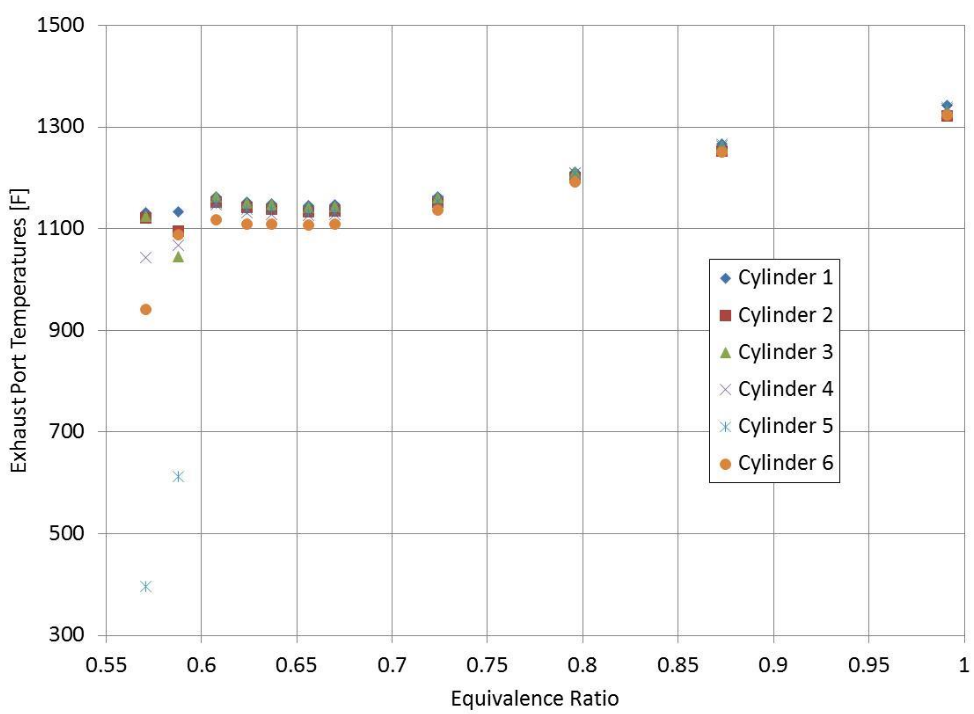

Figure 67. Exhaust Port Temerperatures vs. Equivalence Ratio without MN Control.

The similar shape of the 10-90% burn curve and COV of IMEP curve proves the effectiveness of using the COV of IMEP to determine the lean limit. Increased burn durations indicate declining combustion stability and are accompanied with a spike in COV of IMEP. Cylinder pressure data is not common in normal engine application, presenting a problem with this method. The best method for field testing lies in specifying a threshold quantity of THC's in the exhaust stream. The measurement also increases as combustion stability declines and can be measured with a portable emissions sampling device.

Chapter 5 – Low Viscosity Oil Test Data

5.1 Summary

The goal for the low viscosity oil testing was to quantify and understand the effects of two different oil viscosities. The engine used for testing was a Cummins QSK19G. Data collected during the oil testing was compared to the data from the baseline testing. The engine was running with the OEM oil during the baseline testing allowing for a direct comparison of the effects of the different weight oils under consideration in the lube oil testing.

5.2 Test Plan

The lube oil testing began on September 5, 2012 and was concluded on September 13, 2012. The first step was to drain the OEM engine oil and fill the engine with SAE-40 oil provided by Cummins. The engine was run at 50% load for 20 hours to flush the lubrication system. The oil was then then drained and the oil filters were replaced. After refilling the engine with fresh SAE-40 oil, the 1500 RPM load sweep was performed. The engine was started and taken to 100% load. The NO_x was tuned to the given set point in closed loop control. Next, the load was reduced to 90% and three 2 minute data points were recorded. This process was repeated at 75, 50, and 25% load. After the 1500 RPM load sweep, the 1800 RPM ECM calibration files were downloaded and the above load sweep was repeated for 1800 RPM starting with the NO_x tuning at 100% load.

The SAE-30 testing was performed following the SAE-40 testing. The SAE-40 oil was drained and replaced with SAE-30 oil. Then engine was run for 20 hours to flush the system. After the flush, the filters were replaced and the engine was refilled with fresh SAE-30 oil. The 1800 RPM load sweep was preformed first to reduce the number of ECM calibration downloads. The process was identical to the load sweeps outlined for the SAE-40 oil. The process started with NOx tuning at 100% load followed by the three consecutive data points at each load step.

5.3 Test Results

The test results are summarized below in Figure 68 - Figure 73. Brake thermal efficiency, brake specific fuel consumption, and FMEP are plotted versus load. Each plot contains three data series: Baseline, SAE-30, and SAE-40 oils.

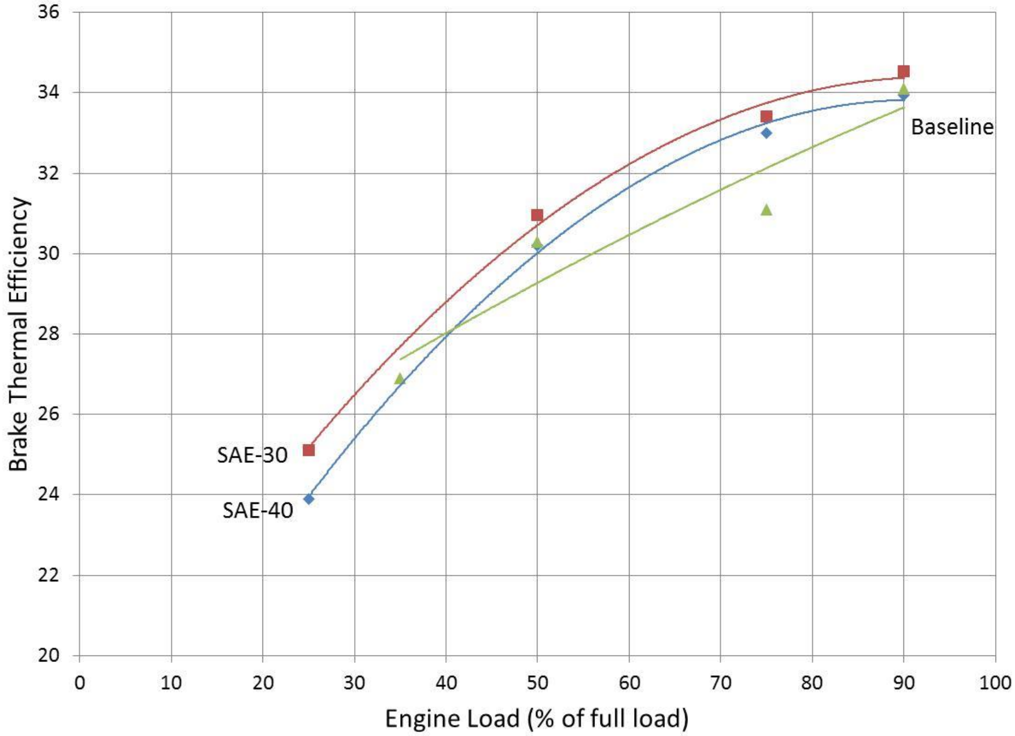

Figure 68. Brake Thermal Efficiency vs. Engine Load @ 1800 RPM.

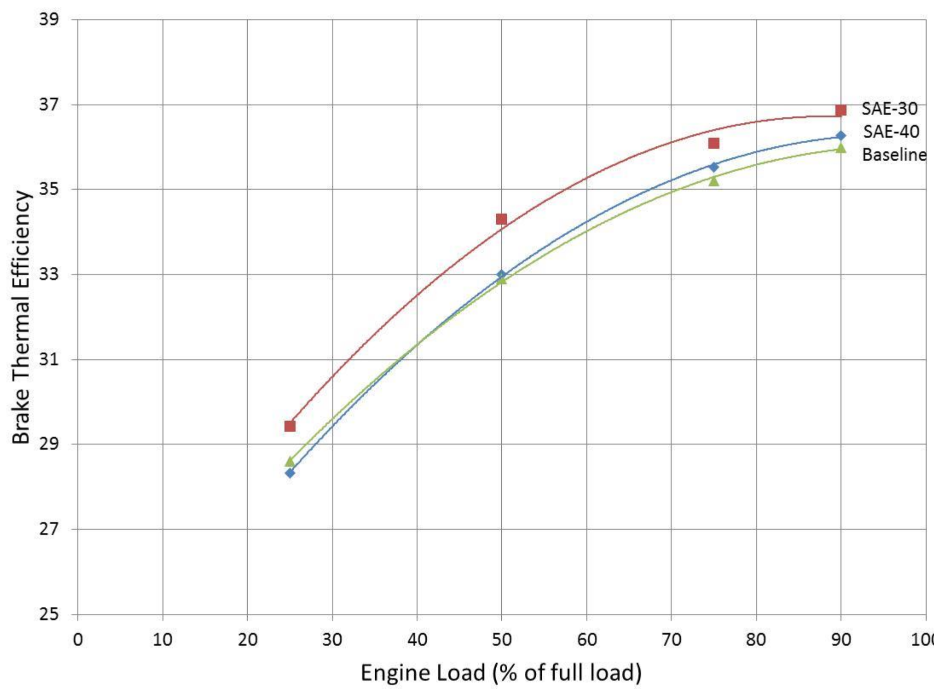

Figure 69. Brake Thermal Efficiency vs. Engine Load @ 1500 RPM.

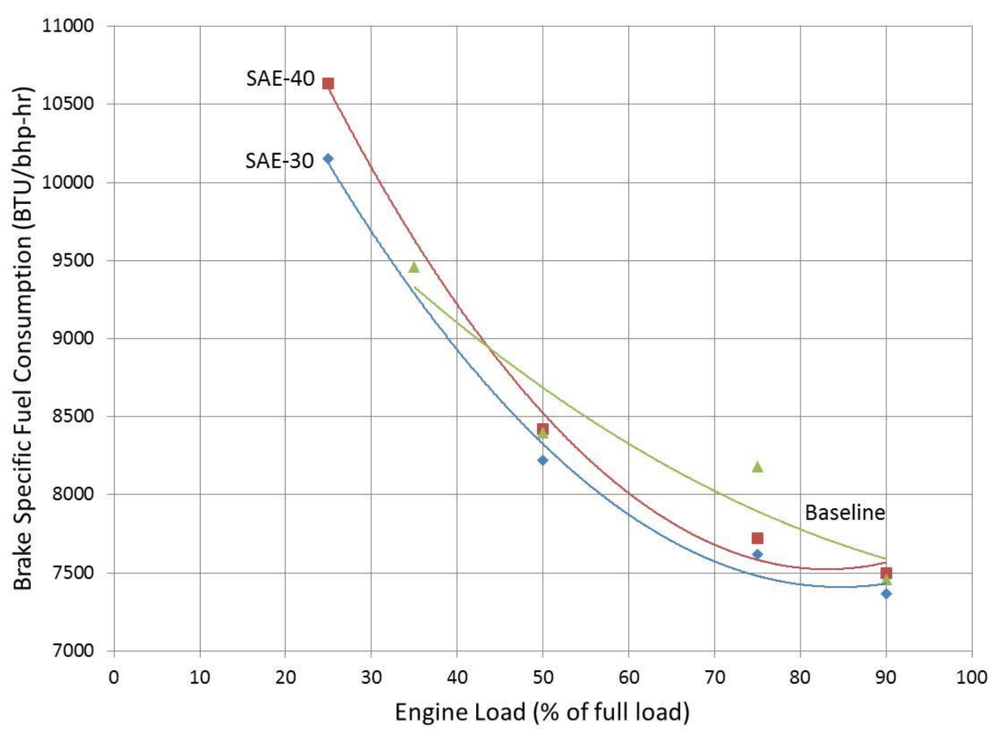

Figure 70. Brake Specific Fuel Consumption vs. Engine Load @ 1800 RPM.

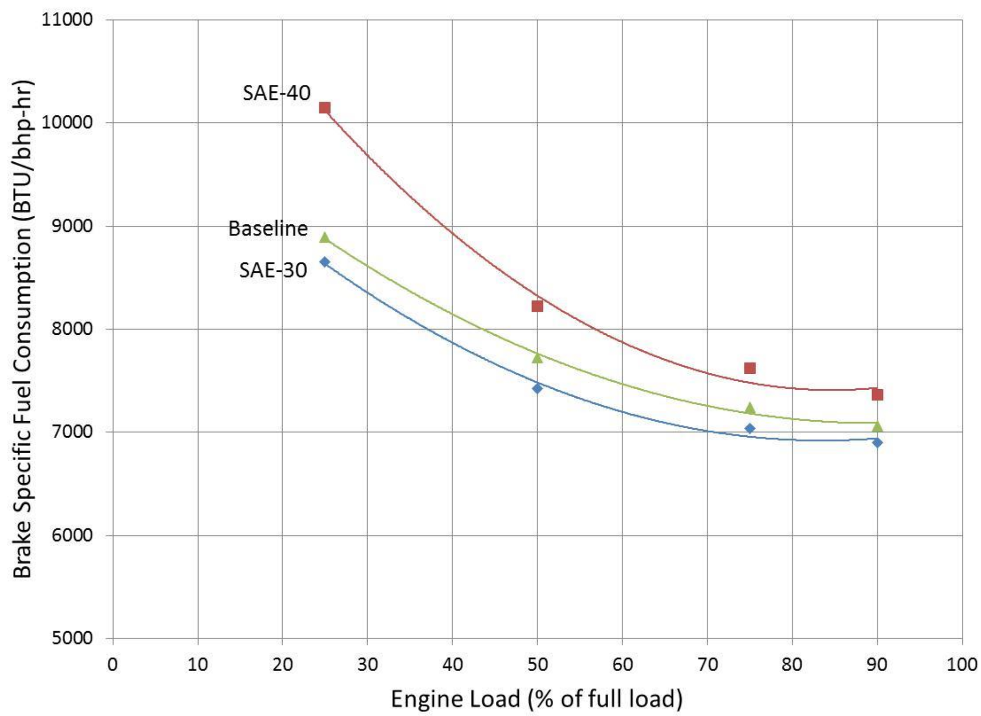

Figure 71. Brake Specific Fuel Consumption vs. Engine Load @ 1500 RPM.

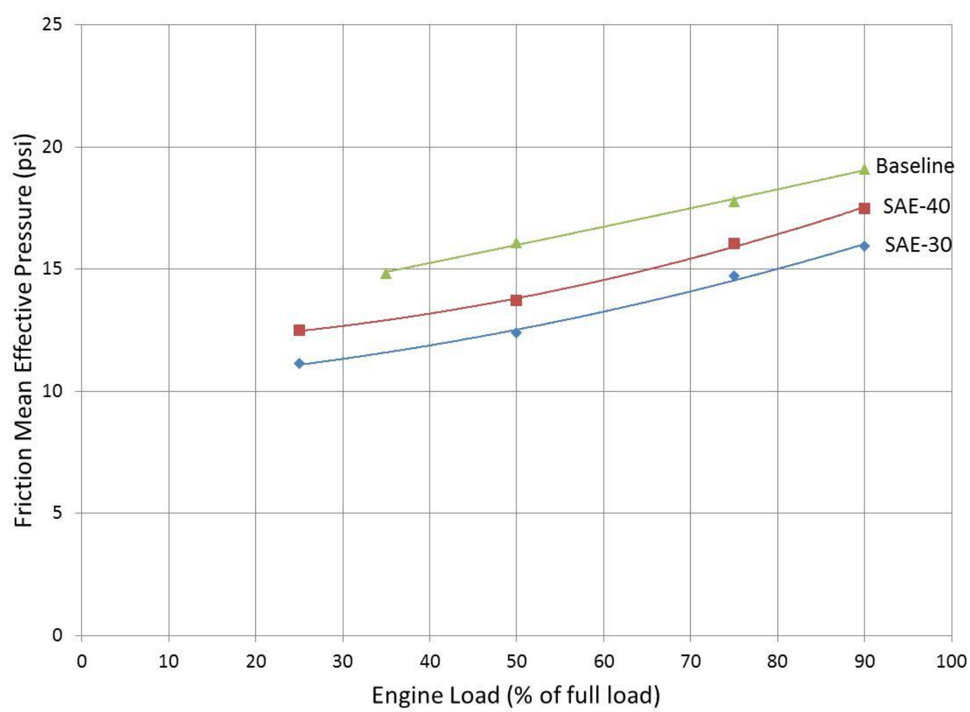

Figure 72. Friction Mean Effective Pressure vs. Engine Load @ 1800 RPM.

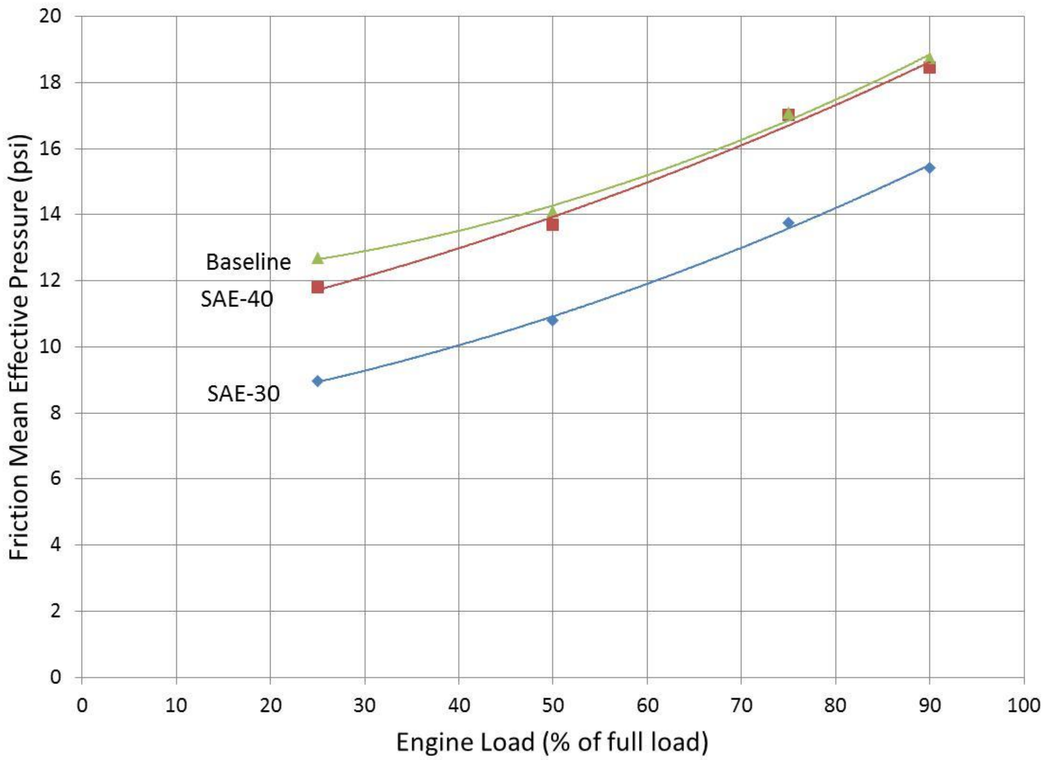

Figure 73. Friction Mean Effective Pressure vs. Engine Load @ 1500 RPM.

5.4 Discussion

The data shows that the engine oil used during the baseline testing has properties closely related to the SAE-40 weight oil. This should be the case because the baseline engine oil is Valvoline Premium Blue 15W-40. Once the baseline engine oil is at operating temperature it should perform as 40 weight oil. The results for the 30 weight oil show a decrease in both FMEP and BSFC while showing an increase in BTE. The FMEP and BSFC for 1500 RPM were reduced on average by 22.5% and 2.9%, respectively. The FMEP and BSFC for 1800 RPM were reduced on average by 18.9% and 3.4%, respectively. This is a direct result of decreased friction from the thinner oil.

The 75% load point in the 1800 RPM test does not follow the overall trend. Both the brake thermal efficiency and brake specific fuel consumption differ. This was caused by engine surging during the data point. The engine throttle is over sized for the application on the QSK19 and therefore small changes in throttle position result in large changes in air flow. The oversized throttle makes it tough for the engine to reach steady state conditions and is what causes the surging effect.

Chapter 6 – Conclusions

The purpose of this paper was to describe in detail the installation process of installing a Cummins QSK19G lean burn natural gas engine as well as present the data obtained from several engine tests. The engine was installed and provided data that matched published data from the manufacturer. The Baseline test data provided a comparison platform for the two tests that followed. The initial equivalence ratio sweeps showed that in order to obtain meaningful data at 100% load, the size of the turbocharger would need to be increased. Another solution would be to increase the waste gate opening pressure to increase the boost pressure or reference the waste gate to inlet air pressure. The first solution would be the most helpful. Neither of the two options was available so the sweep was repeated at 50% load to reduce the demand of intake air and make it possible to obtain meaningful data. No matter how the lean limit is defined, it was reached in the second test. It was clear that combustion stability declined to the point where cylinder 5 ceased to ignite. In order to operate effectively at leaner conditions, a different ignition type would be necessary. The standard J-Gap spark plug is not capable of igniting the lean mixture. The conclusions made from the lean limit sweeps are listed below:

- Stock turbocharger size is not sufficient to reach the lean limit at 100% load.
- The following prove that combustion stability declines as ϕ is made leaner
    - Increased burn durations
    - Increased COV IMEP
    - Increased BSTHC in exhaust stream
- Lean limit occurs at $\phi \sim 0.62$ (COV of IMEP > 5%).
- Efficiency peak at $\phi \sim 0.8$.

The low viscosity oil test proved that engine oil viscosity directly effects the FMEP of the engine. The SAE30 oil clearly showed lower FMEP values than the SAE40 oil. The exact results are listed below.

- The SAE 30 FMEP and BSFC values for 1500 RPM were reduced on average by 22.5% and 2.9% respectively.
- The SAE 30 FMEP and BSFC values for 1800 RPM were reduced on average by 18.9% and 3.4% respectively.
- FMEP and BSFC values for SAE40 weight were very similar to the stock oil that was also base 40 weight oil.

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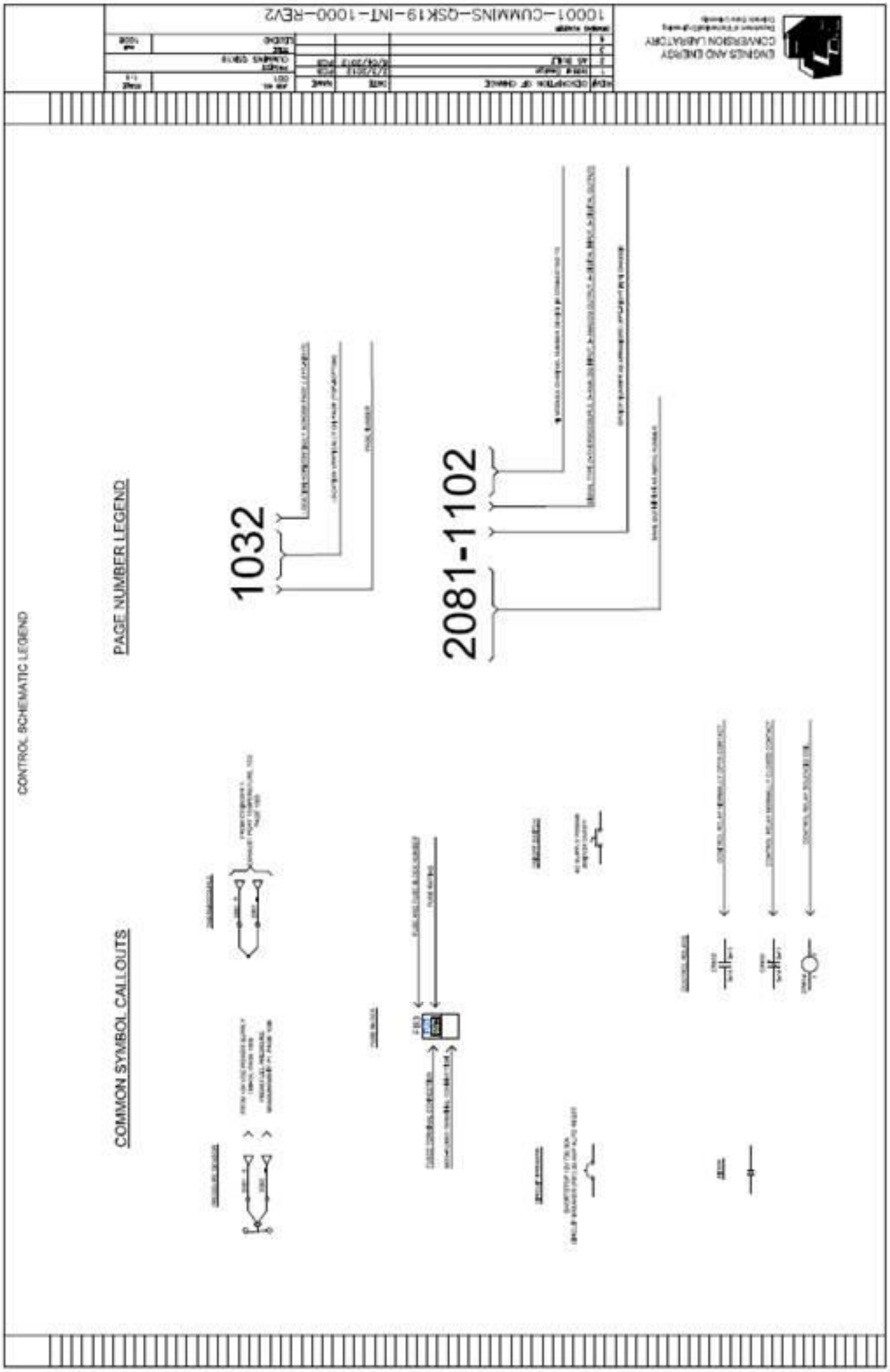
Appendix A - QSK19G Controls Layout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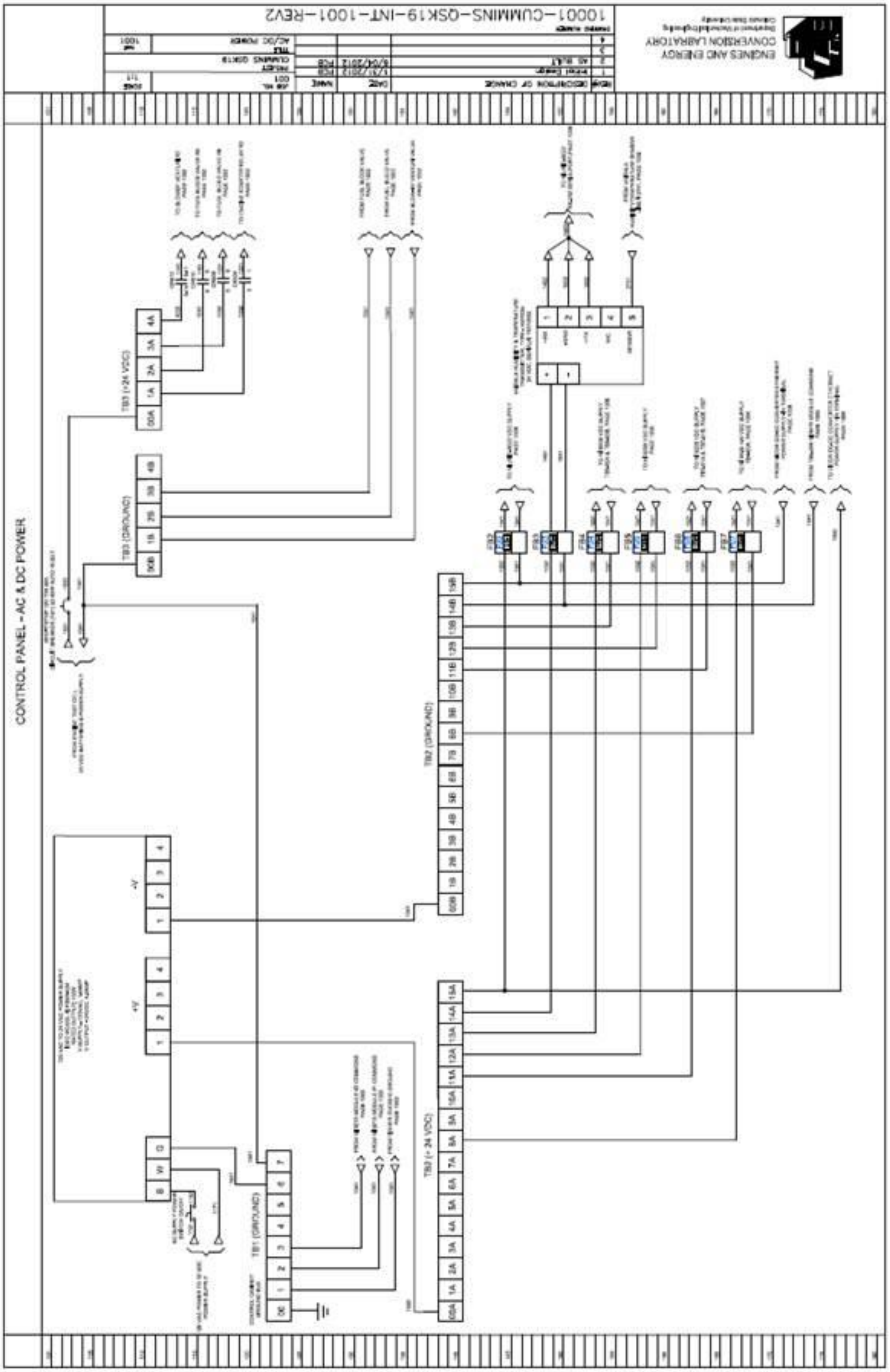
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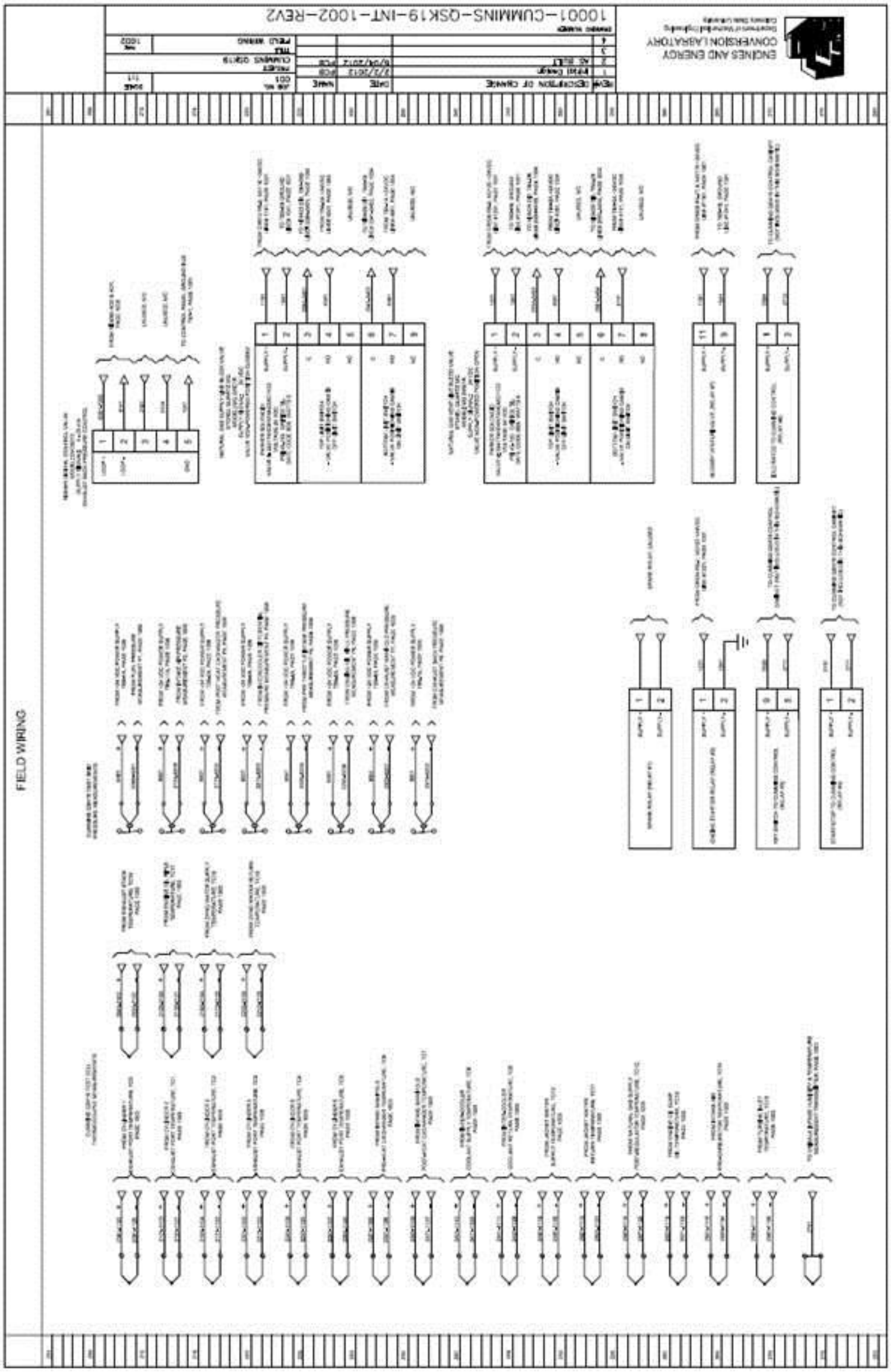
TB2 (GROUND)
TB3 (GROUND)
TB2 (+24 VDC)
TB3 (+24 VDC)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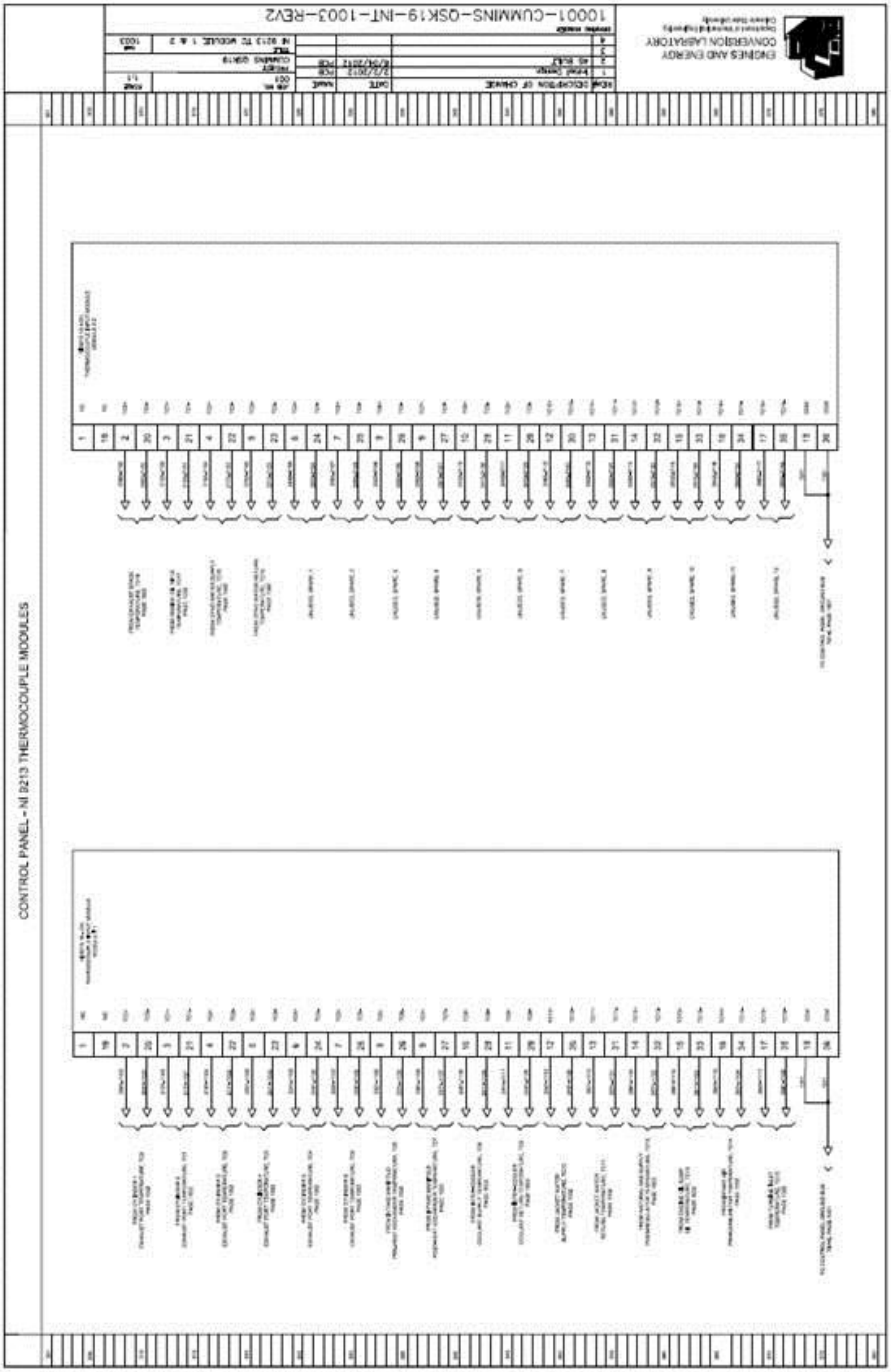
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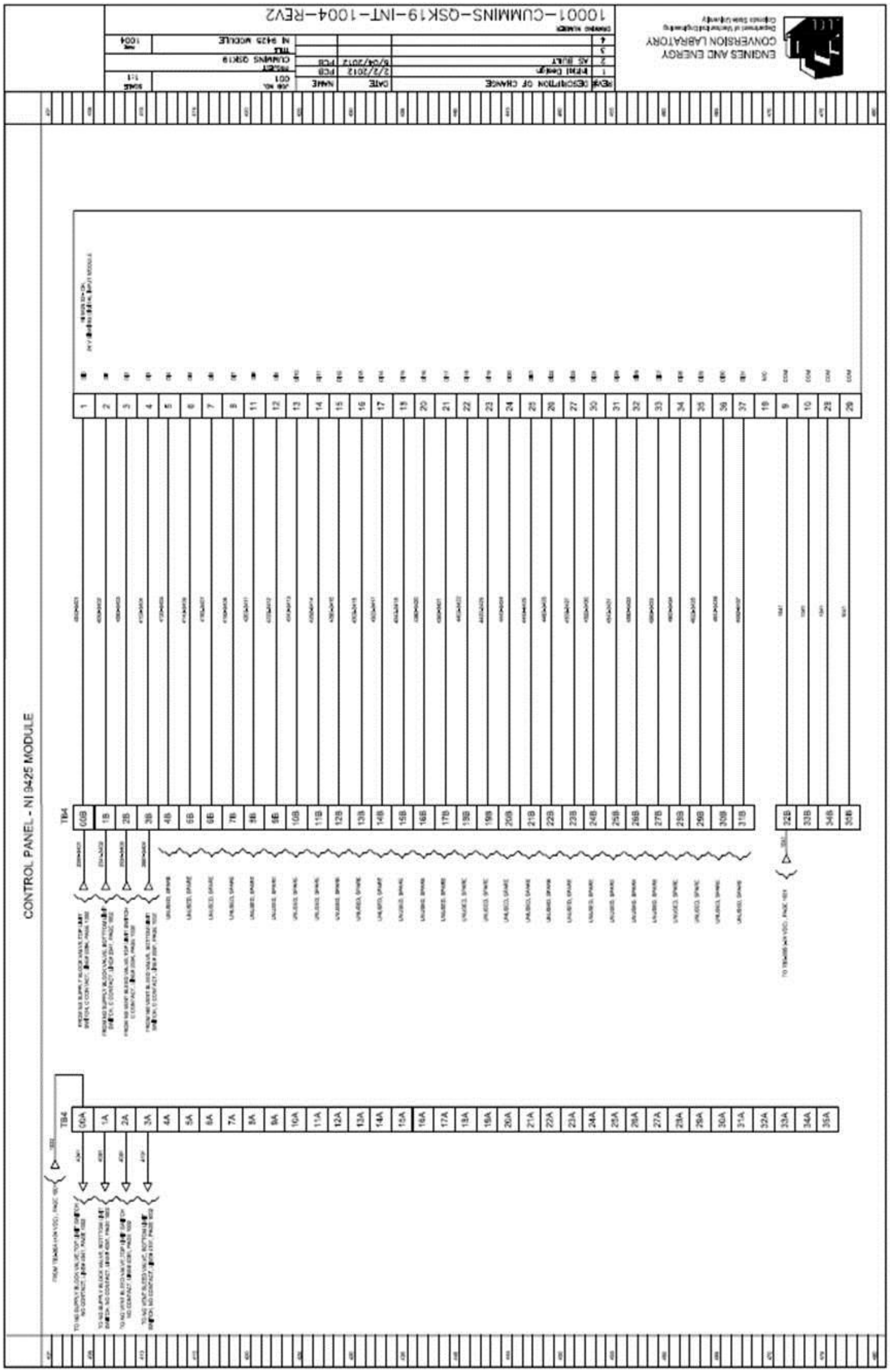

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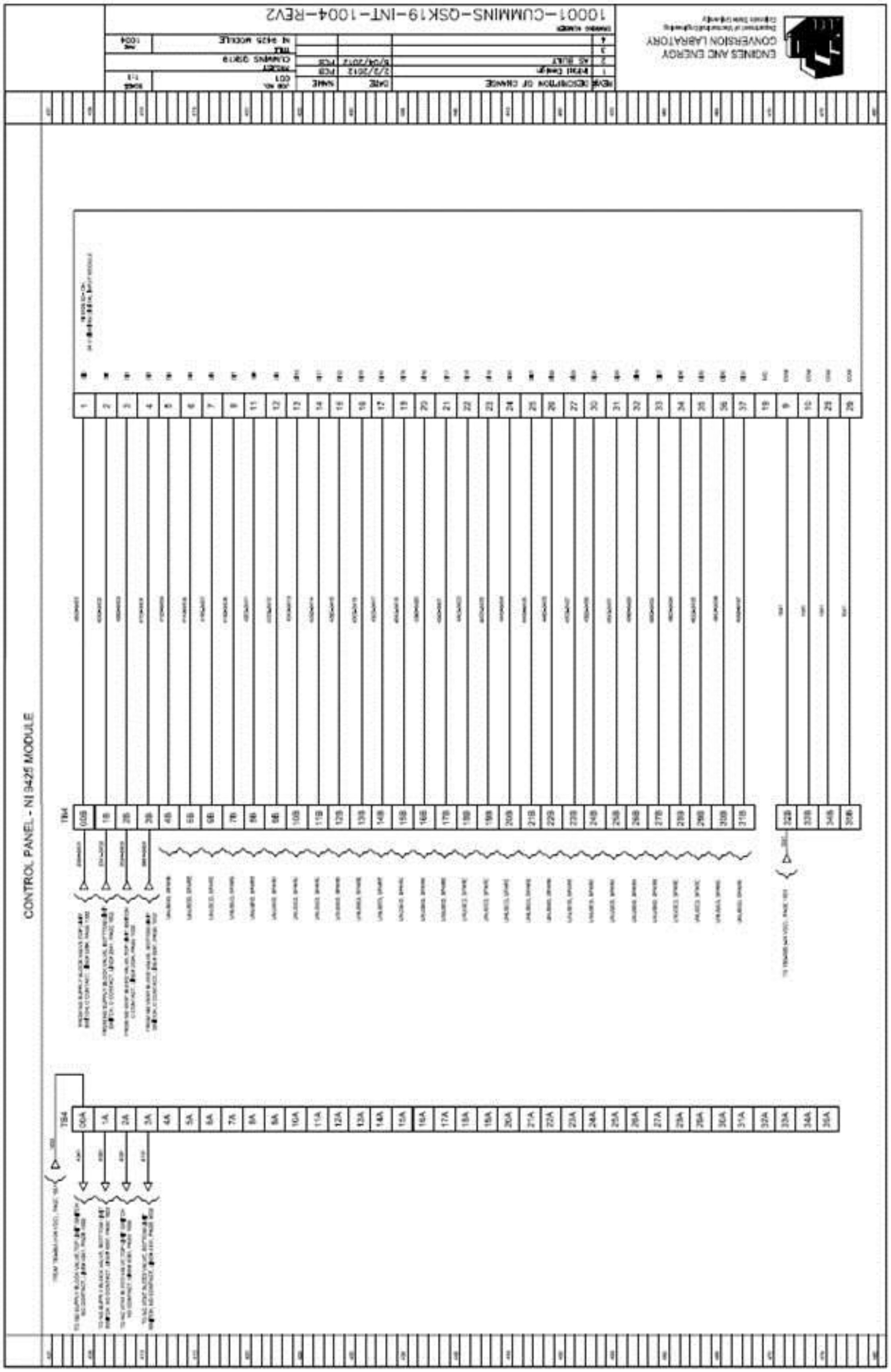
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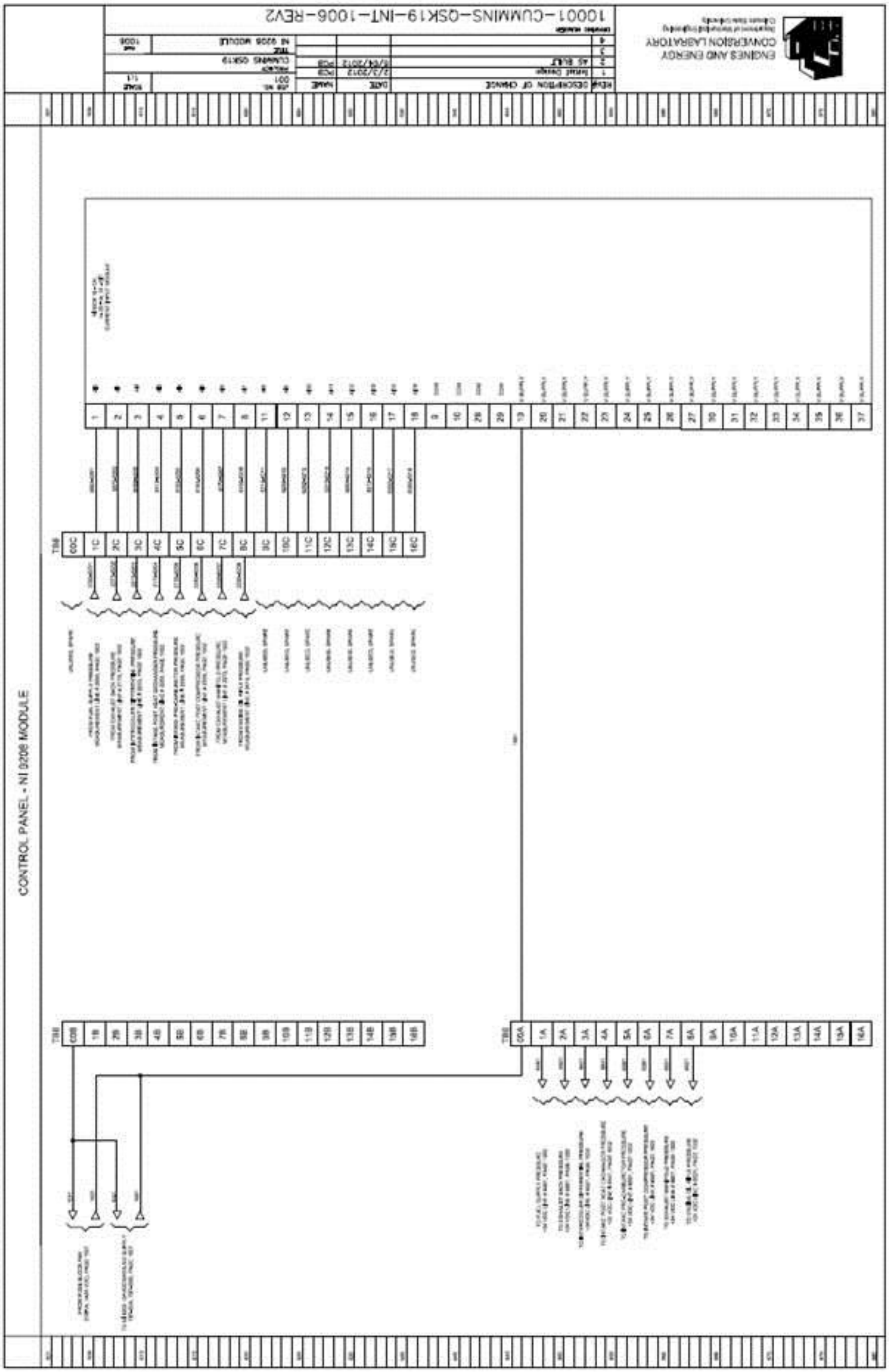
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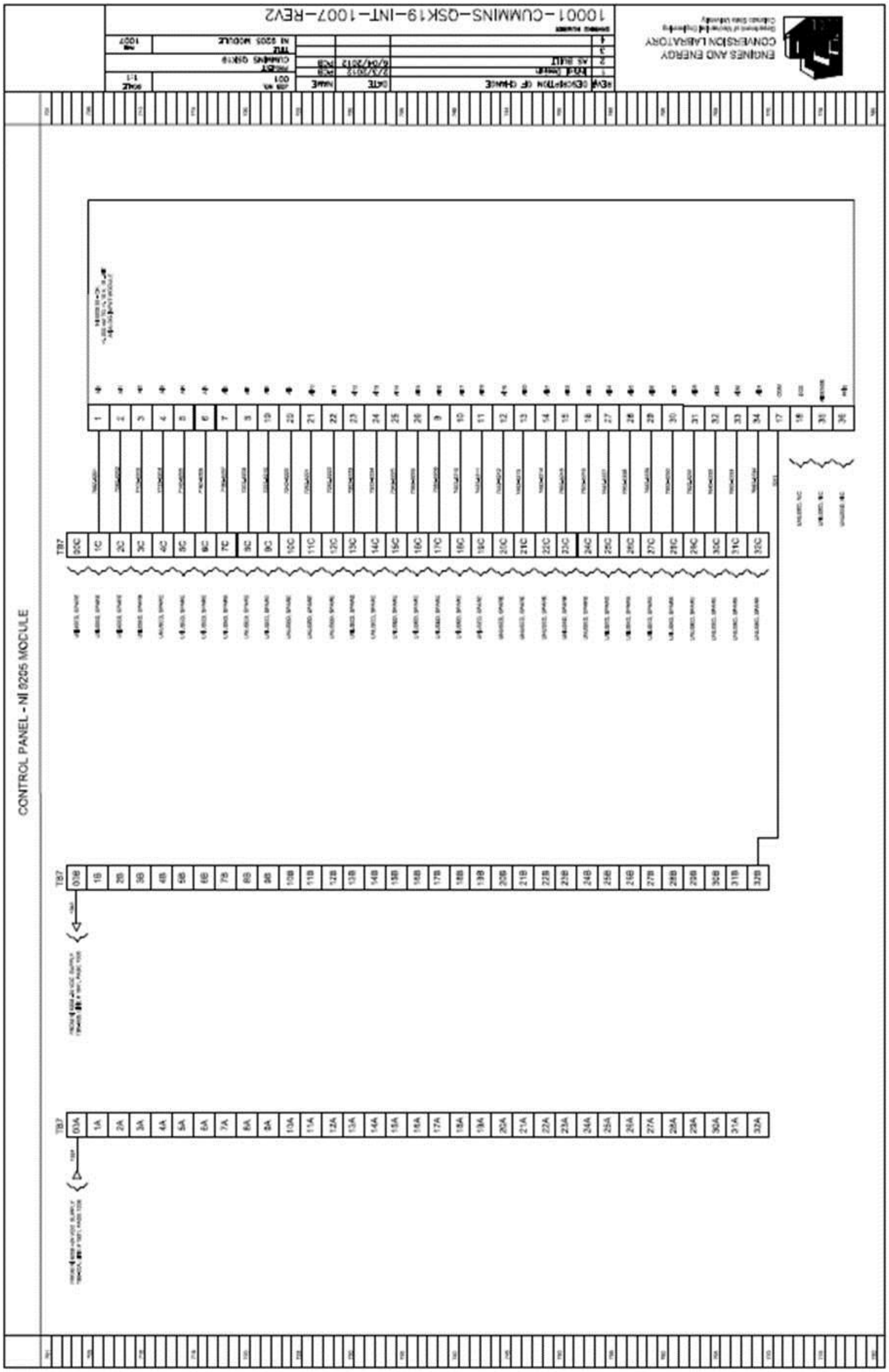
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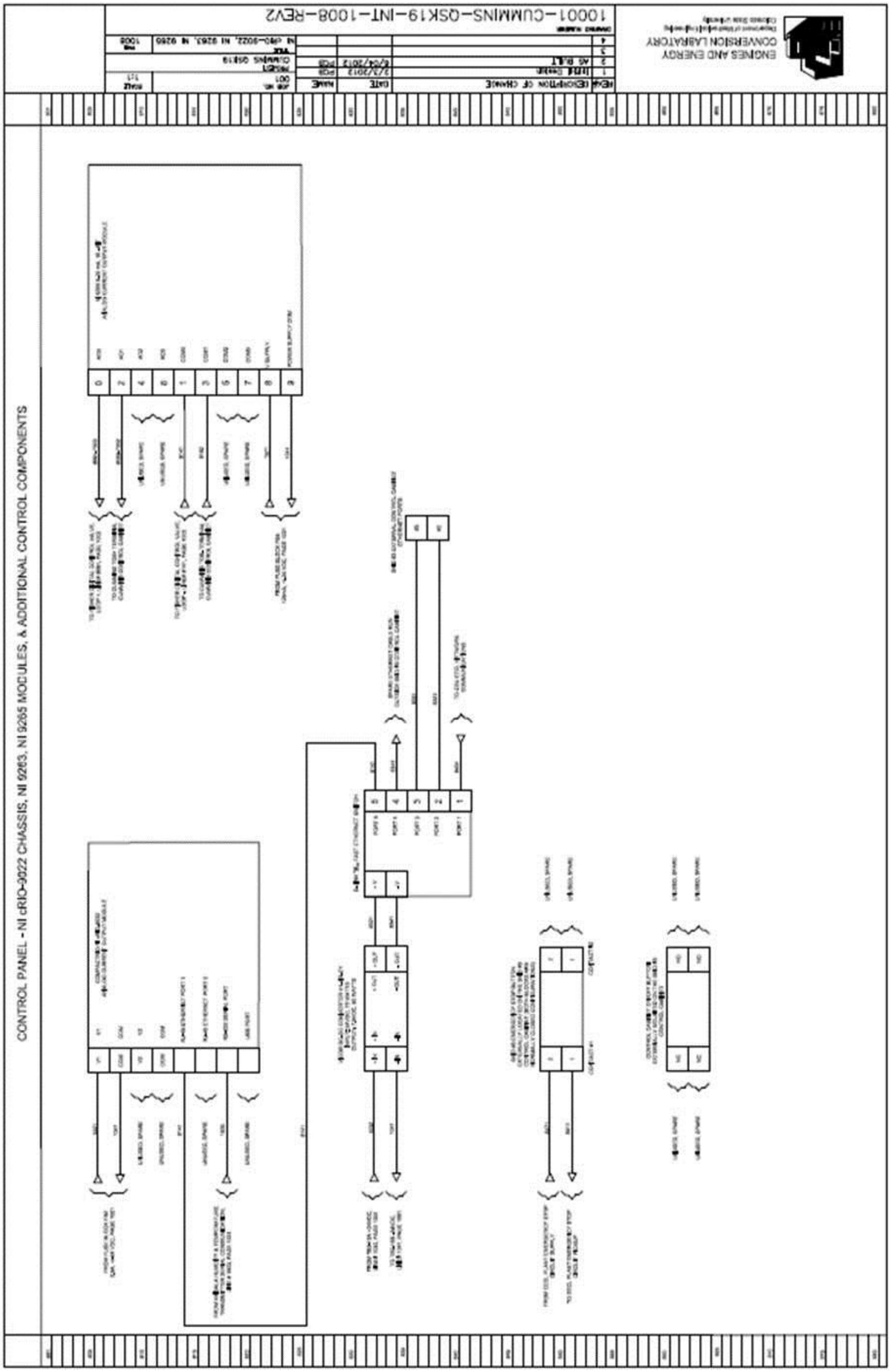
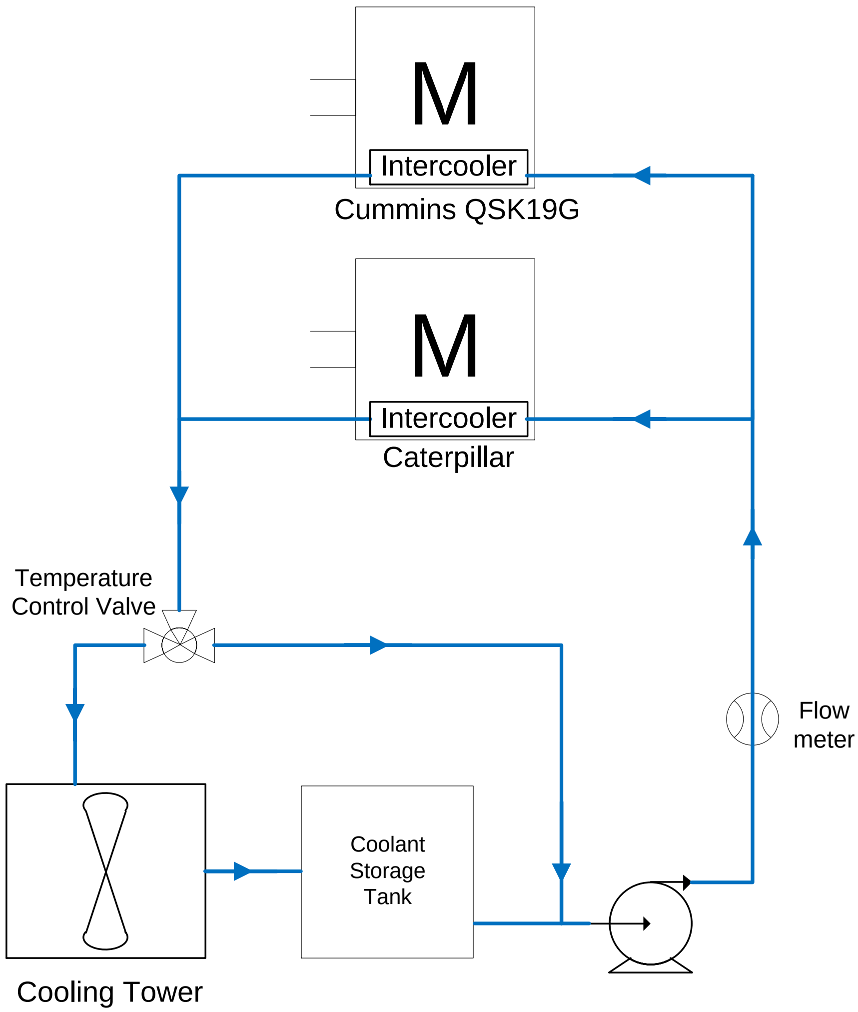
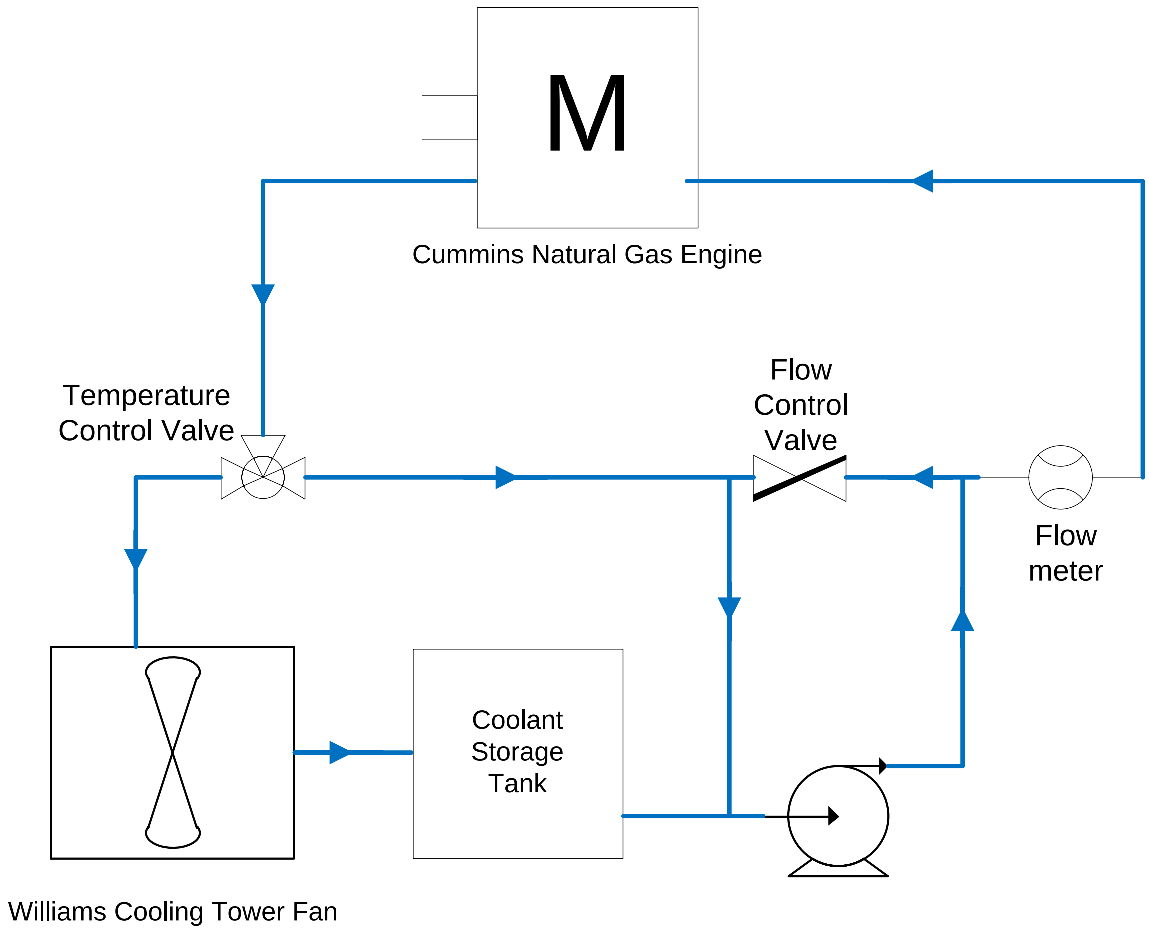

CONTROL PANEL - NI cRIO-9022 CHASSIS, NI 9263, NI 9265 MODULES, & ADDITIONAL CONTROL COMPONENTS
10001-CUMMINS-QSK19-INT-1008-REV2
ENGINES AND ENERGY CONVERSION LABARATORY

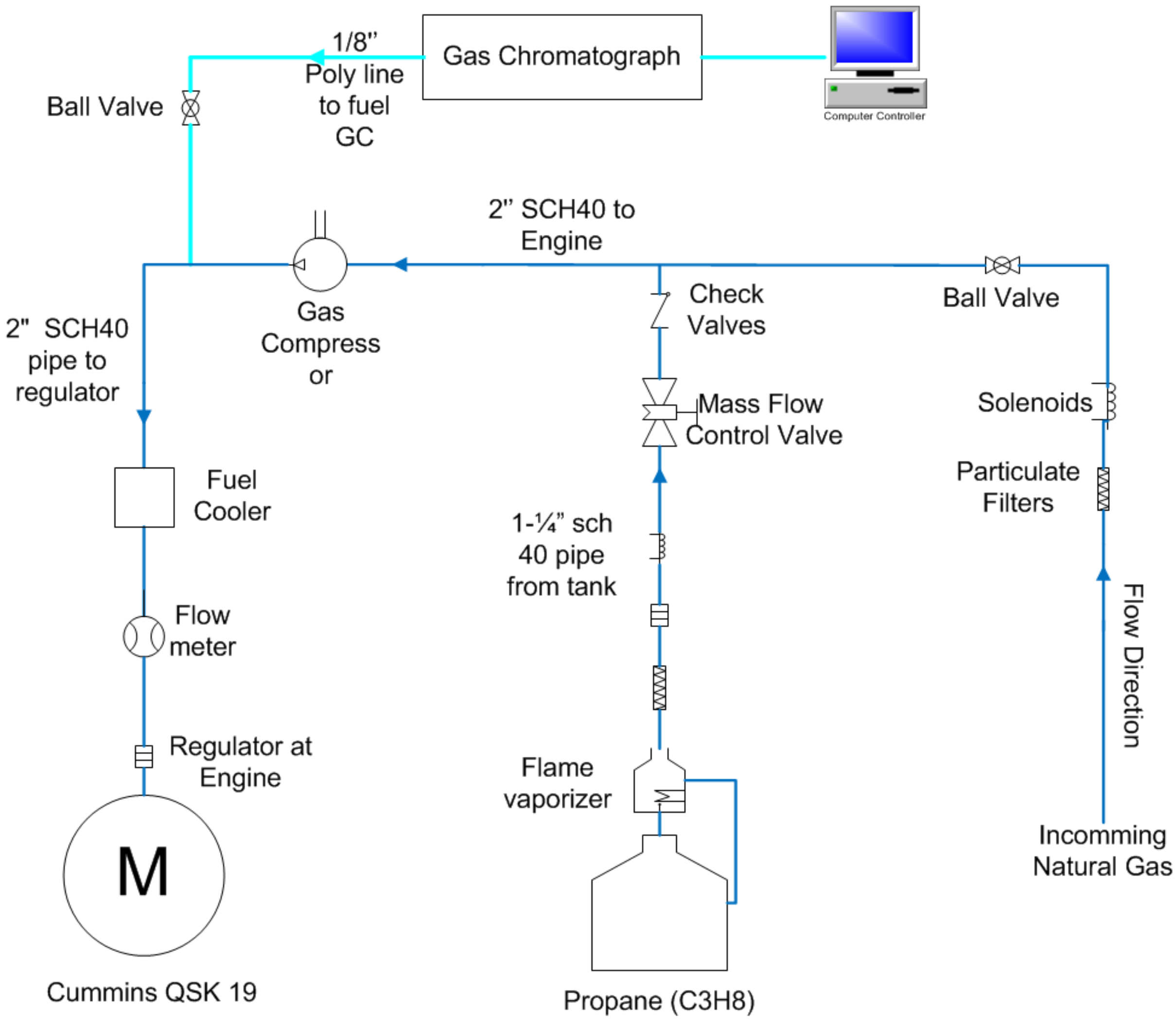
Appendix B - Plumbing Schematics



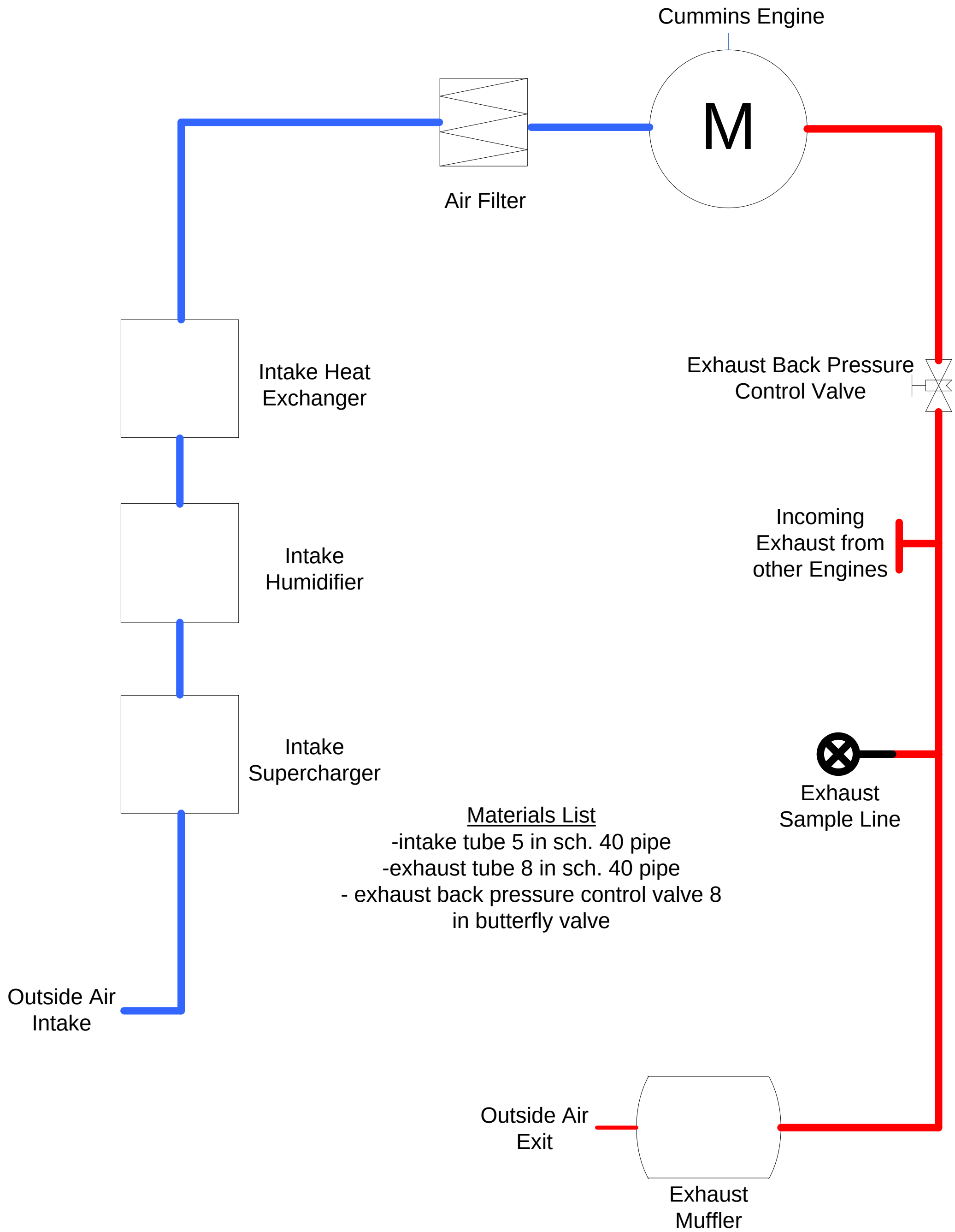
Intercooler Coolant Plumbing Schematic.



Engine Coolant Plumbing Schematic.



Fuel Plumbing Schematic.



Breathing Plumbing Schematic.

Appendix C – Commissioning Tabular Data

Load Point Name	QSK-05-100% Load		QSK-06-75% Load		QSK-07-50% Load	
Engine Parameter	Average Value	Standard Deviation	Average Value	Standard Deviation	Average Value	Standard Deviation
Speed [RPM]	1800	0.17	1800	0.50	1799	1.37
Power [hp]	472	0.65	353	0.21	235	0.64
Torque [ft-lb]	1376	0.65	1030	0.70	686	0.70
Fuel Flow [lb/hr]	189	1.03	153	0.84	119	1.65
Intake Air Flow [lm/hr]	5161		4164		3287	
Lamda Offset [Calterm]	0.214		0.214		0.21	
Lamda [Calculated]	1.68		1.68		1.69	
Fuel Pressure [psig]	6.41	0.01	6.56	0.01	6.62	0.02
Fuel Temperature [F]	96.0	0.41	96	0.39	96.2	0.41
Inlet Air Pressure [inHg]	3.60	0.01	3.60	0.01	3.59	0.03
Intake Manifold Pressure [psia]	37.8	0.08	29.4	0.11	22.6	0.40
IC Differential Pressure [inH2O]	3.35	0.28	-1.4	0.10	-1.95	0.11
Boost Pressure [psig]	27.4	0.21	28.7	0.10	24.5	0.62
Inlet Air Temperature [F]	117	0.36	116	0.42	114	0.45
Intake Manifold Temperature [F]	146	0.68	144	1.68	145	1.43
Boost Temperature [F]	405	1.98	367	0.62	335	3.14
Inlet Air Relative Humidity [%]	10.0	0.00	10.0	0.00	10.0	0.00
Exhaust Back Pressure [inHg]	4.70	0.03	4.70	0.06	4.70	0.10
Exhaust Manifold Pressure [psia]	47.5	0.23	37.6	0.18	31.3	0.49
Exhaust Stack Temperature [F]	967	1.12	975	5.26	973	4.84
Turbine In Temp [F]	1258	1.23	1236	2.68	1215	10.07
Exh Port 1 Temp [F]	1152	1.57	1129	2.25	1132	11.43
Exh Port 2 Temp [F]	1160	1.99	1136	2.46	1103	8.66
Exh Port 3 Temp [F]	1152	1.54	1129	3.79	1126	11.87
Exh Port 4 Temp [F]	1168	1.09	1142	2.88	1126	11.24
Exh Port 5 Temp [F]	1167	1.73	1145	2.67	1132	11.38
Exh Port 6 Temp [F]	1140	1.65	1116	2.44	1094	10.02
Jacket Water In Temp [F]	188	0.91	190	1.82	191	2.57
Jacket Water Out Temp [F]	200	1.13	201	2.09	200	2.63
IC Water In Temp [F]	127	1.10	130	2.17	134	2.02
IC Water Out Temp [F]	142	0.95	140	2.05	141	1.94
Dyno Inlet Temp [F]	121	0.21	120	0.68	116	1.06
Dyno Outlet Temp [F]	149	0.17	141	1.88	130	1.03
Oil Sump Temperature [F]	228	0.34	226	0.61	222	0.53
Oil Rifle Temperature [F]	220	0.37	219	0.89	217	0.79
Oil Pressure [psig]	70.8	4.06	72.9	2.58	75.0	3.40

THC [ppm dry]	1705	13.32	2099	47.43	2834	129.05
O2 [% dry]	9.28	0.05	9.40	0.08	9.6	0.08
NOx [ppm dry]	127	2.79	84.4	5.89	37.2	4.83
NO [ppm dry]	78.4	1.96	51.8	4.63	18.5	3.16
NO2 [ppm dry]	48.8	1.80	32.6	2.20	18.7	2.52
CO2 [% dry]	6.56	0.01	6.52	0.02	6.34	0.04
CO [ppm dry]	521	2.70	502	6.90	608	20.82
Supercharger Speed [% speed]	39.2	0.06	33.0	0.13	27.7	0.28
SC IC CV Pos. [% Closed]	0	0.00	0	0.00	0	0.00
Steam Valve Pos. [% Closed]	0	0.00	0	0.00	0	0.00
ICW CV Pos. [% Closed]	37.6	3.68	46.6	6.27	52.5	6.36
Exh Back Pres CV Pos. [% Closed]	58.5	0.23	63.7	0.42	70.4	0.67
JW CV Pos. [% Closed]	60.3	2.72	60.6	3.10	62.4	3.01
JW Flow CV	100	0.00	100	0.00	100	0.00
Jacket Water Flow [gpm]	160	0.48	160	0.60	159	0.76
Intercooler Water Flow [gpm]	190	0.72	192	1.02	193	0.63
Dyno Water Flow [gpm]	104	0.39	104	0.36	104	0.36
Boiler Return Temp [C]	58.5	3.74	69.8	2.69	68.0	0.84
Boiler Supply Temp [C]	56.5	1.06	67.4	2.25	68.1	0.83
BMEP [psi]	89.5	0.12	66.9	0.04	44.6	0.11
Ambient Pressure [psia]	12.3	0.00	12.3	0.00	12.3	0.00
LHV [BTU/lbm]	20315		20315		20318	
BS CO [g/bhp_hr]	2.37		2.45		3.54	
BS NOx [g/bhp_hr]	0.95		0.76		0.36	
BS THC [g/bhp_hr]	4.45		5.87		9.44	
Brake Thermal Efficiency	31.2		28.9		24.6	
BS Fuel Consumption [BTU/bhp-hr]	8155		8799		10329	

Load Point Name	QSK-08-100% Load		QSK-09-75% Load		QSK-10-50% Load	
Engine Parameter	Average Value	Standard Deviation	Average Value	Standard Deviation	Average Value	Standard Deviation
Speed [RPM]	1500	0.36	1500	0.36	1500	0.50
Power [hp]	451	0.15	338	0.04	225	0.04
Torque [ft-lb]	1579	0.53	1184	0.58	789	0.61
Fuel Flow [lb/hr]	171	0.81	137	0.73	103	0.69
Intake Air Flow [lm/hr]	4697		3731		2790	
Lamda Offset [Calterm]	0.26		0.26		0.26	
Lamda [Calculated]	1.71		1.69		1.69	
Fuel Pressure [psig]	6.53	0.01	6.61	0.00	6.66	0.01

Fuel Temperature [F]	95.5	0.54	94.7	0.38	94.6	0.29
Inlet Air Pressure [inHg]	3.60	0.01	3.60	0.01	3.60	0.01
Intake Manifold Pressure [psia]	38.3	0.28	30.1	0.05	21.7	0.08
IC Differential Pressure [inH2O]	1.72	0.15	-1.15	0.08	-1.07	0.07
Boost Pressure [psig]	29.0	0.06	27.5	0.08	19.0	0.12
Inlet Air Temperature [F]	110	0.49	110	0.35	109	0.35
Intake Manifold Temperature [F]	146	0.81	146	0.92	144	0.47
Boost Temperature [F]	368	0.85	350	0.65	287	0.75
Inlet Air Relative Humidity [%]	10.0	0.00	10.0	0.00	10.0	0.00
Exhaust Back Pressure [inHg]	4.70	0.04	4.71	0.03	4.70	0.05
Exhaust Manifold Pressure [psia]	41.6	0.25	34.7	0.09	26.8	0.11
Exhaust Stack Temperature [F]	926	16.63	921	8.93	949	2.19
Turbine In Temp [F]	1193	2.41	1181	1.57	1156	2.21
Exh Port 1 Temp [F]	1072	2.03	1070	1.14	1055	2.38
Exh Port 2 Temp [F]	1080	2.97	1083	2.14	1068	2.71
Exh Port 3 Temp [F]	1078	1.92	1070	1.58	1050	2.50
Exh Port 4 Temp [F]	1088	2.62	1070	1.70	1056	2.59
Exh Port 5 Temp [F]	1091	1.99	1075	1.51	1060	2.54
Exh Port 6 Temp [F]	1059	2.35	1042	1.25	1025	3.50
Jacket Water In Temp [F]	190	1.36	192	2.09	194	2.04
Jacket Water Out Temp [F]	200	1.28	201	1.93	201	1.88
IC Water In Temp [F]	130	1.12	134	1.41	135	0.85
IC Water Out Temp [F]	141	1.07	142	1.28	139	0.80
Dyno Inlet Temp [F]	110	1.35	112	0.98	109	0.64
Dyno Outlet Temp [F]	136	1.21	132	1.17	122	0.65
Oil Sump Temperature [F]	223	0.43	221	0.55	218	0.42
Oil Rifle Temperature [F]	216	0.45	216	0.65	214	0.65
Oil Pressure [psig]	65.5	2.70	65.9	2.02	69.1	2.02
THC [ppm dry]	1908	36.96	2038	23.11	2256	31.27
O2 [% dry]	9.5	0.07	9.46	0.06	9.5	0.11
NOx [ppm dry]	135	10.93	111	5.02	61.2	2.44
NO [ppm dry]	85.1	8.59	67.8	3.85	29.3	1.15
NO2 [ppm dry]	49.8	2.85	43.0	1.60	31.9	2.46
CO2 [% dry]	6.48	0.04	6.56	0.01	6.57	0.01
CO [ppm dry]	476	1.37	461	1.69	470	3.09
Supercharger Speed [% speed]	36.1	0.15	30.2	0.06	24.6	0.04
SC IC CV Pos. [% Closed]	0	0.00	0	0.00	0	0.00
Steam Valve Pos. [% Closed]	0	0.00	0	0.00	0	0.00
ICW CV Pos. [% Closed]	39.7	1.35	42.6	2.38	50.8	1.85
Exh Back Pres CV Pos. [% Closed]	60.7	0.33	66.8	0.45	75.5	0.29
JW CV Pos. [% Closed]	61.0	2.39	60.8	2.77	63.3	2.93

JW Flow CV	100	0.00	100	0.00	100	0.00
Jacket Water Flow [gpm]	154	0.48	154	0.50	154	0.50
Intercooler Water Flow [gpm]	191	0.57	192	0.62	193	0.38
Dyno Water Flow [gpm]	106	0.42	106	0.44	106	0.44
Boiler Return Temp [C]	62.8	0.75	59.8	0.59	56.3	0.57
Boiler Supply Temp [C]	62.9	0.59	59.9	0.63	56.3	0.54
BMEP [psi]	103	0.04	76.9	0.02	51.3	0.02
Ambient Pressure [psia]	12.3	0.00	12.3	0.00	12.3	0.00
LHV [BTU/lbm]	20156		20154		20132	
BS CO [g/bhp_hr]	2.06		2.11		2.40	
BS NOx [g/bhp_hr]	0.96		0.83		0.51	
BS THC [g/bhp_hr]	4.74		5.33		6.60	
Brake Thermal Efficiency	33.3		31.1		27.7	
BS Fuel Consumption [BTU/bhp-hr]	7641		8181		9175	

Appendix D – Cummins Engine Performance Data

Engine Performance Data Cummins Inc Columbus, Indiana 47202-3005 http://www.cummins.com	Power Generation **QSK19G** **FR 4560**	471 hp (351 kWm) @ 1800 rpm 1374 lb-ft (1863 N-m) @ 1800 rpm		
		Configuration D483002GX03	CPL Code 2113	Revision 27-May-11

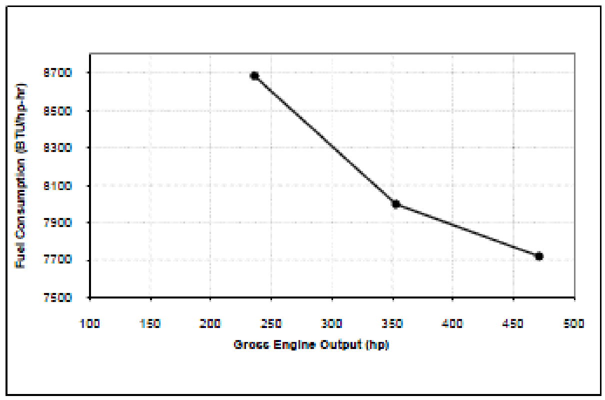
Compression Ratio:	**11.0:1**	Displacement:	**1150 in^3 (18.8 L)**
Fuel System:	**Natural Gas**	Cylinders:	**6**
Combustion:	**Lean Burn**	Bore x Stroke:	**6.25 x 6.25 in (159 x 159 mm)**
Emission Certification:	**1 g/hp-hr NOx EPA NSPS Compliant Capable**	Aspiration:	**Turbocharged and Aftercooled**

Engine Rating:

Engine Speed	Continuous Power	
rpm	hp	kWm
1,800	471	351

Engine Fuel Consumption @ 1800 rpm

Output Power			Fuel Consumption	
%	hp	kWm	BTU/hp-hr	MJ/kWm-hr
Continuous Power				
100	471	351	7720	10.9
75	353	263	7998	11.3
50	236	176	8683	12.3
25	118	88	N/A	N/A



These guidelines have been formulated to ensure proper application of generator drive engines in A.C. generator set installations.

~~STANDBY POWER RATING: Applicable for supplying emergency power for the duration of the utility power outage. No overload capability is available for this rating. Under no condition is an engine allowed to operate in parallel with the public utility at the Standby Power rating. This rating should be applied where reliable utility power is available. A Standby rated engine should be sized for a maximum of an 80% average load factor and 200 hours of operation per year. This includes less than 25 hours per year at the Standby Power rating. Standby ratings should never be applied except in true emergency power outages. Negotiated power outages contracted with a utility company are not considered an emergency.~~

~~PRIME POWER RATING: Applicable for supplying electric power in lieu of commercially purchased power. Prime Power applications must be in the form of one of the following two categories:~~

~~UNLIMITED TIME RUNNING PRIME POWER: Prime Power is available for an unlimited number of hours per year in a variable load application. Variable load should not exceed a 70% average of the Prime Power rating during any operating period of 250 hours. The total operating time at 100% Prime Power shall not exceed 500 hours per year. A 10% overload capability is available for a period of 1 hour within a 12-hour period of operation. Total operating time at the 10% overload power shall not exceed 25 hours per year.~~

~~LIMITED TIME RUNNING PRIME POWER: Limited Time Prime Power is available for a limited number of hours in a non-variable load application. It is intended for use in situations where power outages are contracted, such as in utility power curtailment. Engines may be operated in parallel to the public utility up to 750 hours per year at power levels never to exceed the Prime Power rating. The customer should be aware, however, that the life of any engine will be reduced by this constant high load operation. Any operation exceeding 750 hours per year at the Prime Power rating should use the Continuous Power rating.~~

CONTINUOUS POWER RATING: Applicable for supplying utility power at a constant 100% load for an unlimited number of hours per year. No overload capability is available for this rating.

Reference AEB 10.47 for determining Electrical Output.

Data shown above represents gross engine performance capabilities obtained and corrected in accordance with reference conditions of 99.51 kPa (29.38 in-Hg) barometric pressure, 152 m (500 ft) altitude, 25 °C (77 °F) air inlet temperature, and relative humidity of 50% using dry processed gas natural gas fuel with 48 Mega Joules per Kilogram lower heating value. Derates shown are based on 15 in-H_2O air intake restriction and 2 in-Hg exhaust back pressure.

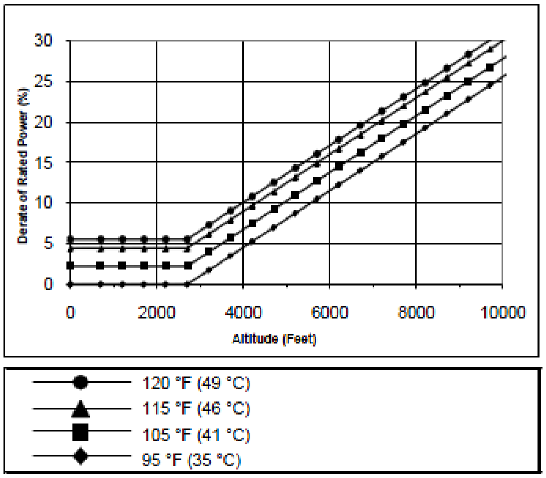
Power output curves are based on the engine operating with fuel system, water pump and lubricating oil pump; not included are battery charging alternator, fan, optional equipment and driven components.

Data Status:Preliminary, Pending Final Review

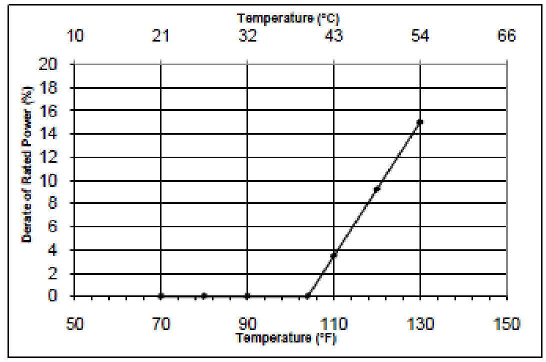
Data Tolerance: +/- 5%

CHIEF ENGINEER: Alfred S Weber

Altitude and Ambient Temperature Derate Curve

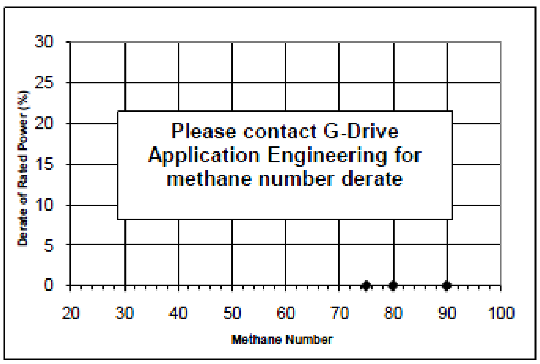


LTA Coolant Temperature Derate Curve



Operation at Elevated Temperature and Altitude:
For continuous operation above these conditions, derate by an additional 3.5% per 1,000 ft (305 m), and 2.25% per 10 delta °F (5.6 delta °C)

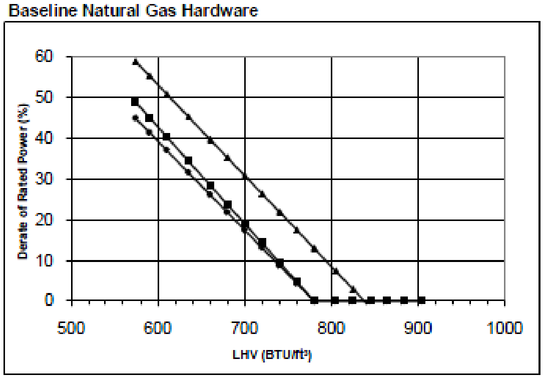
Methane Number Derate Curve

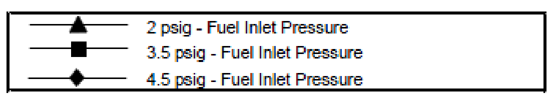


MN > N/A: Timing is N/A degrees BTDC
N/A < MN < N/A: Timing is N/A degrees BTDC
N/A < MN < N/A: Timing is N/A degrees BTDC

Energy Content Derate Curve

Baseline Natural Gas Hardware





General Engine Data				
Type	Four Cycle; Inline; 6 Cylinder			
Aspiration	Turbocharged and Aftercooled			
Compression Ratio	11.0:1			
Bore x Stroke	6.25 x 6.25	in	159 x 159	mm
Displacement	1,150	in^3	18.9	L
Approximate Engine Weight (Wet)	4,534	lbm	2,057	kg
Moment of Inertia of Rotating Components Without Flywheel	16.1	$in\text{-}lbf\text{-}s^2$	1.82	$kg\text{-}m^2$
Center of Gravity				
from Rear Face of Block	23.6	in	599	mm
from Engine Centerline to Left Side of Engine	0.0	in	0.0	mm
above Crankshaft Centerline	11.1	in	282	mm
Maximum Static Loading at Rear Main Bearing	N/A	lbm	N/A	kg
Engine Mounting				
Maximum Bending Moment at Rear Face of Block	1,000	lb-ft	1,356	N-m
Maximum Crankshaft Thrust Bearing Load	750	lbf	3,336	N
Exhaust System				
Maximum Back Pressure	2	in-Hg	7	kPa
Air Induction System				
Maximum Intake Air Restriction				
with Dirty Filter Element	25	$in\text{-}H_2O$	6.2	kPa
with Normal Duty Air Cleaner and Clean Filter Element	15	$in\text{-}H_2O$	3.7	kPa
Cooling System				
Coolant Capacity				
Engine	36	quarts	34.1	L
Aftercoolers	5	quarts	4.7	L
Minimum Pressure Cap Rating at Sea Level	7	psi	48	kPa
Maximum Static Head of Coolant Above Crankshaft Centerline	60	ft	18.3	m
Acceptable Types of Deaeration System	Positive			
Jacket Water Circuit Requirements				
Maximum Coolant Friction Head External to Engine	5	psi	34	kPa
Maximum Coolant Temperature (Maximum Top Tank Temp.)	203	°F	95	°C
Thermostat (Modulating) Range	180 - 202	°F	82 - 94	°C
Aftercooler Circuit Requirements				
Maximum Coolant Friction Head External to Engine	5	psi	34	kPa
Maximum Coolant Temperature Into the Aftercooler	130	°F	54	°C
without Power Derate	104	°F	40	°C
Thermostat (Modulating) Range	80 - 100	°F	27 - 38	°C
Lubrication System				
Oil Pressure				
@ Minimum Low Idle	20	psi	138	kPa
@ Governed Speed	50 - 70	psi	345 - 483	kPa
Maximum Oil Temperature	250	°F	121	°C
Oil System Capacity (Including Filter)	29	gal	110	L
Fuel System				
Minimum Fuel Inlet Pressure	28	$in\text{-}H_2O$	7.0	kPa
Maximum Fuel Inlet Pressure	139	$in\text{-}H_2O$	34.6	kPa
Acceptable Fuel	Pipeline Quality Natural Gas, Low MN Fuel, Low BTU Fuel			
Minimum Fuel Methane Number*	75	MN		
Minimum Fuel Energy Content*	840	BTU/ft^3	31.3	MJ/m^3

* when equipped with original fuel system hardware and original ignition timing, at 2 psig fuel inlet pressure

Electrical System

System Voltage	24	V		
Minimum Battery Capacity: Cold Soak at -18 °C (0 °F) or Above				
Engine Only Cold Cranking Amps	900	CCA		
Engine Only Reserve Capacity	320	min		
Maximum Starting Circuit Resistance	0.002	Ohm		

Cold Start Capability

Unaided Cold Start				
Minimum Cranking Speed	N/A	rpm		
Minimum Ambient Temperature for Unaided Cold Start	45	°F	7.2	°C
Minimum Ambient Temperature for NFPA 110 Cold Start (90 °F Minimum Coolant Temperature)	N/A	°F	N/A	°C
Cranking Torque at Minimum Unaided Cold Start Temperature	N/A	lb-ft	N/A	N-m

Performance Data

All data is based on:

-Engine operating with fuel system, water pump, lubricating oil pump, air cleaner and exhaust silencer; not included are battery charging alternator, fan, and optional driven components

-Engine operating with 905 BTU/ft^3 fuel

-Reference Conditions of:

Barometric Pressure:	99.5 kPa (29.39 in-Hg)	Air Temperature:	25 °C (77 °F)
Altitude:	152 m (500 ft)	Relative Humidity:	50%

Estimated Free Field Sound Pressure Level: 1800 rpm, @ 7.5 m from Engine (ISO-3744)	83.8	dBa
Exhaust Noise at Rated: 1.4 m Horizontally From Centerline of Exhaust Pipe Outlet, Upwards at 45°: 1800 rpm	101.9	dBa
Steady State Speed Stability at Any Constant Load	+/- 0.75	%
Governed Engine Speed	1,800	rpm
Engine Idle Speed	900	rpm

		Continuous Power		
		100% Load	75% Load	50% Load
Gross Engine Power Output	hp (kWm)	471 (351)	353 (263)	236 (176)
Brake Mean Effective Pressure	psi (kPa)	180 (1240)	135 (931)	90 (623)
Intake Air Flow	ft^3/min (L/s)	1021 (482)	762 (360)	537 (253)
Exhaust Gas Temp - Dry Stack	°F (°C)	993 (534)	979 (526)	968 (520)
Exhaust Gas Flow	ft^3/min (L/s)	2903 (1370)	2196 (1036)	1535 (724)
Air to Fuel Ratio (Mass Basis)		1.59	1.57	1.55
Heat Rejection to Ambient	BTU/min (kW)	2163 (38)	2334 (41)	1765 (31)
Heat Rejection to Exhaust	BTU/min (kW)	20150 (354)	14856 (261)	10246 (180)
Heat Rejection to Jacket Coolant	BTU/min (kW)	12408 (218)	10587 (186)	9506 (167)
Engine Jacket Water Flow at:				
2.5 psi External Friction Head	gpm (L/min)	176 (666)	176 (666)	176 (666)
Maximum Friction Head	gpm (L/min)	165 (625)	165 (625)	165 (625)
Heat Rejection to Aftercooler Coolant	BTU/min (kW)	4895 (86)	3529 (62)	1992 (35)
Engine Aftercooler Water Flow at:				
2.5 psi External Friction Head	gpm (L/min)	32 (121)	32 (121)	32 (121)
Maximum External Friction Head	gpm (L/min)	30 (114)	30 (114)	30 (114)
Ignition Timing (BTDC)	deg	17	17	17
O_2	%	8.7	8.4	8.1

End of Report

Engine Performance Data **Cummins Inc** Columbus, Indiana 47202-3005 http://www.cummins.com	Power Generation **QSK19G** **FR 4562**	450 hp (336 kWm) @ 1500 rpm 1576 lb-ft (2137 N-m) @ 1500 rpm		
		Configuration D483002GX03	CPL Code **2112**	Revision **9-Aug-12**

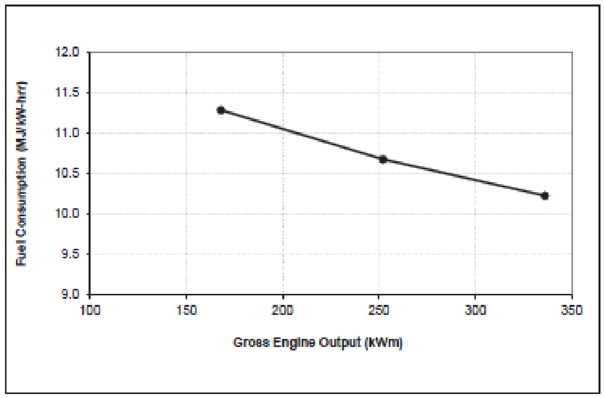
Compression Ratio:	**11.0:1**	Displacement:	**1150 in³ (18.8 L)**
Fuel System:	**Natural Gas**	Cylinders:	**6**
Combustion:	**Lean Burn**	Bore x Stroke:	**6.25 x 6.25 in (159 x 159 mm)**
Emission Certification:	**500 mg/nm3 NOx (1 TALuft) Capable**	Aspiration:	**Turbocharged and Aftercooled**

Engine Rating:

Engine Speed	Continuous Power	
rpm	hp	kWm
1,500	450	336

Engine Fuel Consumption @ 1500 rpm

Output Power			Fuel Consumption	
%	hp	kWm	BTU/hp-hr	MJ/kWm-hr
Continuous Power				
100	450	336	7232	10.2
75	338	252	7548	10.7
50	225	168	7979	11.3
25	113	84	N/A	N/A



These guidelines have been formulated to ensure proper application of generator drive engines in A.C. generator set installations.

~~STANDBY POWER RATING: Applicable for supplying emergency power for the duration of the utility power outage. No overload capability is available for this rating. Under no condition is an engine allowed to operate in parallel with the public utility at the Standby Power rating. This rating should be applied where reliable utility power is available. A Standby rated engine should be sized for a maximum of an 80% average load factor and 200 hours of operation per year. This includes less than 25 hours per year at the Standby Power rating. Standby ratings should never be applied except in true emergency power outages. Negotiated power outages contracted with a utility company are not considered an emergency.~~

~~PRIME POWER RATING: Applicable for supplying electric power in lieu of commercially purchased power. Prime Power applications must be in the form of one of the following two categories:~~

~~UNLIMITED TIME RUNNING PRIME POWER: Prime Power is available for an unlimited number of hours per year in a variable load application. Variable load should not exceed a 70% average of the Prime Power rating during any operating period of 250 hours. The total operating time at 100% Prime Power shall not exceed 500 hours per year. A 10% overload capability is available for a period of 1 hour within a 12 hour period of operation. Total operating time at the 10% overload power shall not exceed 25 hours per year.~~

~~LIMITED TIME RUNNING PRIME POWER: Limited Time Prime Power is available for a limited number of hours in a non-variable load application. It is intended for use in situations where power outages are contracted, such as in utility power curtailment. Engines may be operated in parallel to the public utility up to 750 hours per year at power levels never to exceed the Prime Power rating. The customer should be aware, however, that the life of any engine will be reduced by this constant high load operation. Any operation exceeding 750 hours per year at the Prime Power rating should use the Continuous Power rating.~~

CONTINUOUS POWER RATING: Applicable for supplying utility power at a constant 100% load for an unlimited number of hours per year. No overload capability is available for this rating.

Reference AEB 10.47 for determining Electrical Output.

Data shown above represents gross engine performance capabilities obtained and corrected in accordance with reference conditions of 99.51 kPa (29.39 in-Hg) barometric pressure, 152 m (500 ft) altitude, 25 °C (77 °F) air inlet temperature, and relative humidity of 50% using dry processed gas natural gas fuel with 45 Mega Joules per Kilogram lower heating value. Derates shown are based on 15 in-H_2O air intake restriction and 2 in-Hg exhaust back pressure.

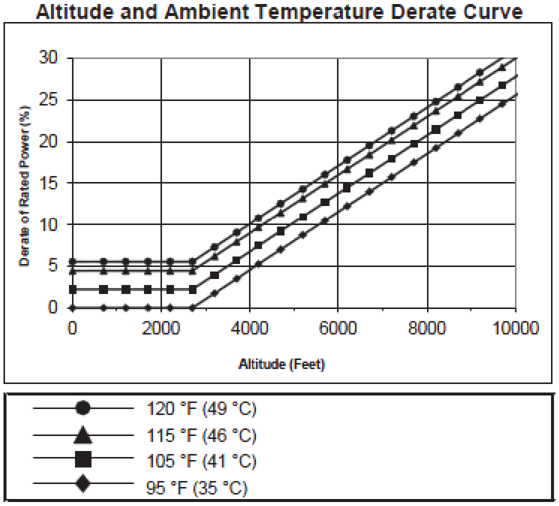
Power output curves are based on the engine operating with fuel system, water pump and lubricating oil pump; not included are battery charging alternator, fan, optional equipment and driven components.

Data Status:Final-(Measured data)

Data Tolerance: +/- 10%

CHIEF ENGINEER: Lynn Zopff

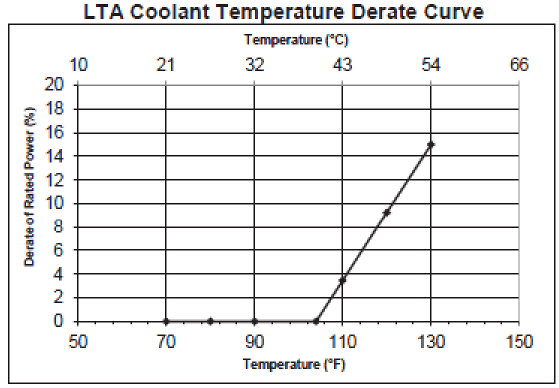
Altitude and Ambient Temperature Derate Curve



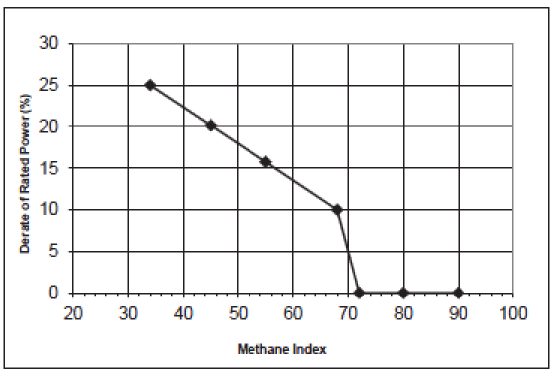
Operation at Elevated Temperature and Altitude:

For continuous operation above these conditions, derate by an additional 3.5% per 1,000 ft (305 m). Do not operate engine at ambient temperatures higher than 120° F (49° C).

LTA Coolant Temperature Derate Curve



Methane Index Derate Curve

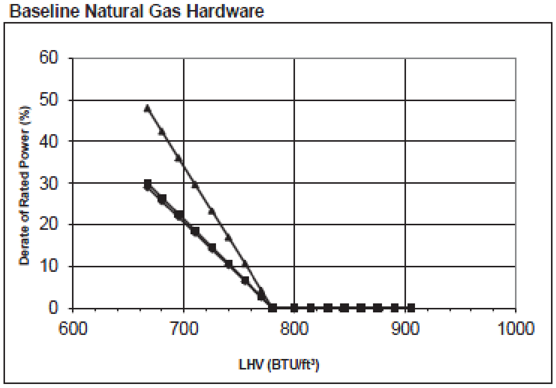


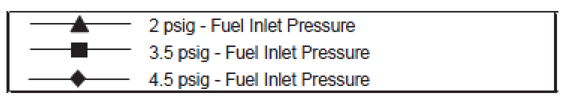
MI > 34: Timing is 17 degrees BTDC

Methane index calculated using AVL 3.2 software. Cummins recommends not including inert gasses when calculating methane index.

Energy Content Derate Curve

Baseline Natural Gas Hardware

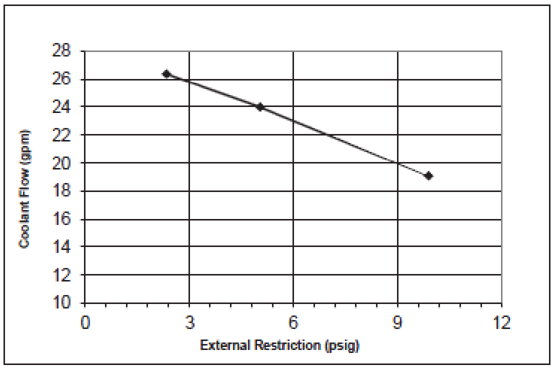




Condensation Derate Table

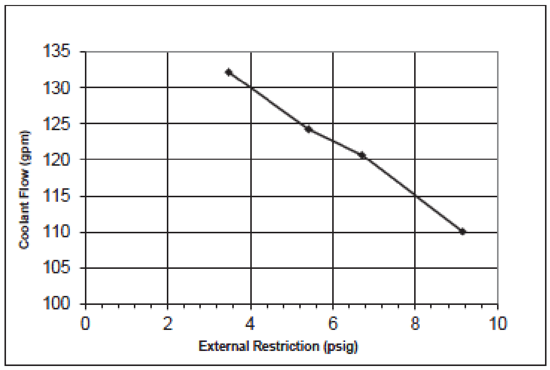
LT Return Temperature	Intake Manifold Temperature	% Derate Due to Condensation										
86°F / 30°C	95°F / 35°C	0	0	0	0	0	7	19	28	37	44	
90°F / 32°C	99°F / 37°C	0	0	0	0	0	0	8	19	29	37	45
93°F / 34°C	102°F / 39°C	0	0	0	0	0	0	0	8	20	29	38
97°F / 36°C	106°F / 41°C	0	0	0	0	0	0	0	0	9	20	30
100°F / 38°C	109°F / 43°C	0	0	0	0	0	0	0	0	0	10	21
104°F / 40°C	113°F / 45°C	0	0	0	0	0	0	0	0	0	0	11
Dewpoint	°F	50	54	57	61	64	68	72	75	79	82	86
	°C	10	12	14	16	18	20	22	24	26	28	30

Aftercooler Coolant Pump Restriction Curve



Engine operation is not recommended with an aftercooler external restriction higher than 8 psi (55 kPa). Engine damage may result if run under unapproved conditions.

Jacket Water Coolant Pump Restriction Curve



Engine operation is not recommended with a jacket water external restriction higher than 8 psi (55 kPa). Engine damage may result if run under unapproved conditions.

General Engine Data				
Type	Four Cycle; Inline; 6 Cylinder			
Aspiration	Turbocharged and Aftercooled			
Compression Ratio	11.0:1			
Bore x Stroke	6.25 x 6.25	in	159 x 159	mm
Displacement	1,150	in^3	18.9	L
Approximate Engine Weight (Wet)	4,534	lbm	2,057	kg
Moment of Inertia of Rotating Components Without Flywheel	16.1	$in\text{-}lbf\text{-}s^2$	1.82	$kg\text{-}m^2$
Center of Gravity				
from Rear Face of Block	23.6	in	599	mm
from Engine Centerline to Left Side of Engine	0.0	in	0.0	mm
above Crankshaft Centerline	11.1	in	282	mm
Maximum Static Loading at Rear Main Bearing	N/A	lbm	N/A	kg
Engine Mounting				
Maximum Bending Moment at Rear Face of Block	1,000	lb-ft	1,356	N-m
Maximum Crankshaft Thrust Bearing Load	750	lbf	3,336	N
Exhaust System				
Maximum Back Pressure	2	in-Hg	7	kPa
Air Induction System				
Maximum Intake Air Restriction				
with Dirty Filter Element	20	$in\text{-}H_2O$	5.0	kPa
with Normal Duty Air Cleaner and Clean Filter Element	10	$in\text{-}H_2O$	2.5	kPa
with Heavy Duty Air Cleaner and Clean Filter Element	15	$in\text{-}H_2O$	3.7	kPa
Cooling System				
Coolant Capacity				
Engine	36	quarts	34.1	L
Aftercoolers	5	quarts	4.7	L
Minimum Pressure Cap Rating at Sea Level	7	psi	48	kPa
Maximum Static Head of Coolant Above Crankshaft Centerline	60	ft	18.3	m
Acceptable Types of Deaeration System	Positive			
<u>Jacket Water Circuit Requirements</u>				
Maximum Coolant Friction Head External to Engine	8	psi	55	kPa
Maximum Coolant Temperature (Maximum Top Tank Temp.)	203	°F	95	°C
Thermostat (Modulating) Range	180 - 202	°F	82 - 94	°C
<u>Aftercooler Circuit Requirements</u>				
Maximum Coolant Friction Head External to Engine	8	psi	55	kPa
Maximum Coolant Temperature Into the Aftercooler	130	°F	54	°C
without Power Derate	104	°F	40	°C
Thermostat (Modulating) Range	80 - 100	°F	27 - 38	°C
Lubrication System				
Oil Pressure				
@ Minimum Low Idle	20	psi	138	kPa
@ Governed Speed	50 - 70	psi	345 - 483	kPa
Maximum Oil Temperature	250	°F	121	°C
Oil System Capacity (Including Filter)	29	gal	110	L
Fuel System				
Minimum Fuel Inlet Pressure @ Inlet of GMF Housing	1	psi	6.9	kPa
Maximum Fuel Inlet Pressure @ Inlet of GMF Housing	5	psi	34.5	kPa
Acceptable Fuel	Pipeline Quality Natural Gas, Low MN Fuel, Low BTU Fuel			
Minimum Fuel Methane Number*	75	MN		
Minimum Fuel Energy Content*	780	BTU/ft^3	29.1	MJ/m^3

* when equipped with original fuel system hardware and original ignition timing, at 2 psig fuel inlet pressure

Electrical System

System Voltage	24	V		
Minimum Battery Capacity: Cold Soak at -18 °C (0 °F) or Above				
Engine Only Cold Cranking Amps	900	CCA		
Engine Only Reserve Capacity	320	min		
Maximum Starting Circuit Resistance	0.002	Ohm		

Cold Start Capability

Unaided Cold Start				
Minimum Cranking Speed	N/A	rpm		
Minimum Ambient Temperature for Unaided Cold Start	45	°F	7.2	°C
Minimum Ambient Temperature for NFPA 110 Cold Start (90 °F Minimum Coolant Temperature)	N/A	°F	N/A	°C
Cranking Torque at Minimum Unaided Cold Start Temperature	N/A	lb-ft	N/A	N-m

Performance Data

All data is based on:
-Engine operating with fuel system, water pump, lubricating oil pump, air cleaner and exhaust silencer; not included are battery charging alternator, fan, and optional driven components
-Engine operating with 905 BTU/ft^3 fuel
-Reference Conditions of:

Barometric Pressure:	99.5 kPa (29.39 in-Hg)	Air Temperature:	25 °C (77 °F)
Altitude:	152 m (500 ft)	Relative Humidity:	50%

Estimated Free Field Sound Pressure Level: 1500 rpm, @ 7.5 m from Engine (ISO-3744)	N/A	dBa
Exhaust Noise at Rated: 1 m Horizontally From Centerline of Exhaust Pipe Outlet, Upwards at 45°: 1500 rpm	N/A	dBa
Steady State Speed Stability at Any Constant Load	+/- 0.75	%
Governed Engine Speed	1,500	rpm
Engine Idle Speed	900	rpm

		Continuous Power		
		100% Load	75% Load	50% Load
Gross Engine Power Output	hp (kWm)	450 (336)	338 (252)	225 (168)
Brake Mean Effective Pressure	psi (kPa)	206 (1422)	155 (1070)	103 (712)
Intake Air Flow	ft^3/min (L/s)	917 (433)	692 (327)	467 (220)
Exhaust Gas Temp - Dry Stack	°F (°C)	946 (508)	941 (505)	943 (506)
Exhaust Gas Flow	ft^3/min (L/s)	2536 (1197)	1922 (907)	1323 (624)
Air to Fuel Ratio (Mass Basis)		26.7:1	25.7:1	24.7:1
Heat Rejection to Ambient	BTU/min (kW)	2277 (40)	1708 (30)	1935 (34)
Heat Rejection to Exhaust	BTU/min (kW)	17133 (301)	12693 (223)	8709 (153)
Heat Rejection to Jacket Coolant	BTU/min (kW)	10701 (188)	9335 (164)	7172 (126)
Engine Jacket Water Flow at:				
5 psi External Friction Head	gpm (L/min)	125 (473)	125 (473)	125 (473)
Maximum Friction Head	gpm (L/min)	115 (435)	115 (435)	115 (435)
Heat Rejection to Aftercooler Coolant	BTU/min (kW)	4098 (72)	3017 (53)	1366 (24)
Engine Aftercooler Water Flow at:				
5 psi External Friction Head	gpm (L/min)	23 (87)	23 (87)	23 (87)
Maximum External Friction Head	gpm (L/min)	21 (79)	21 (79)	21 (79)
Ignition Timing (BTDC)	deg	17	17	17
O_2	%	8.9	8.5	8.0

End of Report

Engine Test Report

[CIC Test Home Page]

SOLD ENGINE

FULL PRINT OUT REPORT

Engine Serial Number:	37250814	Fuel Pump Code:	EN27A03
Date:	06Sep2011	Time:	17:03:26
Engine Hours:	2.23	Cell Hours:	11.29
Test Cell No:	808	Operator Name/No:	32738

No data for ALTERNATOR TEST

FUEL READINGS AT WARMUP Tested On 06Sep2011 At 14:46:19

PARAMETER NAME	UNITS	MIN	FIRST	LAST	MAX
FUEL READINGS AT WARMUP 1800 RPM					
SPEED	RPM	NONE	1502	1503	NONE
TORQUE	LB-FT	NONE	625	114	NONE
AIR RESTRICTION PRESSURE 1	IN_H2O	NONE	0.38	0.00	NONE
FUEL INLET PRESSURE	PSI	NONE	3.08	3.16	NONE
FUEL INLET TEMPERATURE	DEG_F	NONE	66	71	NONE
SSM558 ANFIP	PSIA	NONE	17.422	17.565	NONE
SSM558 ANFOP	PSIA	NONE	14.387	14.470	NONE
SSM558 ANGMF	#/HR	NONE	74.63	28.17	NONE
SSM558 AF PCTDC	%	NONE	26.590	17.527	NONE
SSM558 ANAAP	PSIA	NONE	14.453	14.469	NONE

RATED Tested On 06Sep2011 At 15:40:17

PARAMETER NAME	UNITS	MIN	FIRST	LAST	MAX
RATED 1800 RPM					
SPEED	RPM	1787	1800	1800	1814
TORQUE	LB-FT	1364	1375	1375	5000
MANIFOLD CHARGE PRESSURE	IN_HG	37.0	40.1	40.4	53.0
COMPRESSOR OUTLET PRESSURE	IN_HG	45.0	62.9	61.4	70.0
LT WATER INLET TEMPERATURE	DEG_F	0	86	87	105
MANIFOLD CHARGE TEMP	DEG_F	NONE	97	98	NONE
EGO SENSOR SUPPLY VOLTAGE	VOLT	0.0	0.0	0.0	0.0
LUBE OIL PRESSURE	PSI	60.0	80.9	79.5	80.0
PISTON COOLING PRESSURE 1	PSI	60.0	79.5	78.2	80.0
BLOWBY	IN_H2O	0.1	3.1	2.8	4.0
HORSEPOWER	BHP	NONE	471	471	NONE
WATER TEMPERATURE 1 OUTLET	DEG_F	100	186	188	205
WATER IN TEMPERATURE	DEG_F	169	160	172	181
LUBE OIL TEMPERATURE	DEG_F	194	199	204	220
INLET AIR TEMPERATURE	DEG_F	80	87	84	90
AIR RESTRICTION PRESSURE 1	IN_H2O	14.00	5.15	14.57	16.00
EXHAUST STACK PRESSURE 1	IN_HG		-0.03	-0.04	1.60
FUEL INLET TEMPERATURE	DEG_F	NONE	78	79	NONE
FUEL INLET PRESSURE	PSI	NONE	2.76	2.75	NONE
EXHAUST STACK TEMPERATURE	DEG_F	0	953	951	0
RATED OXYGEN	%	NONE	8.89	8.91	NONE
SSM558 ANNGKOFF	N/A	NONE	5.0000	5.0000	NONE
SSM558 ANMAP	PSIA	NONE	34.302	34.420	NONE
SSM558 ENGRPM	RPM	NONE	1799.966	1800.045	NONE
MCM700 ENGRPM	RPM	NONE	1799.820	1800.678	NONE
SSM558 ANVBT	VOLT	NONE	24.994	24.994	NONE
MCM700 ANVBT	VOLT	NONE	24.931	24.931	NONE
SSM558 ANFIP	PSIA	NONE	17.141	17.145	NONE
SSM558 ANFOP	PSIA	NONE	14.076	13.704	NONE
SSM558 ANGMF	#/HR	NONE	165.73	165.78	NONE
SSM558 ANIMT	DEGF	NONE	116.576	118.349	NONE
SSM558 ANEBP	PSIA	NONE	14.3631	14.3679	NONE
SSM558 THDCCD	%	NONE	35.870	36.453	NONE
SSM558 AF PCTDC	%	NONE	38.727	37.936	NONE
SSM558 ANKNOCK5	VOLT	NONE	1.396	1.388	NONE
SSM558 ANKNOCK6	VOLT	NONE	1.605	1.573	NONE
SSM558 ANAAP	PSIA	NONE	14.469	14.469	NONE

LOW IDLE Tested On 06Sep2011 At 15:42:54

PARAMETER NAME	UNITS	MIN	FIRST	LAST	MAX
LOW IDLE					
SPEED	RPM	700	900	900	1349
TORQUE	LB-FT	NONE	82	82	NONE
COMPRESSOR OUTLET PRESSURE	IN_HG	NONE	0.9	0.9	NONE
MANIFOLD CHARGE TEMP	DEG_F	NONE	120	120	NONE

MANIFOLD CHARGE PRESSURE	IN_HG	NONE	-3.1	-3.1	NONE
AIR RESTRICTION PRESSURE 1	IN_H2O	NONE	0.00	0.00	NONE
EXHAUST STACK PRESSURE 1	IN_HG	NONE	-0.03	-0.03	NONE
LUBE OIL PRESSURE	PSI	25.0	50.1	50.1	100.0
FUEL INLET TEMPERATURE	DEG_F	NONE	80	80	NONE
FUEL INLET PRESSURE	PSI	NONE	3.11	3.11	NONE
EXHAUST STACK TEMPERATURE	DEG_F	NONE	877	877	NONE
PISTON COOLING PRESSURE 1	PSI	NONE	49.5	49.5	NONE
BLOWBY	IN_H2O	NONE	0.1	0.1	NONE
WATER TEMPERATURE 1 OUTLET	DEG_F	NONE	180	180	NONE
WATER IN TEMPERATURE	DEG_F	NONE	158	158	NONE
LUBE OIL TEMPERATURE	DEG_F	NONE	200	200	NONE
INLET AIR TEMPERATURE	DEG_F	NONE	85	85	NONE
SSM558 ENGRPM	RPM	NONE	906.813	906.813	NONE
MCM700 ENGRPM	RPM	NONE	890.669	890.669	NONE
SSM558 ANFIP	PSIA	NONE	17.600	17.600	NONE
SSM558 ANFOP	PSIA	NONE	14.476	14.476	NONE
SSM558 ANGMF	#/HR	NONE	18.04	18.04	NONE
SSM558 ANIMT	DEGF	NONE	135.267	135.267	NONE
SSM558 ANEBP	PSIA	NONE	14.3456	14.3456	NONE
SSM558 THDCCD	%	NONE	14.101	14.101	NONE
SSM558 AF PCTDC	%	NONE	10.000	10.000	NONE
SSM558 ANKNOCK5	VOLT	NONE	0.859	0.859	NONE
SSM558 ANKNOCK6	VOLT	NONE	0.880	0.880	NONE
SSM558 ANAAP	PSIA	NONE	14.469	14.469	NONE
SSM558 ANMAP	PSIA	NONE	5.194	5.194	NONE

Appendix E – Cummins QSK19 NO_x Tuning Procedure

Emissions Setup Procedure at Customer Site using Calterm on Q19G units with TOB Feature

No Load (Fan Power and Parasitic) – Assumed as 25 KW
Alternator Efficiency – Assumed as 95%
100% Load – (352-25)*0.95 = 310 KWe
If there is no fan power and parasitic, then 100% load will be 334 KWe with 95% alternator efficiency.

1. Download the new calibrations (SSM 558 and MCM 700) with TOB feature to the respective modules using Calterm tool.
2. Populate the Calterm screen file with the parameters provided as a text file.
3. Start the engine and let it operate at no load.

EMISSIONS ANALYZER NOT AVAILABLE AT SITE

1. Gradually increase the load in 10% intervals to 50% load and let it warm up for good 30 minutes.
2. Gradually increase the load in 10% intervals to 100% and make sure the engine runs stable.
3. Proceed with the steps below if the emissions analyzer is available.

OPEN LOOP on TOB CONTROL TUNING

1. If the hand held emissions analyzer is available then operate the engine at no load in open loop control (TOB inactive) by setting C_TBGN parameter to 0.
2. Gradually add load steps in 10% to make it 100% and allow the generator set to run for 15 minutes.
3. The NOx targets at different units at 100% load both speeds are given below in tabular format.
4. If the NOx measurement is higher than the target, then the mixture should be made leaner by applying a positive offset to C_LMDOFF.
5. If the NOx measurement is lower than the target, then the mixture should be made richer by applying a negative offset to C_LMDOFF.
6. Wait for 3-4 minutes for the offset to take effect and monitor NOx emissions. Emissions data recorded must be an average value over a minimum of 3 minute period.
7. Log calterm data for 2 minutes
8. Run the engine at 75% and 50% load and record emissions and calterm data
9. Note the final offset value (C_LMDOFF) that satisfies NOx emissions target for 100%, 75% and 50% loads.

10. Iterate the above steps until an offset is obtained that will satisfy emissions at 3 loads.
11. Satisfactory tuning should be achievable with values of +/- 0.4 for open loop offset. If larger values are required contact G-drive for assistance.
12. Operate at no load and verify the exhaust oxygen meets the no load (verify that ANMAP is below 10 PSIa) target (dry O2 curve Vs manifold pressure) to make sure the shift in lambda has not affected the open loop operation at no load. If not, adjust ANNGKOFF parameter to meet the oxygen target (Reduction in number will increase % oxygen and increase in number will lower the % oxygen).

CLOSED LOOP CONTROL TUNING

1. Ensure the engine is in open loop condition (C_TBGN=0).
2. Gradually add load steps in 10% to make it 100% and allow the generator set to stabilize.
3. Monitor the parameters TB_DES and TOB_SENS and note the difference between them.
4. Apply an offset equal to the difference between the desired and sensed values in calterm to the parameter C_TBOFF.
5. Reduce the load back to 50% and switch to closed loop operation by setting the parameter C_TBGN to 1.
6. Increase the load in 10% intervals back to 100% and allow the genset to stabilize for 15 minutes before recording emissions data.
7. The NOx targets in different units at 100% load both speeds are given below in tabular format.
8. If the NOx measurement is lower than the target, then the mixture should be made richer by applying a positive offset to C_TBOFF.
9. If the NOx measurement is higher than the target, then the mixture should be made leaner by applying a negative offset to C_TBOFF.
10. Wait for 3-4 minutes for the offset to take effect and monitor NOx emissions.
11. Log calterm data for 2 minutes
12. Run the engine at 75% and 50% load and record emissions and calterm data.
13. Note the final closed loop fueling offset value (C_TBOFF) that satisfies NOx emissions target for 100%, 75% and 50% loads.
14. Satisfactory tuning should be achievable with values of +/- 0.05 for closed loop offset. If larger values are required contact G-drive for assistance
15. The determined final closed loop fueling offset value needs to be saved permanently in the calibration. It can be done by having the calterm in default mode and setting the parameter C_TBOFF or modifying the parameter C_TBOFF to the determined value and downloading a new calibration back to the module.

16. Please contact G-drive Gas Application Engineering, Sudharsan (763-574-5143(W)) if you have any questions at any point.

Q19G Emissions Data	Nox Emissions Level				
	g/bhp-hr	mg/Nm^3 @5% O2	PPM, dry	K_{DW} (Dry to Wet Factor)	PPM, wet
60 Hz, FR 4560 (1g/bhp-hr NOx)					
100% Load	0.90	363	136	0.87	119
75% Load	0.88	345	134	0.87	116
50% Load	0.84	314	124	0.86	107
50 Hz, FR 4562 (500mg/Nm3 Nox)					
100% Load	1.02	445	163	0.87	143
75% Load	0.93	392	150	0.87	131
50% Load	1.04	417	163	0.86	141

Dry Oxygen Vs Manifold Pressure below 10 PSIa

1800 rpm 1gm/BHP-hr NOx

O2 (dry)	%	7.103	5.7833	3.8038
ECM_ANMAP_A	PSIa	10.118	7.2579	4.947

1500 rpm 500 mg/Nm3 NOx

O2 (dry)	%	6.9273	5.8911	2.1512
ECM_ANMAP_A	PSIa	9.9581	6.9393	4.2222

Appendix F – Baseline and Lean Limit Tabular Data

Data Point Name	QSK-100-Base-01	QSK-90-Base-08	QSK-75-Base-09	QSK-50-Base-10	QSK-25-Base-11
Engine Data					
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	4.51E+02	4.06E+02	3.38E+02	2.25E+02	1.14E+02
Power[kW]	3.36E+02	3.03E+02	2.52E+02	1.68E+02	8.48E+01
Torque[ft-lb]	1.58E+03	1.42E+03	1.18E+03	7.89E+02	3.98E+02
Fuel Flow[#ph]	1.57E+02	1.42E+02	1.22E+02	8.67E+01	5.03E+01
Fuel Pressure[psig]	4.81E+00	4.84E+00	4.87E+00	4.92E+00	4.95E+00
Fuel Temp[F]	9.14E+01	9.44E+01	9.47E+01	9.54E+01	9.67E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.54E+01	3.24E+01	2.75E+01	1.93E+01	1.12E+01
IC Diff Pressure[inH2O]	2.43E-01	-5.76E-01	-1.53E+00	-1.12E+00	-4.57E-01
Boost Pressure[psig]	2.96E+01	2.88E+01	2.70E+01	1.74E+01	6.79E+00
Inlet Air Temperature[F]	1.00E+02	9.99E+01	1.00E+02	9.96E+01	9.98E+01
Intake Manifold Temp[F]	1.30E+02	1.30E+02	1.30E+02	1.28E+02	1.28E+02
Boost Temp[F]	3.52E+02	3.45E+02	3.33E+02	2.62E+02	1.67E+02
Inlet Air RH[%]	5.02E+01	5.09E+01	5.11E+01	5.15E+01	4.68E+01
Exhaust Back Pres[inHg]	4.70E+00	4.70E+00	4.70E+00	4.70E+00	4.70E+00
EMAP[psia]	3.98E+01	3.72E+01	3.34E+01	2.55E+01	1.83E+01
Exhaust Temp[F]	9.69E+02	9.61E+02	9.51E+02	9.82E+02	1.02E+03
Turbine In Temp[F]	1.20E+03	1.19E+03	1.18E+03	1.14E+03	1.08E+03
Exh Port 1[F]	1.09E+03	1.09E+03	1.09E+03	1.07E+03	1.07E+03
Exh Port 2[F]	1.09E+03	1.09E+03	1.09E+03	1.07E+03	1.07E+03
Exh Port 3[F]	1.10E+03	1.09E+03	1.09E+03	1.06E+03	1.07E+03
Exh Port 4[F]	1.11E+03	1.10E+03	1.08E+03	1.06E+03	1.07E+03
Exh Port 5[F]	1.11E+03	1.10E+03	1.09E+03	1.07E+03	1.07E+03
Exh Port 6[F]	1.08E+03	1.07E+03	1.06E+03	1.04E+03	1.04E+03
JW In Temp[F]	1.79E+02	1.79E+02	1.80E+02	1.81E+02	1.83E+02
JW Out Temp[F]	1.89E+02	1.89E+02	1.89E+02	1.89E+02	1.89E+02
ACW In Temp[F]	1.14E+02	1.16E+02	1.16E+02	1.16E+02	1.16E+02
ACW Out Temp[F]	1.24E+02	1.25E+02	1.24E+02	1.20E+02	1.17E+02
Dyno In Temp[F]	9.11E+01	9.67E+01	9.75E+01	9.36E+01	9.06E+01
Dyno Out Temp[F]	1.16E+02	1.19E+02	1.16E+02	1.06E+02	9.71E+01
Oil Sump Temp[F]	2.14E+02	2.13E+02	2.12E+02	2.09E+02	2.06E+02
Oil Rifle Temp[F]	2.07E+02	2.06E+02	2.05E+02	2.03E+02	2.02E+02
Oil Pressure[psig]	6.87E+01	6.90E+01	7.01E+01	7.21E+01	7.46E+01
THC[ppm dry]	1.95E+03	1.95E+03	1.98E+03	2.21E+03	2.25E+03
O2[%dry]	8.63E+00	8.69E+00	8.52E+00	8.36E+00	7.00E+00

NOx[ppm dry]	1.46E+02	1.47E+02	1.26E+02	9.09E+01	1.99E+02
NO[ppm dry]	8.42E+01	9.02E+01	6.61E+01	3.57E+01	1.07E+02
NO2[ppm dry]	6.22E+01	5.72E+01	6.02E+01	5.52E+01	9.12E+01
NO2/NOx	4.25E-01	3.88E-01	4.77E-01	6.08E-01	4.59E-01
CO2[% dry]	7.14E+00	7.14E+00	7.28E+00	7.43E+00	8.16E+00
CO[ppm dry]	5.52E+02	5.69E+02	5.43E+02	5.11E+02	5.87E+02
Supercharger Speed	3.37E+01	3.19E+01	2.84E+01	2.31E+01	1.67E+01
SC IC CV Pos.	7.42E+01	7.51E+00	9.54E+01	1.00E+02	1.00E+02
Steam Valve Position	1.69E+01	1.76E+01	1.70E+01	1.13E+01	6.79E+00
ICW CV Pos.	3.31E+01	3.77E+01	4.01E+01	4.54E+01	5.12E+01
Exh Back Pres CV	6.16E+01	6.30E+01	6.75E+01	7.69E+01	8.71E+01
JW Temp Valve Pos.	6.02E+01	6.21E+01	6.29E+01	6.42E+01	6.33E+01
Jacket Water Flow Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	1.37E+02	1.36E+02	1.36E+02	1.36E+02	1.36E+02
Intercooler Flow [gpm]	1.37E+02	1.37E+02	1.38E+02	1.38E+02	1.38E+02
Dyno Water Flow [gpm]	1.10E+02	1.10E+02	1.09E+02	1.09E+02	1.09E+02
Boiler Return Temp [C]	5.61E+01	6.32E+01	6.01E+01	5.59E+01	5.79E+01
Boiler Supply Temp [C]	5.61E+01	6.33E+01	6.03E+01	5.58E+01	5.76E+01
BMEP[psi]	2.05E+02	1.85E+02	1.54E+02	1.03E+02	5.18E+01
Ambient Pressure[psia]	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Propane Flow[lb/hr]	9.70E+00	8.08E+00	6.93E+00	5.80E+00	3.37E+00
Propane Valve Pos	6.70E+00	5.02E+00	4.47E+00	4.22E+00	3.03E+00
Propane VFD speed	7.68E+01	7.10E+01	6.43E+01	5.86E+01	4.46E+01
Propane Pressure[psig]	2.50E+01	2.50E+01	2.48E+01	2.50E+01	2.50E+01
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data					
PHI Comb.	6.29E-01	6.25E-01	6.35E-01	6.44E-01	7.06E-01
BSFC [BTU/BHP_hr]	6.98E+03	7.06E+03	7.24E+03	7.72E+03	8.89E+03
Stoich. A/F	1.68E+01	1.67E+01	1.68E+01	1.67E+01	1.67E+01
U & S A/F	2.68E+01	2.68E+01	2.64E+01	2.60E+01	2.37E+01
U & S Total A/F	2.52E+01	2.57E+01	2.52E+01	2.47E+01	2.25E+01
Air Flow [lb/hr]	4.07E+03	3.74E+03	3.14E+03	2.22E+03	1.21E+03
BMEP [psi]	2.05E+02	1.85E+02	1.54E+02	1.03E+02	5.17E+01
Thermal Eff. [%]	3.64E+01	3.60E+01	3.52E+01	3.29E+01	2.86E+01
Wobbe Index [BTU/cuft]	1.26E+03	1.30E+03	1.28E+03	1.30E+03	1.29E+03
Methane [%]	8.63E+01	8.12E+01	8.19E+01	7.94E+01	8.03E+01
LHV [BTU/cuft]	1.04E+03	1.09E+03	1.07E+03	1.10E+03	1.09E+03

Abs. Humidity	1.43E+02	1.60E+02	1.87E+02	2.57E+02	4.21E+02
NOx @ 15% O2 [BHP-hr]	7.04E+01	7.12E+01	6.01E+01	4.27E+01	8.43E+01
BS THC [g/BHP-hr]	4.88E+00	5.25E+00	5.27E+00	6.34E+00	6.71E+00
BS NOx Actual [g/BHP-hr]	7.08E-01	7.15E-01	6.39E-01	5.10E-01	1.10E+00
BS NOx EPA Meth. 20 [g/BHP-hr]	8.85E-01	9.08E-01	7.82E-01	5.91E-01	1.35E+00
BS NO FTIR [g/BHP-hr]	3.32E-01	3.63E-01	2.67E-01	1.51E-01	4.77E-01
BS NO2 FTIR [g/BHP-hr]	3.76E-01	3.52E-01	3.73E-01	3.59E-01	6.22E-01
BS CO [g/BHP-hr]	2.03E+00	2.14E+00	2.05E+00	2.02E+00	2.44E+00
BS CO2 [g/BHP-hr]	4.13E+02	4.21E+02	4.31E+02	4.62E+02	5.32E+02
PHI Total	6.36E-01	6.26E-01	6.36E-01	6.45E-01	7.09E-01
H2O MF	3.84E+02	3.55E+02	3.14E+02	2.43E+02	1.65E+02
Exh MF	4.22E+03	3.88E+03	3.26E+03	2.31E+03	1.26E+03
BS O2 [g/BHP-hr]	3.63E+02	3.72E+02	3.67E+02	3.78E+02	3.32E+02
Gas Density [lbm/1000cuft]	5.45E+01	5.72E+01	5.63E+01	5.80E+01	5.75E+01
Methane Number	9.28E+01	6.71E+01	6.14E+01	6.29E+01	6.00E+01
Vapor Pressure[kPa]	1.12E+00	1.15E+00	1.13E+00	1.08E+00	9.89E-01
Combustion Data					
Cylinder 1-5 avg 50% Burn Loc	20.1699	19.895	19.931	21.173	18.79
Cylinder 1-5 avg 0-10% Burn Dur	21.9887	21.927	22.183	22.94	22.016
Cylinder 1-5 avg 10-90% Burn Dur	30.7253	30.87	30.299	30.985	26.68
Cylinder 1-5 avg COV PP	6.927	12.267	8.573	7.463	8.01
Cylinder 1-5 avg COV IMEP	2.437	7.568	4.205	2.585	1.893
Cylinder 1-5 avg PP Location	20.333	19.851	20.444	20.661	23.012
Cylinder 6 50% Burn Loc	17.089	17.233	17.101	18.048	16.761
Cylinder 6 0-10% Burn Dur	22.1066	22.245	22.449	22.993	22.451
Cylinder 6 10-90% Burn Dur	27.5403	28.556	27.7254	28.236	26.2708
Cylinder 6 COV PP	6.721	12.49	8.177	7.264	7.235
Cylinder 7 COV IMEP	2.081	6.803	3.612	2.112	1.609
Cylinder 8 PP Location	19.274	18.972	19.46	20.134	21.122
FMEP [psi]	20.30	18.75	17.10	14.10	12.60
PMEP [psi]	14.81	14.61	14.10	12.00	10.96
Calterm Data					
Spark Timing [cylinder 1-5 avg]	16.99	17.11	17.2	17.025	16.84
Spark Timing [cylinder 6]	18.99	19.11	19.19	19.03	18.84

Data Point Name	QSK-100-Lean-02	QSK-100-Lean-03	QSK-100-Lean-04	QSK-100-Lean-05	QSK-100-Lean-06
Engine Data					
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	4.51E+02	4.51E+02	4.51E+02	4.51E+02	4.50E+02
Power[kW]	3.36E+02	3.36E+02	3.36E+02	3.36E+02	3.36E+02
Torque[ft-lb]	1.58E+03	1.58E+03	1.58E+03	1.58E+03	1.58E+03
Fuel Flow[#ph]	1.56E+02	1.61E+02	1.67E+02	1.66E+02	1.60E+02
Fuel Pressure[psig]	4.81E+00	4.80E+00	4.80E+00	4.81E+00	4.82E+00
Fuel Temp[F]	9.23E+01	9.30E+01	9.34E+01	9.36E+01	9.38E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.62E+01	3.82E+01	4.02E+01	3.94E+01	3.72E+01
IC Diff Pressure[inH2O]	7.18E-01	1.70E+00	3.08E+00	2.62E+00	1.38E+00
Boost Pressure[psig]	2.98E+01	3.00E+01	2.97E+01	2.98E+01	2.98E+01
Inlet Air Temperature[F]	1.01E+02	9.99E+01	1.00E+02	1.00E+02	1.00E+02
Intake Manifold Temp[F]	1.28E+02	1.30E+02	1.31E+02	1.30E+02	1.29E+02
Boost Temp[F]	3.55E+02	3.60E+02	3.68E+02	3.64E+02	3.56E+02
Inlet Air RH[%]	5.05E+01	5.07E+01	4.98E+01	4.94E+01	4.97E+01
Exhaust Back Pres[inHg]	4.70E+00	4.71E+00	4.70E+00	4.70E+00	4.70E+00
EMAP[psia]	4.07E+01	4.26E+01	4.50E+01	4.40E+01	4.17E+01
Exhaust Temp[F]	9.71E+02	9.71E+02	9.68E+02	9.67E+02	9.64E+02
Turbine In Temp[F]	1.20E+03	1.21E+03	1.22E+03	1.21E+03	1.20E+03
Exh Port 1[F]	1.09E+03	1.09E+03	1.10E+03	1.09E+03	1.09E+03
Exh Port 2[F]	1.10E+03	1.10E+03	1.10E+03	1.10E+03	1.09E+03
Exh Port 3[F]	1.10E+03	1.10E+03	1.11E+03	1.10E+03	1.10E+03
Exh Port 4[F]	1.11E+03	1.11E+03	1.11E+03	1.11E+03	1.11E+03
Exh Port 5[F]	1.12E+03	1.12E+03	1.12E+03	1.12E+03	1.11E+03
Exh Port 6[F]	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
JW In Temp[F]	1.79E+02	1.79E+02	1.78E+02	1.78E+02	1.78E+02
JW Out Temp[F]	1.89E+02	1.90E+02	1.88E+02	1.88E+02	1.89E+02
ACW In Temp[F]	1.10E+02	1.12E+02	1.10E+02	1.10E+02	1.11E+02
ACW Out Temp[F]	1.21E+02	1.24E+02	1.23E+02	1.23E+02	1.23E+02
Dyno In Temp[F]	9.45E+01	9.70E+01	9.67E+01	9.80E+01	9.92E+01
Dyno Out Temp[F]	1.19E+02	1.22E+02	1.21E+02	1.22E+02	1.24E+02
Oil Sump Temp[F]	2.13E+02	2.13E+02	2.13E+02	2.11E+02	2.13E+02
Oil Rifle Temp[F]	2.07E+02	2.07E+02	2.06E+02	2.04E+02	2.06E+02
Oil Pressure[psig]	6.79E+01	6.77E+01	6.88E+01	6.93E+01	6.87E+01
THC[ppm dry]	2.09E+03	2.33E+03	2.65E+03	2.48E+03	2.12E+03
O2[%dry]	8.83E+00	9.24E+00	9.61E+00	9.53E+00	9.15E+00
NOx[ppm dry]	9.82E+01	5.63E+01	3.40E+01	3.84E+01	6.70E+01
NO[ppm dry]	4.93E+01	2.02E+01	4.92E+00	7.80E+00	2.60E+01
NO2[ppm dry]	4.90E+01	3.61E+01	2.91E+01	3.06E+01	4.10E+01

NO2/NOx	4.99E-01	6.41E-01	8.55E-01	7.97E-01	6.12E-01
CO2[% dry]	7.00E+00	6.80E+00	6.61E+00	6.70E+00	6.92E+00
CO[ppm dry]	5.54E+02	6.26E+02	7.81E+02	7.31E+02	5.90E+02
Supercharger Speed	3.47E+01	3.62E+01	3.78E+01	3.73E+01	3.56E+01
SC IC CV Pos.	3.33E+01	3.92E+01	8.27E+01	1.79E-01	4.98E-01
Steam Valve Position	1.71E+01	1.68E+01	1.84E+01	1.98E+01	1.89E+01
ICW CV Pos.	3.60E+01	3.51E+01	2.89E+01	3.37E+01	3.69E+01
Exh Back Pres CV	6.07E+01	5.95E+01	5.81E+01	5.87E+01	6.01E+01
JW Temp Valve Pos.	6.08E+01	6.00E+01	6.13E+01	6.21E+01	6.15E+01
Jacket Water Flow Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	1.37E+02	1.37E+02	1.37E+02	1.37E+02	1.37E+02
Intercooler Flow [gpm]	1.36E+02	1.36E+02	1.36E+02	1.36E+02	1.36E+02
Dyno Water Flow [gpm]	1.10E+02	1.10E+02	1.10E+02	1.10E+02	1.10E+02
Boiler Return Temp [C]	6.51E+01	6.38E+01	6.05E+01	5.78E+01	5.61E+01
Boiler Supply Temp [C]	6.25E+01	6.38E+01	6.06E+01	5.78E+01	5.59E+01
BMEP[psi]	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02
Ambient Pressure[psia]	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Propane Flow[lb/hr]	9.69E+00	9.98E+00	1.04E+01	1.02E+01	9.13E+00
Propane Valve Pos	6.74E+00	6.88E+00	7.27E+00	7.23E+00	6.15E+00
Propane VFD speed	7.75E+01	7.84E+01	7.90E+01	7.85E+01	7.51E+01
Propane Pressure[psig]	2.50E+01	2.50E+01	2.48E+01	2.49E+01	2.50E+01
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data					
PHI Comb.	6.20E-01	6.03E-01	5.89E-01	5.92E-01	6.06E-01
BSFC [BTU/BHP_hr]	7.07E+03	7.29E+03	7.56E+03	7.45E+03	7.17E+03
Stoich. A/F	1.68E+01	1.68E+01	1.68E+01	1.68E+01	1.67E+01
U & S A/F	2.72E+01	2.79E+01	2.85E+01	2.83E+01	2.76E+01
U & S Total A/F	2.60E+01	2.68E+01	2.75E+01	2.72E+01	2.65E+01
Air Flow [lb/hr]	4.17E+03	4.40E+03	4.67E+03	4.58E+03	4.32E+03
BMEP [psi]	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02
Thermal Eff. [%]	3.60E+01	3.49E+01	3.37E+01	3.42E+01	3.55E+01
Wobbe Index [BTU/cuft]	1.28E+03	1.28E+03	1.30E+03	1.30E+03	1.30E+03
Methane [%]	8.66E+01	8.58E+01	8.35E+01	8.15E+01	7.98E+01
LHV [BTU/cuft]	1.05E+03	1.06E+03	1.08E+03	1.09E+03	1.10E+03
Abs. Humidity	1.31E+02	1.33E+02	1.26E+02	1.25E+02	1.31E+02
NOx @ 15% O2 [BHP-hr]	4.80E+01	2.85E+01	1.78E+01	1.99E+01	3.36E+01
BS THC [g/BHP-hr]	5.40E+00	6.42E+00	7.93E+00	7.38E+00	6.01E+00

BS NOx Actual [g/BHP-hr]	5.04E-01	3.24E-01	2.26E-01	2.44E-01	3.74E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	6.10E-01	3.70E-01	2.38E-01	2.63E-01	4.33E-01
BS NO FTIR [g/BHP-hr]	1.99E-01	8.66E-02	2.24E-02	3.49E-02	1.10E-01
BS NO2 FTIR [g/BHP-hr]	3.04E-01	2.37E-01	2.03E-01	2.09E-01	2.65E-01
BS CO [g/BHP-hr]	2.09E+00	2.50E+00	3.32E+00	3.05E+00	2.32E+00
BS CO2 [g/BHP-hr]	4.16E+02	4.27E+02	4.42E+02	4.39E+02	4.28E+02
PHI Total	6.24E-01	6.06E-01	5.91E-01	5.93E-01	6.06E-01
H2O MF	3.82E+02	3.96E+02	4.03E+02	3.96E+02	3.84E+02
Exh MF	4.32E+03	4.56E+03	4.83E+03	4.74E+03	4.48E+03
BS O2 [g/BHP-hr]	3.81E+02	4.22E+02	4.67E+02	4.54E+02	4.11E+02
Gas Density [lbm/1000cuft]	5.44E+01	5.48E+01	5.60E+01	5.69E+01	5.77E+01
Methane Number	6.64E+01	6.74E+01	6.64E+01	6.37E+01	6.18E+01
Vapor Pressure[kPa]	1.06E+00	1.13E+00	1.13E+00	1.10E+00	1.09E+00
Combustion Data					
Cylinder 1-5 avg 50% Burn Loc	21.449	23.418	25.017	24.418	22.303
Cylinder 1-5 avg 0-10% Burn Dur	22.569	23.2928	23.999	23.6617	22.852
Cylinder 1-5 avg 10-90% Burn Dur	32.751	36.5332	40.3529	38.9993	34.407
Cylinder 1-5 avg COV PP	6.963	6.532	5.911	6.465	6.952
Cylinder 1-5 avg COV IMEP	2.94	3.833	4.955	4.884	3.469
Cylinder 1-5 avg PP Location	19.175	16.439	13.669	14.649	17.92
Cylinder 6 50% Burn Loc	17.991	19.46	21.686	20.897	18.476
Cylinder 6 0-10% Burn Dur	22.516	23.043	24.0538	23.594	22.633
Cylinder 6 10-90% Burn Dur	29.22	32.112	37.11	35.404	30.3
Cylinder 6 COV PP	6.739	6.936	6.928	7.227	6.969
Cylinder 7 COV IMEP	2.391	3.154	4.65	4.27	2.791
Cylinder 8 PP Location	18.751	17.58	15.354	16.169	18.27
Calterm Data					
Throttle Position [% Open]	39.39	43.45	57.23	48.54	41.61
Spark Timing [cylinder 1-5 avg]	17	16.975	17.215	17.055	16.97
Spark Timing [cylinder 6]	19	18.98	19.23	19.05	18.97

Data Point Name	QSK-100-Base-01	QSK-100-Base-02	QSK-90-Base-03	QSK-75-Base-04	QSK-50-Base-05	QSK-35-Base-06
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	4.71E+02	4.71E+02	4.24E+02	3.53E+02	2.36E+02	1.64E+02

Power[kW]	3.51E+02	3.51E+02	3.16E+02	2.63E+02	1.76E+02	1.23E+02
Torque[ft-lb]	1.38E+03	1.38E+03	1.24E+03	1.03E+03	6.87E+02	4.80E+02
Fuel Flow[#ph]	1.73E+02	1.73E+02	1.58E+02	1.37E+02	9.90E+01	7.62E+01
Fuel Pressure[psig]	4.78E+00	4.78E+00	4.81E+00	4.85E+00	4.90E+00	4.92E+00
Fuel Temp[F]	9.23E+01	9.34E+01	9.40E+01	9.45E+01	9.50E+01	9.53E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.36E+01	3.36E+01	3.05E+01	2.64E+01	1.92E+01	1.49E+01
IC Diff Pressure[inH2O]	2.72E-01	2.38E-01	-1.08E+00	-1.96E+00	-1.88E+00	-1.20E+00
Boost Pressure[psig]	2.98E+01	2.99E+01	2.96E+01	2.83E+01	2.12E+01	1.46E+01
Inlet Air Temperature[F]	1.00E+02	1.00E+02	1.01E+02	1.01E+02	1.00E+02	1.00E+02
Intake Manifold Temp[F]	1.30E+02	1.30E+02	1.30E+02	1.29E+02	1.30E+02	1.31E+02
Boost Temp[F]	3.59E+02	3.60E+02	3.51E+02	3.39E+02	2.91E+02	2.38E+02
Inlet Air RH[%]	5.08E+01	5.10E+01	5.09E+01	5.16E+01	5.07E+01	4.98E+01
Exhaust Back Pres[inHg]	4.70E+00	4.70E+00	4.70E+00	4.69E+00	4.70E+00	4.70E+00
EMAP[psia]	4.25E+01	4.26E+01	3.93E+01	3.55E+01	2.81E+01	2.34E+01
Exhaust Temp[F]	1.01E+03	1.01E+03	1.01E+03	1.00E+03	1.01E+03	1.03E+03
Turbine In Temp[F]	1.24E+03	1.24E+03	1.23E+03	1.22E+03	1.19E+03	1.16E+03
Exh Port 1[F]	1.15E+03	1.15E+03	1.15E+03	1.15E+03	1.13E+03	1.12E+03
Exh Port 2[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.13E+03	1.12E+03
Exh Port 3[F]	1.15E+03	1.15E+03	1.14E+03	1.14E+03	1.13E+03	1.11E+03
Exh Port 4[F]	1.17E+03	1.17E+03	1.16E+03	1.15E+03	1.12E+03	1.11E+03
Exh Port 5[F]	1.17E+03	1.18E+03	1.17E+03	1.16E+03	1.14E+03	1.12E+03
Exh Port 6[F]	1.14E+03	1.14E+03	1.14E+03	1.13E+03	1.10E+03	1.09E+03
JW In Temp[F]	1.77E+02	1.77E+02	1.77E+02	1.77E+02	1.78E+02	1.79E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.84E+02	1.85E+02
ACW In Temp[F]	1.13E+02	1.13E+02	1.15E+02	1.15E+02	1.19E+02	1.20E+02
ACW Out Temp[F]	1.25E+02	1.25E+02	1.26E+02	1.24E+02	1.24E+02	1.23E+02
Dyno In Temp[F]	9.90E+01	1.01E+02	1.02E+02	1.01E+02	9.87E+01	9.52E+01
Dyno Out Temp[F]	1.25E+02	1.27E+02	1.25E+02	1.20E+02	1.12E+02	1.05E+02
Oil Sump Temp[F]	2.15E+02	2.15E+02	2.14E+02	2.12E+02	2.10E+02	2.07E+02
Oil Rifle Temp[F]	2.06E+02	2.05E+02	2.05E+02	2.04E+02	2.02E+02	2.00E+02
Oil Pressure[psig]	7.49E+01	7.53E+01	7.60E+01	7.63E+01	7.79E+01	7.83E+01
THC[ppm dry]	1.61E+03	1.62E+03	1.70E+03	1.86E+03	2.10E+03	2.30E+03
O2[%dry]	~~0.00E+00~~	8.43E+00	8.36E+00	8.35E+00	8.21E+00	8.16E+00
NOx[ppm dry]	1.37E+02	1.36E+02	1.30E+02	9.86E+01	7.74E+01	5.65E+01
NO[ppm dry]	7.17E+01	7.03E+01	6.69E+01	4.65E+01	3.48E+01	2.03E+01
NO2[ppm dry]	6.53E+01	6.58E+01	6.35E+01	5.21E+01	4.26E+01	3.63E+01
NO2/NOx	4.77E-01	4.83E-01	4.87E-01	5.29E-01	5.50E-01	6.42E-01
CO2[% dry]	7.21E+00	7.21E+00	7.25E+00	7.25E+00	7.34E+00	7.39E+00
CO[ppm dry]	5.58E+02	5.58E+02	5.53E+02	5.33E+02	5.17E+02	5.15E+02
Supercharger Speed	3.63E+01	3.64E+01	3.40E+01	3.06E+01	2.48E+01	2.11E+01

SC IC CV Pos.	3.48E+01	8.90E-03	1.67E-03	2.11E-03	1.11E+00	7.31E+01
Steam Valve Position	1.75E+01	1.78E+01	1.63E+01	1.50E+01	1.08E+01	8.45E+00
ICW CV Pos.	3.32E+01	2.81E+01	3.40E+01	3.73E+01	4.38E+01	4.47E+01
Exh Back Pres CV	5.88E+01	5.88E+01	6.10E+01	6.46E+01	7.37E+01	7.94E+01
JW Temp Valve Pos.	6.09E+01	6.08E+01	6.23E+01	6.26E+01	6.43E+01	6.45E+01
Jacket Water Flow Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	2.06E+02	2.06E+02	2.06E+02	2.06E+02	2.06E+02	2.06E+02
Intercooler Flow [gpm]	1.36E+02	1.36E+02	1.37E+02	1.37E+02	1.39E+02	1.39E+02
Dyno Water Flow [gpm]	1.08E+02	1.08E+02	1.08E+02	1.08E+02	1.08E+02	1.07E+02
Boiler Return Temp [C]	5.70E+01	6.69E+01	6.30E+01	5.96E+01	5.65E+01	6.34E+01
Boiler Supply Temp [C]	5.69E+01	6.60E+01	6.31E+01	5.97E+01	5.66E+01	6.00E+01
BMEP[psi]	1.79E+02	1.79E+02	1.61E+02	1.34E+02	8.94E+01	6.24E+01
Ambient Pressure[psia]	1.24E+01	1.24E+01	1.24E+01	1.24E+01	1.24E+01	1.24E+01
Propane Flow[lb/hr]	1.21E+00	1.19E+00	1.79E+00	1.58E+00	1.14E+00	8.72E-01
Propane Valve Pos	9.11E-01	9.18E-01	8.54E-01	8.41E-01	1.09E+00	1.47E+00
Propane VFD speed	6.52E+01	6.52E+01	6.87E+01	6.53E+01	6.44E+01	5.94E+01
Propane Pressure[psig]	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
	~~1.02E+00~~					
PHI Comb.	~~7.34E+03~~	6.35E-01	6.39E-01	6.42E-01	6.49E-01	6.53E-01
BSFC [BTU/BHP_hr]	~~1.69E+01~~	7.34E+03	7.46E+03	8.18E+03	8.40E+03	9.46E+03
Stoich. A/F	~~1.65E+01~~	1.69E+01	1.69E+01	1.69E+01	1.69E+01	1.69E+01
U & S A/F	~~1.55E+01~~	2.66E+01	2.64E+01	2.64E+01	2.60E+01	2.58E+01
U & S Total A/F	~~4.42E+03~~	2.51E+01	2.49E+01	2.60E+01	2.46E+01	2.49E+01
Air Flow [lb/hr]	~~1.79E+02~~	4.48E+03	4.08E+03	3.65E+03	2.54E+03	1.99E+03
BMEP [psi]	-	1.79E+02	1.61E+02	1.34E+02	8.93E+01	6.24E+01
Thermal Eff. [%]	~~1.25E+03~~	3.69E+01	3.63E+01	3.30E+01	3.21E+01	2.86E+01
Wobbe Index [BTU/cuft]	~~8.30E+01~~	1.24E+03	1.25E+03	1.28E+03	1.26E+03	1.27E+03
Methane [%]	~~1.02E+03~~	8.29E+01	8.30E+01	8.66E+01	8.26E+01	8.40E+01
LHV [BTU/cuft]	~~1.52E+02~~	1.01E+03	1.02E+03	1.02E+03	1.03E+03	1.03E+03
Abs. Humidity	~~3.87E+01~~	1.54E+02	1.70E+02	1.94E+02	2.76E+02	3.55E+02
NOx @ 15% O2 [BHP-hr]	~~4.15E+00~~	6.44E+01	6.13E+01	4.63E+01	3.60E+01	2.62E+01
BS THC [g/BHP-hr]	~~7.10E-01~~	4.17E+00	4.47E+00	5.08E+00	6.17E+00	7.41E+00
BS NOx Actual [g/BHP-hr]	~~8.68E-01~~	7.09E-01	6.86E-01	5.64E-01	4.63E-01	3.89E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	~~2.96E-01~~	8.64E-01	8.35E-01	6.74E-01	5.49E-01	4.44E-01
BS NO FTIR [g/BHP-hr]	~~4.14E-01~~	2.91E-01	2.79E-01	2.07E-01	1.61E-01	1.04E-01
BS NO2 FTIR [g/BHP-hr]	~~2.16E+00~~	4.17E-01	4.07E-01	3.57E-01	3.02E-01	2.85E-01

BS CO [g/BHP-hr]	~~4.37E+02~~	2.16E+00	2.16E+00	2.22E+00	2.23E+00	2.46E+00
BS CO2 [g/BHP-hr]	~~1.03E+00~~	4.37E+02	4.44E+02	4.75E+02	4.99E+02	5.55E+02
PHI Total	~~4.31E+02~~	6.35E-01	6.38E-01	6.46E-01	6.48E-01	6.55E-01
H2O MF	~~4.59E+03~~	4.34E+02	4.03E+02	3.80E+02	2.87E+02	2.46E+02
Exh MF	~~0.00E+00~~	4.65E+03	4.23E+03	3.79E+03	2.64E+03	2.07E+03
BS O2 [g/BHP-hr]	~~5.38E+01~~	3.72E+02	3.72E+02	3.97E+02	4.05E+02	4.46E+02
Gas Density [lbm/1000cuft]	~~1.13E+00~~	5.39E+01	5.44E+01	5.14E+01	5.47E+01	5.36E+01
Vapor Pressure[kPa]		1.15E+00	1.15E+00	1.13E+00	1.14E+00	1.13E+00
Combustion Data						
Cylinder 1-5 avg 50% Burn Loc	19.574	19.638	19.737	20.525	21.228	22.434
Cylinder 1-5 avg 0-10% Burn Dur	21.683	21.733	21.8498	22.315	22.826	23.506
Cylinder 1-5 avg 10-90% Burn Dur	30.177	30.2468	30.22	31.067	31.5165	32.909
Cylinder 1-5 avg COV PP	6.669	6.611	6.686	6.76	7.149	7.203
Cylinder 1-5 avg COV IMEP	2.322	2.316	2.333	2.434	2.624	2.961
Cylinder 1-5 avg PP Location	19.578	19.578	19.713	19.417	19.287	18.2
Cylinder 6 50% Burn Loc	17.19	17.247	17.714	18.553	18.894	20.196
Cylinder 6 0-10% Burn Dur	22.092	22.146	22.463	22.955	23.2976	24.073
Cylinder 6 10-90% Burn Dur	28.557	28.6385	29.211	30.1617	30.2414	31.857
Cylinder 6 COV PP	6.643	6.616	6.715	6.893	7.279	7.496
Cylinder 7 COV IMEP	2.035	2.045	2.14	2.285	2.329	2.676
Cylinder 8 PP Location	18.679	18.668	18.661	18.54	19.085	18.77
FMEP [psi]		20.00	19.10	17.80	16.00	14.84
PMEP [psi]		22.53	21.04	19.65	16.62	14.6
Calterm Data						
Spark Timing [cylinder 1-5 avg]	16.98	16.99	16.99	17	16.995	17.04
Spark Timing [cylinder 6]	18.99	18.99	19	19	19	19.05

Data Point Name	**QSK-100-Lean-07**	**QSK-100-Lean-08**	**QSK-100-Lean-09**	**QSK-100-Lean-10**	**QSK-100-Lean-11**	**QSK-100-Lean-12**	**QSK-100-Lean-13**
Engine Data							
RPM	1.80E+03	1.80E+03	1.80E+03	1.79E+03	1.80E+03	1.80E+03	1.76E+03
Power[hp]	4.71E+02	4.71E+02	4.71E+02	4.68E+02	4.70E+02	4.71E+02	4.61E+02
Power[kW]	3.51E+02	3.51E+02	3.51E+02	3.49E+02	3.50E+02	3.51E+02	3.44E+02
Torque[ft-lb]	1.38E+03	1.38E+03	1.38E+03	1.38E+03	1.37E+03	1.38E+03	1.37E+03
Fuel Flow[#ph]	1.73E+02	1.81E+02	1.85E+02	1.83E+02	1.84E+02	1.86E+02	1.82E+02
Fuel Pressure[psig]	4.78E+00	4.75E+00	4.74E+00	4.74E+00	4.74E+00	4.73E+00	4.70E+00

Fuel Temp[F]	9.51E+01	9.58E+01	9.64E+01	9.73E+01	9.86E+01	9.91E+01	9.89E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.65E+00
IMAP[psia]	3.35E+01	3.62E+01	3.79E+01	3.78E+01	3.78E+01	3.77E+01	3.77E+01
IC Diff Pressure[inH2O]	1.62E-01	2.30E+00	3.71E+00	4.21E+00	4.21E+00	3.20E+00	4.28E+00
Boost Pressure[psig]	2.99E+01	2.89E+01	2.61E+01	2.60E+01	2.61E+01	2.64E+01	2.59E+01
Inlet Air Temperature[F]	1.00E+02	1.01E+02	1.03E+02	1.05E+02	1.03E+02	1.00E+02	1.02E+02
Intake Manifold Temp[F]	1.30E+02	1.31E+02	1.33E+02	1.31E+02	1.31E+02	1.30E+02	1.30E+02
Boost Temp[F]	3.60E+02	3.76E+02	4.03E+02	4.02E+02	4.03E+02	4.00E+02	3.98E+02
Inlet Air RH[%]	5.07E+01	5.01E+01	4.93E+01	4.71E+01	5.00E+01	4.99E+01	5.10E+01
Exhaust Back Pres[inHg]	4.71E+00	4.69E+00	4.70E+00	4.70E+00	4.70E+00	4.70E+00	4.64E+00
EMAP[psia]	4.26E+01	4.63E+01	5.01E+01	4.99E+01	5.02E+01	4.99E+01	4.94E+01
Exhaust Temp[F]	1.01E+03	1.00E+03	9.79E+02	9.64E+02	9.72E+02	9.87E+02	9.63E+02
Turbine In Temp[F]	1.24E+03	1.25E+03	1.25E+03	1.24E+03	1.25E+03	1.26E+03	1.24E+03
Exh Port 1[F]	1.15E+03	1.16E+03	1.17E+03	1.15E+03	1.16E+03	1.17E+03	1.14E+03
Exh Port 2[F]	1.14E+03	1.15E+03	1.16E+03	1.15E+03	1.16E+03	1.16E+03	1.14E+03
Exh Port 3[F]	1.15E+03	1.16E+03	1.16E+03	1.15E+03	1.16E+03	1.17E+03	1.15E+03
Exh Port 4[F]	1.17E+03	1.18E+03	1.18E+03	1.17E+03	1.17E+03	1.19E+03	1.16E+03
Exh Port 5[F]	1.17E+03	1.18E+03	1.18E+03	1.17E+03	1.18E+03	1.19E+03	1.16E+03
Exh Port 6[F]	1.14E+03	1.15E+03	1.15E+03	1.13E+03	1.14E+03	1.15E+03	1.13E+03
JW In Temp[F]	1.76E+02	1.77E+02	1.76E+02	1.76E+02	1.76E+02	1.76E+02	1.76E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.84E+02	1.84E+02	1.85E+02	1.85E+02
ACW In Temp[F]	1.13E+02	1.11E+02	1.06E+02	1.05E+02	1.05E+02	1.04E+02	1.04E+02
ACW Out Temp[F]	1.25E+02	1.24E+02	1.24E+02	1.23E+02	1.23E+02	1.22E+02	1.21E+02
Dyno In Temp[F]	9.81E+01	9.74E+01	1.01E+02	1.02E+02	1.01E+02	1.00E+02	1.01E+02
Dyno Out Temp[F]	1.24E+02	1.23E+02	1.27E+02	1.28E+02	1.27E+02	1.26E+02	1.27E+02
Oil Sump Temp[F]	2.15E+02	2.13E+02	2.14E+02	2.14E+02	2.14E+02	2.14E+02	2.14E+02
Oil Rifle Temp[F]	2.05E+02	2.04E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.04E+02
Oil Pressure[psig]	7.42E+01	7.59E+01	7.57E+01	7.57E+01	7.56E+01	7.57E+01	7.49E+01
THC[ppm dry]	1.60E+03	1.89E+03	2.06E+03	2.19E+03	2.12E+03	2.03E+03	2.31E+03
O2[%dry]	8.42E+00	8.89E+00	9.06E+00	9.17E+00	9.11E+00	9.06E+00	9.28E+00
NOx[ppm dry]	1.35E+02	6.39E+01	5.09E+01	4.99E+01	5.01E+01	4.95E+01	4.47E+01
NO[ppm dry]	6.69E+01	2.40E+01	1.78E+01	1.72E+01	1.73E+01	1.72E+01	1.49E+01
NO2[ppm dry]	6.78E+01	4.00E+01	3.31E+01	3.27E+01	3.29E+01	3.22E+01	2.98E+01
NO2/NOx	5.04E-01	6.25E-01	6.51E-01	6.55E-01	6.56E-01	6.51E-01	6.66E-01
CO2[% dry]	7.20E+00	6.88E+00	6.76E+00	6.70E+00	6.74E+00	6.77E+00	6.63E+00
CO[ppm dry]	5.59E+02	6.03E+02	6.88E+02	7.18E+02	7.04E+02	6.75E+02	7.48E+02
Supercharger Speed	3.63E+01	3.86E+01	3.98E+01	3.98E+01	3.98E+01	3.99E+01	3.98E+01
SC IC CV Pos.	1.25E-02	4.68E+00	0.00E+00	0.00E+00	0.00E+00	2.84E+00	2.35E-04
Steam Valve Position	1.82E+01	2.02E+01	3.01E+01	2.90E+01	2.75E+01	2.48E+01	2.64E+01
ICW CV Pos.	3.45E+01	2.76E+01	3.43E+00	2.82E-01	3.01E-01	8.27E+00	1.62E+01

Exh Back Pres CV	5.91E+01	5.70E+01	5.66E+01	5.70E+01	5.65E+01	5.62E+01	5.70E+01
JW Temp Valve Pos.	6.22E+01	6.15E+01	6.17E+01	6.21E+01	6.19E+01	6.12E+01	6.20E+01
Jacket Water Flow Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	2.05E+02	2.06E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.04E+02
Intercooler Flow [gpm]	1.37E+02	1.35E+02	1.19E+02	1.18E+02	1.18E+02	1.18E+02	1.21E+02
Dyno Water Flow [gpm]	1.08E+02	1.08E+02	1.08E+02	1.08E+02	1.08E+02	1.08E+02	1.08E+02
Boiler Return Temp [C]	5.87E+01	6.37E+01	6.04E+01	5.82E+01	5.60E+01	6.17E+01	7.11E+01
Boiler Supply Temp [C]	5.87E+01	6.37E+01	6.05E+01	5.82E+01	5.61E+01	5.89E+01	6.87E+01
BMEP[psi]	1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.79E+02	NaN
Ambient Pressure[psia]	1.24E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Propane Flow[lb/hr]	2.01E+00	2.08E-03	2.08E-03	2.08E-03	2.08E-03	2.08E-03	2.08E-03
Propane Valve Pos	8.04E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Propane VFD speed	6.21E+01	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Propane Pressure[psig]	2.50E+01	2.22E+01	2.19E+01	2.17E+01	2.20E+01	2.18E+01	2.15E+01
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data							
PHI Comb.	6.35E-01	6.16E-01	6.09E-01	6.05E-01	6.08E-01	6.09E-01	6.01E-01
BSFC [BTU/BHP_hr]	7.35E+03	7.67E+03	7.84E+03	7.80E+03	7.85E+03	7.88E+03	7.87E+03
Stoich. A/F	1.69E+01	1.70E+01	1.70E+01	1.70E+01	1.70E+01	1.70E+01	1.70E+01
U & S A/F	2.66E+01	2.75E+01	2.78E+01	2.80E+01	2.79E+01	2.78E+01	2.82E+01
U & S Total A/F	2.51E+01	2.59E+01	2.62E+01	2.64E+01	2.63E+01	2.62E+01	2.66E+01
Air Flow [lb/hr]	4.48E+03	4.82E+03	4.98E+03	4.95E+03	4.98E+03	5.00E+03	4.95E+03
BMEP [psi]	1.79E+02	1.79E+02	1.79E+02	1.79E+02	1.78E+02	1.79E+02	1.77E+02
Thermal Eff. [%]	3.65E+01	3.51E+01	3.44E+01	3.45E+01	3.43E+01	3.42E+01	3.42E+01
Wobbe Index [BTU/cuft]	1.25E+03	1.23E+03	1.23E+03	1.23E+03	1.23E+03	1.23E+03	1.23E+03
Methane [%]	8.31E+01	8.48E+01	8.49E+01	8.51E+01	8.51E+01	8.53E+01	8.53E+01
LHV [BTU/cuft]	1.02E+03	9.90E+02	9.88E+02	9.86E+02	9.87E+02	9.85E+02	9.84E+02
Abs. Humidity	1.52E+02	1.42E+02	1.40E+02	1.27E+02	1.35E+02	1.33E+02	1.34E+02
NOx @ 15% O2 [BHP-hr]	6.37E+01	3.14E+01	2.54E+01	2.51E+01	2.51E+01	2.47E+01	2.27E+01
BS THC [g/BHP-hr]	4.12E+00	5.12E+00	5.78E+00	6.14E+00	5.95E+00	5.69E+00	6.55E+00
BS NOx Actual [g/BHP-hr]	7.09E-01	3.82E-01	3.18E-01	3.13E-01	3.15E-01	3.11E-01	2.85E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	8.57E-01	4.39E-01	3.62E-01	3.55E-01	3.57E-01	3.53E-01	3.23E-01
BS NO FTIR [g/BHP-hr]	2.77E-01	1.07E-01	8.24E-02	8.00E-02	8.02E-02	8.03E-02	7.03E-02
BS NO2 FTIR [g/BHP-hr]	4.31E-01	2.74E-01	2.35E-01	2.33E-01	2.34E-01	2.30E-01	2.15E-01
BS CO [g/BHP-hr]	2.17E+00	2.52E+00	2.97E+00	3.11E+00	3.06E+00	2.93E+00	3.29E+00
BS CO2 [g/BHP-hr]	4.38E+02	4.52E+02	4.60E+02	4.56E+02	4.60E+02	4.62E+02	4.59E+02
PHI Total	6.35E-01	6.15E-01	6.09E-01	6.05E-01	6.07E-01	6.09E-01	6.01E-01

H2O MF	4.33E+02	4.49E+02	4.57E+02	4.44E+02	4.54E+02	4.56E+02	4.46E+02
Exh MF	4.65E+03	5.00E+03	5.16E+03	5.13E+03	5.16E+03	5.19E+03	5.13E+03
BS O2 [g/BHP-hr]	3.73E+02	4.24E+02	4.48E+02	4.54E+02	4.52E+02	4.50E+02	4.66E+02
Gas Density [lbm/1000cuft]	5.38E+01	5.24E+01	5.23E+01	5.22E+01	5.23E+01	5.22E+01	5.21E+01
Methane Number							
Vapor Pressure[kPa]	1.13E+00	1.14E+00	1.18E+00	1.07E+00	1.14E+00	1.11E+00	1.12E+00
Combustion Data							
Cylinder 1-5 avg 50% Burn Loc	19.684	22.133	22.405	21.605	22.087	22.902	
Cylinder 1-5 avg 0-10% Burn Dur	21.781	22.793	23.203	23.925	23.512	23.021	
Cylinder 1-5 avg 10-90% Burn Dur	30.276	34.393	35.739	35.2419	35.58	36.1759	
Cylinder 1-5 avg COV PP	6.689	6.257	5.9	5.956	5.973	5.76	
Cylinder 1-5 avg COV IMEP	2.338	3.228	3.5231	3.464	3.619	3.53	
Cylinder 1-5 avg PP Location	19.602	16.788	15.67	15.901	15.756	15.447	
Cylinder 6 50% Burn Loc	17.231	19.55	20.267	19.917	20.118	20.515	
Cylinder 6 0-10% Burn Dur	22.154	23.187	23.811	24.751	24.227	23.526	
Cylinder 6 10-90% Burn Dur	28.566	32.84	34.8856	35.012	35.009	34.9833	
Cylinder 6 COV PP	6.619	6.591	6.407	6.408	6.562	6.383	
Cylinder 7 COV IMEP	2.038	2.944	3.512	3.66	3.73	3.494	
Cylinder 8 PP Location	18.7	16.832	15.6	15.415	15.533	15.664	
Calterm Data							
Throttle Position [% Open]	34.79	52.12	82.46	97.97	87.38	67.84	
Spark Timing [cylinder 1-5 avg]	17	17.12	17.68	18.97	18.23	17.18	
Spark Timing [cylinder 6]	19	19.13	19.68	20.97	20.236	19.17	

Data Point Name	**QSK-50-LEAN-03**	**QSK-50-LEAN-04**	**QSK-50-LEAN-05**	**QSK-50-LEAN-06**	**QSK-50-LEAN-07**	**QSK-50-LEAN-08**
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02
Fuel Flow[#ph]	1.25E+02	9.47E+01	9.41E+01	9.42E+01	9.42E+01	9.52E+01
Fuel Pressure[psig]	4.88E+00	4.92E+00	4.91E+00	4.92E+00	4.92E+00	4.92E+00
Fuel Temp[F]	8.48E+01	8.50E+01	8.49E+01	8.50E+01	8.52E+01	8.56E+01
Inlet Air Pres[inHg]	3.58E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00

IMAP[psia]	2.58E+01	1.49E+01	1.53E+01	1.58E+01	1.64E+01	1.72E+01
IC Diff Pressure[inH2O]	-1.99E+00	-1.50E+00	-1.46E+00	-1.53E+00	-1.53E+00	-1.61E+00
Boost Pressure[psig]	2.86E+01	1.60E+01	1.65E+01	1.71E+01	1.78E+01	1.88E+01
Inlet Air Temperature[F]	1.00E+02	9.99E+01	9.96E+01	9.97E+01	9.95E+01	9.97E+01
Intake Manifold Temp[F]	1.27E+02	1.25E+02	1.29E+02	1.27E+02	1.30E+02	1.27E+02
Boost Temp[F]	3.41E+02	2.52E+02	2.55E+02	2.60E+02	2.66E+02	2.73E+02
Inlet Air RH[%]	4.74E+01	5.24E+01	5.33E+01	5.17E+01	5.15E+01	5.06E+01
Exhaust Back Pres[inHg]	4.73E+00	4.70E+00	4.71E+00	4.68E+00	4.70E+00	4.71E+00
EMAP[psia]	3.53E+01	2.36E+01	2.39E+01	2.44E+01	2.50E+01	2.59E+01
Exhaust Temp[F]	1.03E+03	1.15E+03	1.14E+03	1.11E+03	1.09E+03	1.06E+03
Turbine In Temp[F]	1.27E+03	1.30E+03	1.29E+03	1.26E+03	1.24E+03	1.22E+03
Exh Port 1[F]	1.16E+03	1.24E+03	1.23E+03	1.21E+03	1.19E+03	1.16E+03
Exh Port 2[F]	1.16E+03	1.23E+03	1.22E+03	1.20E+03	1.18E+03	1.15E+03
Exh Port 3[F]	1.17E+03	1.24E+03	1.23E+03	1.21E+03	1.18E+03	1.16E+03
Exh Port 4[F]	1.15E+03	1.24E+03	1.23E+03	1.20E+03	1.18E+03	1.15E+03
Exh Port 5[F]	1.15E+03	1.24E+03	1.23E+03	1.21E+03	1.18E+03	1.16E+03
Exh Port 6[F]	1.12E+03	1.23E+03	1.21E+03	1.19E+03	1.16E+03	1.14E+03
JW In Temp[F]	1.78E+02	1.78E+02	1.78E+02	1.78E+02	1.79E+02	1.78E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.86E+02	1.85E+02
ACW In Temp[F]	1.11E+02	1.12E+02	1.19E+02	1.15E+02	1.20E+02	1.15E+02
ACW Out Temp[F]	1.20E+02	1.16E+02	1.22E+02	1.18E+02	1.24E+02	1.20E+02
Dyno In Temp[F]	5.55E+01	5.66E+01	5.70E+01	5.75E+01	5.77E+01	5.82E+01
Dyno Out Temp[F]	7.62E+01	7.73E+01	7.78E+01	7.84E+01	7.85E+01	7.89E+01
Oil Sump Temp[F]	2.08E+02	2.11E+02	2.11E+02	2.11E+02	2.11E+02	2.10E+02
Oil Rifle Temp[F]	2.01E+02	2.03E+02	2.04E+02	2.03E+02	2.03E+02	2.03E+02
Oil Pressure[psig]	7.69E+01	7.72E+01	7.72E+01	7.74E+01	7.76E+01	7.77E+01
THC[ppm dry]	4.65E+03	9.63E+02	9.44E+02	1.03E+03	1.22E+03	1.55E+03
O2[%dry]	9.66E+00	3.75E+00	4.17E+00	5.04E+00	5.78E+00	6.57E+00
NOx[ppm dry]	1.29E+01	3.10E+03	2.68E+03	1.72E+03	9.72E+02	4.94E+02
NO[ppm dry]	1.44E+00	2.81E+03	2.32E+03	1.45E+03	7.98E+02	3.14E+02
NO2[ppm dry]	1.15E+01	2.84E+02	3.57E+02	2.72E+02	1.74E+02	1.80E+02
CO2[% dry]	6.38E+00	9.92E+00	9.69E+00	9.17E+00	8.73E+00	8.26E+00
CO[ppm dry]	1.11E+03	6.19E+02	6.82E+02	7.71E+02	8.15E+02	7.49E+02
Supercharger Speed	2.81E+01	1.95E+01	1.98E+01	2.04E+01	2.10E+01	2.16E+01
SC IC CV Pos.	6.15E+01	9.86E+01	9.98E+01	9.79E+01	9.00E+01	9.10E+01
Steam Valve Position	2.10E+01	1.53E+01	1.52E+01	1.54E+01	1.57E+01	1.58E+01
ICW CV Pos.	4.97E+01	5.89E+01	6.19E+01	4.77E+01	6.16E+01	5.22E+01
Exh Back Pres CV	6.64E+01	8.12E+01	8.04E+01	8.00E+01	7.93E+01	7.83E+01
JW Temp Valve Pos.	6.39E+01	6.35E+01	6.34E+01	6.40E+01	6.29E+01	6.40E+01
Jacket Water Flow Control Valve	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.88E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.84E+02	1.86E+02	1.87E+02	1.84E+02	1.87E+02	1.85E+02
Dyno Water Flow [gpm]	6.81E+01	6.80E+01	6.79E+01	6.79E+01	6.79E+01	6.79E+01
Boiler Return Temp [C]	7.98E+01	7.87E+01	7.23E+01	7.37E+01	7.82E+01	8.24E+01
Boiler Supply Temp [C]	7.66E+01	7.73E+01	7.09E+01	7.09E+01	7.50E+01	7.90E+01
BMEP[psi]	8.95E+01	8.94E+01	8.94E+01	8.94E+01	8.95E+01	8.95E+01
Ambient Pressure[psia]	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01

Propane Flow[lb/hr]	2.80E+01	2.78E+01	2.76E+01	2.78E+01	2.71E+01	2.63E+01
Propane Valve Pos	6.23E+00	7.06E+00	6.75E+00	7.10E+00	6.12E+00	6.33E+00
Propane VFD speed	3.16E+01	3.20E+01	2.96E+01	3.05E+01	3.09E+01	2.90E+01
Propane Pressure[psig]	2.50E+01	2.50E+01	2.51E+01	2.51E+01	2.51E+01	2.51E+01
Blowby Flow[acfm]	7.10E+00	3.64E+00	3.77E+00	3.97E+00	4.29E+00	4.52E+00
Aux Temp 1	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
Time[sec]	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09
Calculated Data						
Fuel Flow [lb/hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PHI Comb.	5.99E-01	8.37E-01	8.19E-01	7.82E-01	7.51E-01	7.18E-01
BSFC [BTU/BHP_hr]	9.89E+03	7.54E+03	7.48E+03	7.49E+03	7.50E+03	7.58E+03
Stoich. A/F	1.69E+01	1.68E+01	1.68E+01	1.68E+01	1.68E+01	1.68E+01
U & S A/F	2.81E+01	2.01E+01	2.05E+01	2.14E+01	2.23E+01	2.34E+01
U & S Total A/F	2.60E+01	1.86E+01	1.90E+01	1.99E+01	2.07E+01	2.17E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	3.38E+03	1.88E+03	1.92E+03	2.01E+03	2.10E+03	2.21E+03
BMEP [psi]	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01
Thermal Eff. [%]	2.59E+01	3.38E+01	3.39E+01	3.40E+01	3.39E+01	3.37E+01
Wobbe Index [BTU/cuft]	1.25E+03	1.26E+03	1.27E+03	1.27E+03	1.27E+03	1.27E+03
Methane [%]	8.59E+01	8.40E+01	8.31E+01	8.31E+01	8.32E+01	8.36E+01
LHV [BTU/cuft]	1.02E+03	1.05E+03	1.07E+03	1.07E+03	1.07E+03	1.06E+03
Water [%]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Abs. Humidity	1.70E+02	3.19E+02	3.59E+02	3.17E+02	3.24E+02	2.84E+02
NOx @ 15% O2 [BHP-hr]	6.79E+00	1.07E+03	9.46E+02	6.40E+02	3.79E+02	2.03E+02
BS THC [g/BHP-hr]	1.86E+01	2.08E+00	2.11E+00	2.45E+00	3.01E+00	4.08E+00
BS NOx Actual [g/BHP-hr]	1.20E-01	1.08E+01	9.72E+00	6.66E+00	3.98E+00	2.35E+00
BS NOx EPA Meth. 20 [g/BHP-hr]	1.25E-01	1.58E+01	1.39E+01	9.42E+00	5.58E+00	3.01E+00
BS NO FTIR [g/BHP-hr]	9.05E-03	9.35E+00	7.87E+00	5.18E+00	2.99E+00	1.25E+00
BS NO2 FTIR [g/BHP-hr]	1.11E-01	1.45E+00	1.85E+00	1.49E+00	9.98E-01	1.10E+00
BS CO [g/BHP-hr]	6.52E+00	1.92E+00	2.16E+00	2.57E+00	2.85E+00	2.78E+00
BS CH2O [g/BHP-hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS CO2 [g/BHP-hr]	5.90E+02	4.84E+02	4.81E+02	4.81E+02	4.79E+02	4.82E+02
PHI Total	6.08E-01	8.52E-01	8.32E-01	7.95E-01	7.63E-01	7.29E-01
H2O MF	3.08E+02	2.65E+02	2.74E+02	2.67E+02	2.73E+02	2.68E+02
Exh MF	3.51E+03	1.97E+03	2.01E+03	2.10E+03	2.19E+03	2.30E+03
BS O2 [g/BHP-hr]	6.49E+02	1.33E+02	1.51E+02	1.92E+02	2.31E+02	2.79E+02
Gas Density [lbm/1000cuft]	5.48E+01	5.61E+01	5.69E+01	5.71E+01	5.69E+01	5.67E+01
Methane Number	5.44E+01	6.66E+01	6.37E+01	6.20E+01	6.18E+01	6.22E+01
Vapor Pressure[kPa]	9.69E-01	1.02E+00	1.17E+00	1.07E+00	1.14E+00	1.05E+00
Combustion Data						
Cylinder 1-5 avg 50% Burn Loc	31.74	11.51	12.16	12.79	14.00	16.57
Cylinder 1-5 avg 0-10% Burn Dur	28.65	18.57	18.77	19.18	19.87	21.53
Cylinder 1-5 avg 10-90% Burn Dur	52.17	19.66	20.05	21.06	22.21	24.78
Cylinder 1-5 avg COV PP	2.24	5.80	5.98	6.48	6.55	7.03
Cylinder 1-5 avg COV IMEP	7.11	0.89	0.95	1.00	1.14	1.47
Cylinder 1-5 avg PP Location	4.09	17.91	18.44	18.76	19.43	20.34

Cylinder 6 50% Burn Loc	27.89	9.53	10.10	10.38	11.63	13.92
Cylinder 6 0-10% Burn Dur	28.36	18.96	19.10	19.30	19.99	21.51
Cylinder 6 10-90% Burn Dur	47.47	18.22	18.50	19.59	21.12	23.60
Cylinder 6 COV PP	3.84	6.40	6.52	6.42	6.06	6.57
Cylinder 7 COV IMEP	6.40	0.78	0.78	0.82	0.89	1.14
Cylinder 8 PP Location	7.18	16.61	17.09	17.06	17.57	18.52
Calterm Data						
Throttle Position [% Open]	25.08	18.98	19.09	19.47	19.76	20.23
Spark Timing [cylinder 1-5 avg]	17.15	17.08	16.83	17.02	17	17.1
Spark Timing [cylinder 6]	19.15	19.08	18.82	19.02	19	19.1

Data Point Name	QSK-50-LEAN-09	QSK-50-LEAN-10	QSK-50-LEAN-11	QSK-50-LEAN-12	QSK-50-LEAN-13	QSK-50-LEAN-14
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.35E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02
Fuel Flow[#ph]	9.62E+01	9.89E+01	1.03E+02	1.06E+02	1.13E+02	1.62E+02
Fuel Pressure[psig]	4.92E+00	4.92E+00	4.91E+00	4.91E+00	4.90E+00	4.78E+00
Fuel Temp[F]	8.58E+01	8.59E+01	8.62E+01	8.60E+01	8.62E+01	8.66E+01
Inlet Air Pres[inHg]	3.60E+00	3.61E+00	3.60E+00	3.60E+00	3.60E+00	3.57E+00
IMAP[psia]	1.80E+01	1.90E+01	2.02E+01	2.14E+01	2.29E+01	3.66E+01
IC Diff Pressure[inH2O]	-1.63E+00	-1.79E+00	-1.95E+00	-2.02E+00	-2.28E+00	4.06E+00
Boost Pressure[psig]	1.98E+01	2.14E+01	2.33E+01	2.48E+01	2.71E+01	2.50E+01
Inlet Air Temperature[F]	9.93E+01	9.96E+01	9.95E+01	9.95E+01	9.95E+01	9.91E+01
Intake Manifold Temp[F]	1.32E+02	1.29E+02	1.31E+02	1.33E+02	1.28E+02	1.39E+02
Boost Temp[F]	2.80E+02	2.92E+02	3.07E+02	3.18E+02	3.33E+02	3.63E+02
Inlet Air RH[%]	4.93E+01	4.76E+01	4.65E+01	4.74E+01	4.91E+01	3.73E+01
Exhaust Back Pres[inHg]	4.71E+00	4.68E+00	4.70E+00	4.72E+00	4.70E+00	4.69E+00
EMAP[psia]	2.67E+01	2.79E+01	2.95E+01	3.08E+01	3.27E+01	4.75E+01
Exhaust Temp[F]	1.04E+03	1.02E+03	1.01E+03	1.01E+03	1.01E+03	8.46E+02
Turbine In Temp[F]	1.21E+03	1.21E+03	1.22E+03	1.23E+03	1.25E+03	1.24E+03
Exh Port 1[F]	1.15E+03	1.15E+03	1.16E+03	1.15E+03	1.17E+03	1.13E+03
Exh Port 2[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.16E+03	1.12E+03
Exh Port 3[F]	1.15E+03	1.15E+03	1.15E+03	1.15E+03	1.17E+03	1.12E+03
Exh Port 4[F]	1.14E+03	1.13E+03	1.13E+03	1.13E+03	1.15E+03	1.04E+03
Exh Port 5[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	3.96E+02
Exh Port 6[F]	1.12E+03	1.11E+03	1.11E+03	1.11E+03	1.12E+03	9.42E+02
JW In Temp[F]	1.78E+02	1.78E+02	1.78E+02	1.78E+02	1.79E+02	1.78E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.86E+02	1.85E+02
ACW In Temp[F]	1.22E+02	1.18E+02	1.18E+02	1.22E+02	1.15E+02	1.22E+02
ACW Out Temp[F]	1.27E+02	1.23E+02	1.24E+02	1.28E+02	1.23E+02	1.35E+02
Dyno In Temp[F]	5.84E+01	5.88E+01	5.91E+01	5.93E+01	5.94E+01	5.95E+01
Dyno Out Temp[F]	7.93E+01	7.96E+01	7.99E+01	8.01E+01	8.02E+01	8.02E+01
Oil Sump Temp[F]	2.10E+02	2.09E+02	2.09E+02	2.08E+02	2.08E+02	2.09E+02
Oil Rifle Temp[F]	2.03E+02	2.02E+02	2.02E+02	2.01E+02	2.02E+02	2.02E+02

Oil Pressure[psig]	7.74E+01	7.76E+01	7.74E+01	7.75E+01	7.76E+01	7.61E+01
THC[ppm dry]	1.81E+03	2.02E+03	2.25E+03	2.56E+03	3.11E+03	1.61E+04
O2[%dry]	7.19E+00	7.80E+00	8.35E+00	8.72E+00	9.03E+00	1.21E+01
NOx[ppm dry]	2.64E+02	1.14E+02	5.48E+01	3.59E+01	2.13E+01	8.58E+00
NO[ppm dry]	1.68E+02	4.48E+01	1.65E+01	5.20E+00	1.66E+00	9.56E-01
NO2[ppm dry]	9.62E+01	6.95E+01	3.83E+01	3.07E+01	1.97E+01	7.63E+00
CO2[% dry]	7.90E+00	7.53E+00	7.22E+00	6.99E+00	6.77E+00	4.63E+00
CO[ppm dry]	6.30E+02	5.07E+02	5.36E+02	6.24E+02	7.90E+02	1.50E+03
Supercharger Speed	2.22E+01	2.31E+01	2.40E+01	2.48E+01	2.60E+01	3.61E+01
SC IC CV Pos.	9.98E+01	6.77E+01	6.78E+01	7.86E+01	6.90E+01	9.06E+01
Steam Valve Position	1.57E+01	1.61E+01	1.68E+01	1.73E+01	1.98E+01	2.10E+01
ICW CV Pos.	4.70E+01	6.16E+01	4.07E+01	4.69E+01	4.81E+01	4.00E+01
Exh Back Pres CV	7.75E+01	7.61E+01	7.44E+01	7.27E+01	7.05E+01	5.94E+01
JW Temp Valve Pos.	6.41E+01	6.41E+01	6.36E+01	6.41E+01	6.32E+01	6.25E+01
Jacket Water Flow Control Valve	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.85E+02	1.87E+02	1.84E+02	1.85E+02	1.85E+02	1.84E+02
Dyno Water Flow [gpm]	6.78E+01	6.79E+01	6.78E+01	6.78E+01	6.79E+01	6.78E+01
Boiler Return Temp [C]	8.08E+01	7.30E+01	7.24E+01	7.67E+01	8.07E+01	8.21E+01
Boiler Supply Temp [C]	7.92E+01	7.17E+01	7.00E+01	7.36E+01	7.75E+01	7.97E+01
BMEP[psi]	8.94E+01	8.94E+01	8.95E+01	8.95E+01	8.95E+01	8.94E+01
Ambient Pressure[psia]	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01
Propane Flow[lb/hr]	2.72E+01	2.60E+01	2.64E+01	2.59E+01	2.61E+01	-2.15E-02
Propane Valve Pos	6.58E+00	6.01E+00	5.92E+00	5.90E+00	5.47E+00	0.00E+00
Propane VFD speed	2.92E+01	2.87E+01	2.97E+01	2.86E+01	2.99E+01	0.00E+00
Propane Pressure[psig]	2.52E+01	2.51E+01	2.50E+01	2.51E+01	2.50E+01	2.61E+01
Blowby Flow[acfm]	4.78E+00	5.12E+00	5.54E+00	5.96E+00	6.43E+00	8.69E+00
Aux Temp 1	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
Time[sec]	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09
Calculated Data						
Fuel Flow [lb/hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PHI Comb.	6.91E-01	6.64E-01	6.40E-01	6.25E-01	6.15E-01	5.71E-01
BSFC [BTU/BHP_hr]	7.64E+03	7.87E+03	8.17E+03	8.43E+03	8.94E+03	1.29E+04
Stoich. A/F	1.68E+01	1.68E+01	1.68E+01	1.68E+01	1.68E+01	1.71E+01
U & S A/F	2.43E+01	2.53E+01	2.62E+01	2.69E+01	2.74E+01	3.00E+01
U & S Total A/F	2.25E+01	2.34E+01	2.43E+01	2.49E+01	2.54E+01	2.73E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	2.32E+03	2.46E+03	2.65E+03	2.81E+03	3.01E+03	4.54E+03
BMEP [psi]	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01
Thermal Eff. [%]	3.32E+01	3.23E+01	3.11E+01	3.00E+01	2.85E+01	1.97E+01
Wobbe Index [BTU/cuft]	1.27E+03	1.26E+03	1.26E+03	1.27E+03	1.26E+03	1.17E+03
Methane [%]	8.40E+01	8.46E+01	8.43E+01	8.36E+01	8.47E+01	9.33E+01
LHV [BTU/cuft]	1.06E+03	1.05E+03	1.05E+03	1.06E+03	1.04E+03	9.07E+02
Water [%]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Abs. Humidity	3.04E+02	2.48E+02	2.39E+02	2.45E+02	2.09E+02	1.29E+02
NOx @ 15% O2 [BHP-hr]	1.14E+02	5.15E+01	2.57E+01	1.74E+01	1.06E+01	5.73E+00

BS THC [g/BHP-hr]	4.95E+00	5.90E+00	7.11E+00	8.62E+00	1.11E+01	7.82E+01
BS NOx Actual [g/BHP-hr]	1.32E+00	6.80E-01	3.65E-01	2.69E-01	1.77E-01	1.11E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	1.69E+00	7.87E-01	4.07E-01	2.83E-01	1.81E-01	1.15E-01
BS NO FTIR [g/BHP-hr]	7.02E-01	2.01E-01	7.98E-02	2.67E-02	9.23E-03	8.35E-03
BS NO2 FTIR [g/BHP-hr]	6.17E-01	4.79E-01	2.85E-01	2.42E-01	1.67E-01	1.02E-01
BS CO [g/BHP-hr]	2.46E+00	2.13E+00	2.43E+00	3.00E+00	4.10E+00	1.22E+01
BS CH2O [g/BHP-hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS CO2 [g/BHP-hr]	4.84E+02	4.97E+02	5.13E+02	5.27E+02	5.51E+02	5.94E+02
PHI Total	7.02E-01	6.74E-01	6.50E-01	6.33E-01	6.23E-01	5.81E-01
H2O MF	2.79E+02	2.72E+02	2.82E+02	2.94E+02	2.98E+02	3.30E+02
Exh MF	2.41E+03	2.56E+03	2.75E+03	2.91E+03	3.12E+03	4.70E+03
BS O2 [g/BHP-hr]	3.21E+02	3.74E+02	4.32E+02	4.79E+02	5.35E+02	1.12E+03
Gas Density [lbm/1000cuft]	5.64E+01	5.59E+01	5.60E+01	5.63E+01	5.56E+01	4.85E+01
Methane Number	6.24E+01	6.30E+01	6.41E+01	6.37E+01	6.31E+01	6.47E+01
Vapor Pressure[kPa]	1.17E+00	1.02E+00	1.05E+00	1.14E+00	1.05E+00	1.05E+00
Combustion Data						
Cylinder 1-5 avg 50% Burn Loc	17.42	20.19	24.72	25.71	28.87	32.69
Cylinder 1-5 avg 0-10% Burn Dur	21.81	23.30	25.79	26.27	27.65	30.38
Cylinder 1-5 avg 10-90% Burn Dur	26.40	30.20	36.86	39.61	45.74	52.74
Cylinder 1-5 avg COV PP	8.06	7.33	5.56	4.93	3.31	1.37
Cylinder 1-5 avg COV IMEP	1.79	2.47	3.62	4.19	5.21	38.61
Cylinder 1-5 avg PP Location	19.82	18.10	12.58	10.76	6.62	1.91
Cylinder 6 50% Burn Loc	14.69	17.43	21.30	22.25	24.79	33.54
Cylinder 6 0-10% Burn Dur	21.73	23.29	25.44	25.98	27.13	32.08
Cylinder 6 10-90% Burn Dur	25.06	28.59	33.96	36.24	40.80	54.83
Cylinder 6 COV PP	7.55	7.57	7.21	6.68	5.48	1.10
Cylinder 7 COV IMEP	1.36	2.06	3.40	3.83	4.79	29.96
Cylinder 8 PP Location	18.36	17.66	15.14	13.64	10.78	1.55
Calterm Data						
Throttle Position [% Open]	20.6	21	21.55	22.16	23.03	81.6
Spark Timing [cylinder 1-5 avg]	17.06	17.07	17	17.24	17.19	18.42
Spark Timing [cylinder 6]	19.07	19.07	18.98	19.24	19.19	20.40

Data Point Name	**QSK-50-LEAN-16**	**QSK-50-LEAN-17**	**QSK-50-LEAN-18**	**QSK-50-LEAN-19**	**QSK-50-LEAN-20**	**QSK-50-LEAN-21**
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.35E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02
Fuel Flow[#ph]	1.60E+02	1.21E+02	1.09E+02	1.05E+02	1.01E+02	9.92E+01
Fuel Pressure[psig]	4.78E+00	4.86E+00	4.88E+00	4.88E+00	4.89E+00	4.89E+00
Fuel Temp[F]	8.87E+01	8.88E+01	8.85E+01	8.84E+01	8.84E+01	8.85E+01
Inlet Air Pres[inHg]	3.57E+00	3.60E+00	3.59E+00	3.60E+00	3.60E+00	3.60E+00

IMAP[psia]	3.34E+01	2.48E+01	2.21E+01	2.09E+01	1.97E+01	1.91E+01
IC Diff Pressure[inH2O]	1.55E+00	- 2.11E+00	- 2.08E+00	- 2.00E+00	- 1.83E+00	- 1.77E+00
Boost Pressure[psig]	2.72E+01	2.81E+01	2.56E+01	2.39E+01	2.20E+01	2.12E+01
Inlet Air Temperature[F]	1.00E+02	1.00E+02	9.98E+01	9.95E+01	9.96E+01	9.95E+01
Intake Manifold Temp[F]	1.27E+02	1.29E+02	1.33E+02	1.29E+02	1.33E+02	1.31E+02
Boost Temp[F]	3.56E+02	3.41E+02	3.24E+02	3.12E+02	2.99E+02	2.92E+02
Inlet Air RH[%]	4.91E+01	4.92E+01	4.62E+01	4.66E+01	4.81E+01	4.82E+01
Exhaust Back Pres[inHg]	4.73E+00	4.69E+00	4.72E+00	4.73E+00	4.70E+00	4.70E+00
EMAP[psia]	4.35E+01	3.44E+01	3.15E+01	3.01E+01	2.86E+01	2.79E+01
Exhaust Temp[F]	8.92E+02	1.02E+03	1.01E+03	1.01E+03	1.01E+03	1.02E+03
Turbine In Temp[F]	1.22E+03	1.26E+03	1.23E+03	1.22E+03	1.21E+03	1.21E+03
Exh Port 1[F]	1.13E+03	1.16E+03	1.15E+03	1.15E+03	1.15E+03	1.15E+03
Exh Port 2[F]	1.10E+03	1.15E+03	1.14E+03	1.14E+03	1.13E+03	1.14E+03
Exh Port 3[F]	1.05E+03	1.16E+03	1.15E+03	1.15E+03	1.14E+03	1.14E+03
Exh Port 4[F]	1.07E+03	1.15E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03
Exh Port 5[F]	6.13E+02	1.15E+03	1.14E+03	1.14E+03	1.13E+03	1.13E+03
Exh Port 6[F]	1.09E+03	1.12E+03	1.11E+03	1.11E+03	1.11E+03	1.11E+03
JW In Temp[F]	1.78E+02	1.78E+02	1.78E+02	1.78E+02	1.78E+02	1.78E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.85E+02
ACW In Temp[F]	1.06E+02	1.16E+02	1.21E+02	1.17E+02	1.22E+02	1.19E+02
ACW Out Temp[F]	1.19E+02	1.24E+02	1.28E+02	1.23E+02	1.28E+02	1.25E+02
Dyno In Temp[F]	6.10E+01	6.12E+01	6.12E+01	6.10E+01	6.12E+01	6.12E+01
Dyno Out Temp[F]	8.18E+01	8.20E+01	8.19E+01	8.18E+01	8.20E+01	8.20E+01
Oil Sump Temp[F]	2.08E+02	2.08E+02	2.08E+02	2.09E+02	2.09E+02	2.10E+02
Oil Rifle Temp[F]	2.01E+02	2.01E+02	2.01E+02	2.01E+02	2.02E+02	2.02E+02
Oil Pressure[psig]	7.62E+01	7.72E+01	7.75E+01	7.75E+01	7.75E+01	7.71E+01
THC[ppm dry]	1.49E+04	4.44E+03	3.00E+03	2.59E+03	2.27E+03	2.19E+03
O2[%dry]	1.15E+01	9.43E+00	8.85E+00	8.50E+00	8.04E+00	7.73E+00
NOx[ppm dry]	9.28E+00	1.48E+01	3.08E+01	4.60E+01	8.19E+01	1.21E+02
NO[ppm dry]	1.09E+00	1.93E+00	8.67E+00	1.63E+01	4.04E+01	6.41E+01
NO2[ppm dry]	8.20E+00	1.28E+01	2.21E+01	2.96E+01	4.14E+01	5.64E+01
CO2[% dry]	4.96E+00	6.31E+00	6.66E+00	6.89E+00	7.16E+00	7.30E+00
CO[ppm dry]	1.35E+03	9.25E+02	6.16E+02	5.15E+02	4.45E+02	4.37E+02
Supercharger Speed	3.41E+01	2.76E+01	2.53E+01	2.45E+01	2.36E+01	2.32E+01
SC IC CV Pos.	5.59E+01	5.44E+01	8.74E+01	7.57E+01	9.00E+01	7.08E+01
Steam Valve Position	2.68E+01	2.04E+01	1.77E+01	1.69E+01	1.65E+01	1.64E+01
ICW CV Pos.	4.27E+01	4.92E+01	4.20E+01	4.44E+01	4.89E+01	4.22E+01
Exh Back Pres CV	6.05E+01	6.79E+01	7.17E+01	7.35E+01	7.54E+01	7.61E+01
JW Temp Valve Pos.	6.43E+01	6.39E+01	6.46E+01	6.49E+01	6.45E+01	6.39E+01

Jacket Water Flow Control Valve	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.82E+02	1.85E+02	1.84E+02	1.84E+02	1.86E+02	1.84E+02
Dyno Water Flow [gpm]	6.79E+01	6.78E+01	6.77E+01	6.78E+01	6.78E+01	6.77E+01
Boiler Return Temp [C]	7.20E+01	7.75E+01	8.07E+01	7.54E+01	7.16E+01	7.26E+01
Boiler Supply Temp [C]	7.09E+01	7.62E+01	7.73E+01	7.25E+01	6.89E+01	7.13E+01
BMEP[psi]	8.94E+01	8.95E+01	8.94E+01	8.95E+01	8.94E+01	8.95E+01
Ambient Pressure[psia]	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01
Propane Flow[lb/hr]	1.08E-01	1.89E-02	1.05E-02	1.96E-02	2.06E-02	4.52E-02
Propane Valve Pos	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Propane VFD speed	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Propane Pressure[psig]	2.50E+01	2.51E+01	2.53E+01	2.54E+01	2.56E+01	2.57E+01
Blowby Flow[acfm]	8.42E+00	7.24E+00	6.40E+00	6.06E+00	5.53E+00	5.16E+00
Aux Temp 1	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
Time[sec]	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09
Calculated Data						
Fuel Flow [lb/hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PHI Comb.	5.88E-01	6.08E-01	6.24E-01	6.37E-01	6.56E-01	6.70E-01
BSFC [BTU/BHP_hr]	1.27E+04	9.55E+03	8.64E+03	8.30E+03	7.98E+03	7.85E+03
Stoich. A/F	1.71E+01	1.71E+01	1.71E+01	1.71E+01	1.71E+01	1.72E+01
U & S A/F	2.92E+01	2.82E+01	2.75E+01	2.69E+01	2.61E+01	2.56E+01
U & S Total A/F	2.66E+01	2.57E+01	2.51E+01	2.45E+01	2.38E+01	2.32E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	4.36E+03	3.27E+03	2.90E+03	2.73E+03	2.56E+03	2.47E+03
BMEP [psi]	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01
Thermal Eff. [%]	2.00E+01	2.66E+01	2.95E+01	3.07E+01	3.19E+01	3.25E+01
Wobbe Index [BTU/cuft]	1.17E+03	1.17E+03	1.18E+03	1.18E+03	1.17E+03	1.17E+03
Methane [%]	9.29E+01	9.26E+01	9.25E+01	9.26E+01	9.27E+01	9.34E+01
LHV [BTU/cuft]	9.09E+02	9.11E+02	9.13E+02	9.12E+02	9.11E+02	9.02E+02
Water [%]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Abs. Humidity	1.36E+02	1.98E+02	2.31E+02	2.25E+02	2.70E+02	2.66E+02
NOx @ 15% O2 [BHP-hr]	5.83E+00	7.59E+00	1.51E+01	2.19E+01	3.75E+01	5.40E+01
BS THC [g/BHP-hr]	6.91E+01	1.50E+01	8.92E+00	7.21E+00	5.88E+00	5.43E+00
BS NOx Actual [g/BHP-hr]	1.14E-01	1.31E-01	2.26E-01	3.09E-01	4.83E-01	6.75E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	1.19E-01	1.37E-01	2.51E-01	3.52E-01	5.83E-01	8.29E-01
BS NO FTIR [g/BHP-hr]	9.06E-03	1.17E-02	4.61E-02	8.16E-02	1.88E-01	2.88E-01
BS NO2 FTIR [g/BHP-hr]	1.05E-01	1.19E-01	1.80E-01	2.27E-01	2.95E-01	3.88E-01
BS CO [g/BHP-hr]	1.05E+01	5.22E+00	3.06E+00	2.40E+00	1.93E+00	1.83E+00
BS CH2O [g/BHP-hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

BS CO2 [g/BHP-hr]	6.08E+02	5.60E+02	5.20E+02	5.04E+02	4.88E+02	4.80E+02
PHI Total	5.97E-01	6.17E-01	6.33E-01	6.47E-01	6.67E-01	6.81E-01
H2O MF	3.36E+02	3.20E+02	3.05E+02	2.91E+02	2.94E+02	2.87E+02
Exh MF	4.52E+03	3.39E+03	3.01E+03	2.83E+03	2.66E+03	2.57E+03
BS O2 [g/BHP-hr]	1.02E+03	6.08E+02	5.02E+02	4.53E+02	3.98E+02	3.70E+02
Gas Density [lbm/1000cuft]	4.86E+01	4.88E+01	4.88E+01	4.88E+01	4.87E+01	4.84E+01
Methane Number	0.00E+00	8.82E+01	8.68E+01	8.67E+01	8.69E+01	8.72E+01
Vapor Pressure[kPa]	1.01E+00	1.08E+00	1.11E+00	1.02E+00	1.15E+00	1.10E+00
Combustion Data						
Cylinder 1-5 avg 50% Burn Loc	36.70	32.00	27.44	23.33	21.53	20.78
Cylinder 1-5 avg 0-10% Burn Dur	31.04	28.72	26.98	24.73	23.99	23.66
Cylinder 1-5 avg 10-90% Burn Dur	59.85	50.87	41.66	35.38	32.09	30.40
Cylinder 1-5 avg COV PP	4.15	1.83	3.77	5.80	6.81	6.83
Cylinder 1-5 avg COV IMEP	32.64	6.88	4.47	3.33	2.78	2.38
Cylinder 1-5 avg PP Location	1.35	3.48	7.91	13.64	16.18	17.63
Cylinder 6 50% Burn Loc	32.05	28.06	23.82	20.21	18.52	17.84
Cylinder 6 0-10% Burn Dur	30.29	28.34	26.61	24.51	23.84	23.45
Cylinder 6 10-90% Burn Dur	54.27	46.58	38.14	33.05	30.13	28.79
Cylinder 6 COV PP	4.74	3.58	5.64	6.91	7.19	6.97
Cylinder 7 COV IMEP	17.89	6.20	4.16	3.03	2.32	1.94
Cylinder 8 PP Location	3.29	6.79	11.70	15.21	16.68	17.50
Calterm Data						
Throttle Position [% Open]	49.86	24.57	22.67	22.22	21.68	21.37
Spark Timing [cylinder 1-5 avg]	17.38	16.86	17.00	16.97	17.06	16.95
Spark Timing [cylinder 6]	19.40	18.87	19.00	18.95	19.07	18.95

Data Point Name	**QSK-50-LEAN-22**	**QSK-50-LEAN-23**	**QSK-50-LEAN-24**	**QSK-50-LEAN-25**	**QSK-50-LEAN-26**
Engine Data					
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.36E+02	2.36E+02	2.36E+02	2.36E+02	2.36E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	6.88E+02	6.88E+02
Fuel Flow[#ph]	9.60E+01	9.50E+01	9.53E+01	9.80E+01	1.29E+02
Fuel Pressure[psig]	4.90E+00	4.90E+00	4.89E+00	4.89E+00	4.90E+00
Fuel Temp[F]	8.81E+01	8.79E+01	8.77E+01	8.76E+01	8.82E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.64E+00
IMAP[psia]	1.73E+01	1.60E+01	1.49E+01	1.39E+01	2.62E+01

IC Diff Pressure[inH2O]	-1.60E+00	-1.47E+00	-1.46E+00	-1.43E+00	-1.90E+00
Boost Pressure[psig]	1.87E+01	1.70E+01	1.57E+01	1.46E+01	2.88E+01
Inlet Air Temperature[F]	9.96E+01	9.96E+01	9.98E+01	1.00E+02	9.96E+01
Intake Manifold Temp[F]	1.28E+02	1.32E+02	1.29E+02	1.31E+02	1.30E+02
Boost Temp[F]	2.74E+02	2.61E+02	2.52E+02	2.44E+02	3.44E+02
Inlet Air RH[%]	5.12E+01	5.35E+01	5.47E+01	5.39E+01	4.66E+01
Exhaust Back Pres[inHg]	4.69E+00	4.70E+00	4.71E+00	4.71E+00	4.63E+00
EMAP[psia]	2.59E+01	2.44E+01	2.33E+01	2.23E+01	3.56E+01
Exhaust Temp[F]	1.06E+03	1.12E+03	1.18E+03	1.25E+03	1.03E+03
Turbine In Temp[F]	1.23E+03	1.27E+03	1.33E+03	1.40E+03	1.27E+03
Exh Port 1[F]	1.16E+03	1.21E+03	1.27E+03	1.34E+03	1.16E+03
Exh Port 2[F]	1.15E+03	1.20E+03	1.25E+03	1.32E+03	1.16E+03
Exh Port 3[F]	1.16E+03	1.21E+03	1.26E+03	1.33E+03	1.17E+03
Exh Port 4[F]	1.15E+03	1.21E+03	1.26E+03	1.34E+03	1.15E+03
Exh Port 5[F]	1.16E+03	1.21E+03	1.27E+03	1.34E+03	1.13E+03
Exh Port 6[F]	1.14E+03	1.19E+03	1.25E+03	1.32E+03	1.12E+03
JW In Temp[F]	1.78E+02	1.78E+02	1.78E+02	1.78E+02	1.78E+02
JW Out Temp[F]	1.85E+02	1.85E+02	1.85E+02	1.86E+02	1.85E+02
ACW In Temp[F]	1.17E+02	1.22E+02	1.18E+02	1.20E+02	1.17E+02
ACW Out Temp[F]	1.21E+02	1.26E+02	1.21E+02	1.23E+02	1.26E+02
Dyno In Temp[F]	6.09E+01	6.06E+01	6.03E+01	6.00E+01	6.12E+01
Dyno Out Temp[F]	8.18E+01	8.14E+01	8.11E+01	8.08E+01	8.20E+01
Oil Sump Temp[F]	2.11E+02	2.11E+02	2.12E+02	2.12E+02	2.08E+02
Oil Rifle Temp[F]	2.03E+02	2.03E+02	2.04E+02	2.04E+02	2.01E+02
Oil Pressure[psig]	7.76E+01	7.68E+01	7.66E+01	7.69E+01	7.75E+01
THC[ppm dry]	1.80E+03	1.23E+03	1.14E+03	2.02E+03	5.20E+03
O2[%dry]	6.51E+00	4.79E+00	2.97E+00	5.72E-01	9.88E+00
NOx[ppm dry]	4.60E+02	1.79E+03	3.36E+03	2.76E+03	1.01E+01
NO[ppm dry]	3.37E+02	1.49E+03	3.05E+03	2.76E+03	1.22E+00
NO2[ppm dry]	1.22E+02	3.01E+02	3.15E+02	2.92E-02	8.84E+00
CO2[% dry]	7.98E+00	8.92E+00	9.94E+00	1.12E+01	6.20E+00
CO[ppm dry]	6.29E+02	6.87E+02	5.27E+02	1.87E+03	1.20E+03
Supercharger Speed	2.18E+01	2.05E+01	1.93E+01	1.83E+01	2.90E+01
SC IC CV Pos.	4.99E+01	7.22E+01	9.54E+01	9.52E+01	7.59E+01
Steam Valve Position	1.60E+01	1.55E+01	1.48E+01	1.31E+01	2.11E+01
ICW CV Pos.	5.49E+01	4.66E+01	6.04E+01	4.31E+01	4.63E+01
Exh Back Pres CV	7.84E+01	7.99E+01	8.14E+01	8.27E+01	6.61E+01
JW Temp Valve Pos.	6.37E+01	6.37E+01	6.34E+01	6.30E+01	6.38E+01
Jacket Water Flow Control Valve	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.86E+02	1.85E+02	1.86E+02	1.85E+02	1.85E+02
Dyno Water Flow [gpm]	6.78E+01	6.77E+01	6.78E+01	6.78E+01	6.79E+01
Boiler Return Temp [C]	8.05E+01	8.13E+01	7.71E+01	7.32E+01	7.16E+01
Boiler Supply Temp [C]	7.88E+01	7.79E+01	7.40E+01	7.06E+01	6.90E+01
BMEP[psi]	8.95E+01	8.95E+01	8.95E+01	8.94E+01	8.95E+01
Ambient Pressure[psia]	1.22E+01	1.22E+01	1.22E+01	1.22E+01	1.22E+01
Propane Flow[lb/hr]	2.90E-02	4.15E-02	7.77E-03	7.77E-03	2.91E+01
Propane Valve Pos	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.86E+00
Propane VFD speed	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.34E+01
Propane Pressure[psig]	2.59E+01	2.59E+01	2.60E+01	2.60E+01	2.50E+01
Blowby Flow[acfm]	4.45E+00	4.28E+00	3.70E+00	3.48E+00	7.50E+00
Aux Temp 1	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03
Time[sec]	3.44E+09	3.44E+09	3.44E+09	3.44E+09	3.44E+09
Calculated Data					
Fuel Flow [lb/hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PHI Comb.	7.24E-01	7.96E-01	8.73E-01	9.91E-01	5.91E-01
BSFC [BTU/BHP_hr]	7.61E+03	7.53E+03	7.55E+03	7.76E+03	1.03E+04
Stoich. A/F	1.72E+01	1.72E+01	1.72E+01	1.72E+01	1.68E+01
U & S A/F	2.37E+01	2.16E+01	1.97E+01	1.73E+01	2.85E+01
U & S Total A/F	2.15E+01	1.95E+01	1.78E+01	1.56E+01	2.65E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	2.22E+03	2.02E+03	1.84E+03	1.68E+03	3.58E+03
BMEP [psi]	8.94E+01	8.94E+01	8.94E+01	8.94E+01	8.94E+01
Thermal Eff. [%]	3.34E+01	3.38E+01	3.36E+01	3.28E+01	2.48E+01
Wobbe Index [BTU/cuft]	1.17E+03	1.17E+03	1.17E+03	1.17E+03	1.26E+03
Methane [%]	9.38E+01	9.37E+01	9.38E+01	9.36E+01	8.40E+01
LHV [BTU/cuft]	8.99E+02	9.01E+02	9.00E+02	9.00E+02	1.04E+03
Water [%]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Abs. Humidity	2.92E+02	3.71E+02	3.71E+02	4.24E+02	1.79E+02
NOx @ 15% O2 [BHP-hr]	1.88E+02	6.54E+02	1.11E+03	8.02E+02	5.38E+00
BS THC [g/BHP-hr]	3.95E+00	2.42E+00	2.02E+00	3.20E+00	2.23E+01
BS NOx Actual [g/BHP-hr]	2.09E+00	6.94E+00	1.14E+01	7.96E+00	9.85E-02
BS NOx EPA Meth. 20 [g/BHP-hr]	2.81E+00	9.76E+00	1.66E+01	1.22E+01	1.03E-01
BS NO FTIR [g/BHP-hr]	1.35E+00	5.29E+00	9.81E+00	7.96E+00	8.11E-03
BS NO2 FTIR [g/BHP-hr]	7.48E-01	1.64E+00	1.56E+00	1.29E-04	9.04E-02
BS CO [g/BHP-hr]	2.34E+00	2.29E+00	1.58E+00	5.04E+00	7.49E+00
BS CH2O [g/BHP-hr]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BS CO2 [g/BHP-hr]	4.67E+02	4.66E+02	4.69E+02	4.74E+02	6.07E+02

PHI Total	7.38E-01	8.12E-01	8.92E-01	1.01E+00	5.97E-01
H2O MF	2.81E+02	2.94E+02	2.86E+02	2.93E+02	3.22E+02
Exh MF	2.32E+03	2.12E+03	1.94E+03	1.78E+03	3.71E+03
BS O2 [g/BHP-hr]	2.77E+02	1.82E+02	1.02E+02	1.76E+01	7.03E+02
Gas Density [lbm/1000cuft]	4.81E+01	4.82E+01	4.81E+01	4.83E+01	5.55E+01
Methane Number	8.91E+01	8.77E+01	9.00E+01	9.04E+01	8.96E+01
Vapor Pressure[kPa]	1.09E+00	1.26E+00	1.17E+00	1.24E+00	1.03E+00
Combustion Data					
Cylinder 1-5 avg 50% Burn Loc	16.11	13.76	11.56	11.39	37.10
Cylinder 1-5 avg 0-10% Burn Dur	20.88	19.73	18.45	18.39	30.73
Cylinder 1-5 avg 10-90% Burn Dur	24.74	21.81	20.18	20.70	60.68
Cylinder 1-5 avg COV PP	6.80	5.89	5.54	6.41	1.26
Cylinder 1-5 avg COV IMEP	1.41	1.04	0.90	0.99	13.06
Cylinder 1-5 avg PP Location	19.89	19.29	17.76	17.57	1.49
Cylinder 6 50% Burn Loc	13.50	11.43	9.76	9.83	33.38
Cylinder 6 0-10% Burn Dur	20.79	19.84	18.98	19.03	30.47
Cylinder 6 10-90% Burn Dur	23.76	20.85	19.19	19.73	56.82
Cylinder 6 COV PP	6.50	5.50	5.38	6.71	2.01
Cylinder 7 COV IMEP	1.12	0.81	0.75	0.92	10.88
Cylinder 8 PP Location	18.06	17.45	16.33	16.42	2.99
Calterm Data					
Throttle Position [% Open]	20.6	19.79	19.12	18.18	24.84
Spark Timing [cylinder 1-5 avg]	16.92	16.91	17.00	16.90	16.83
Spark Timing [cylinder 6]	18.92	18.91	19.00	18.92	18.82

Appendix G – Low Viscosity Oil Tabular Data

Data Point Name	QSK-90-1500-SAE40-01	QSK-90-1500-SAE40-02	QSK-90-1500-SAE40-03	QSK-90-1500-SAE40-04	QSK-90-1500-SAE40-05
Engine Data					
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	4.06E+02	4.06E+02	4.06E+02	4.06E+02	4.06E+02
Torque[ft-lb]	1.42E+03	1.42E+03	1.42E+03	1.42E+03	1.42E+03
Fuel Flow[#ph]	1.42E+02	1.42E+02	1.42E+02	1.42E+02	1.42E+02
Fuel Pressure[psig]	4.86E+00	4.86E+00	4.86E+00	4.86E+00	4.86E+00
Fuel Temp[F]	8.69E+01	8.69E+01	8.70E+01	8.71E+01	8.72E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.23E+01	3.22E+01	3.22E+01	3.23E+01	3.22E+01
IC Diff Pressure[inH2O]	-8.44E-01	-8.51E-01	-8.40E-01	-8.29E-01	-8.41E-01
Boost Pressure[psig]	2.91E+01	2.90E+01	2.91E+01	2.90E+01	2.90E+01
Inlet Air Temperature[F]	9.98E+01	9.89E+01	9.88E+01	9.89E+01	9.91E+01
Intake Manifold Temp[F]	1.30E+02	1.30E+02	1.30E+02	1.30E+02	1.30E+02
Boost Temp[F]	3.43E+02	3.42E+02	3.42E+02	3.42E+02	3.42E+02
Inlet Air RH[%]	5.05E+01	5.06E+01	5.07E+01	5.05E+01	5.02E+01
Exhaust Back Pres[inHg]	4.69E+00	4.71E+00	4.70E+00	4.72E+00	4.68E+00
EMAP[psia]	3.73E+01	3.72E+01	3.72E+01	3.73E+01	3.72E+01
Exhaust Temp[F]	9.65E+02	9.64E+02	9.64E+02	9.62E+02	9.62E+02
Turbine In Temp[F]	1.19E+03	1.19E+03	1.19E+03	1.19E+03	1.19E+03
Exh Port 1[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.09E+03
Exh Port 2[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.09E+03
Exh Port 3[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.09E+03
Exh Port 4[F]	1.10E+03	1.10E+03	1.10E+03	1.10E+03	1.10E+03
Exh Port 5[F]	1.10E+03	1.10E+03	1.10E+03	1.10E+03	1.10E+03
Exh Port 6[F]	1.07E+03	1.07E+03	1.07E+03	1.07E+03	1.07E+03
JW In Temp[F]	1.77E+02	1.78E+02	1.77E+02	1.77E+02	1.78E+02
JW Out Temp[F]	1.88E+02	1.88E+02	1.87E+02	1.87E+02	1.89E+02
ACW In Temp[F]	1.16E+02	1.16E+02	1.16E+02	1.15E+02	1.15E+02
ACW Out Temp[F]	1.25E+02	1.25E+02	1.25E+02	1.25E+02	1.25E+02
Dyno In Temp[F]	7.76E+01	7.82E+01	7.84E+01	7.81E+01	7.81E+01
Dyno Out Temp[F]	1.11E+02	1.12E+02	1.12E+02	1.12E+02	1.12E+02
Oil Sump Temp[F]	2.11E+02	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Oil Rifle Temp[F]	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02
Oil Pressure[psig]	7.06E+01	7.12E+01	7.00E+01	6.98E+01	7.10E+01
THC[ppm dry]	1.87E+03	1.85E+03	1.85E+03	1.85E+03	1.84E+03
O2[%dry]	8.59E+00	8.61E+00	8.60E+00	8.63E+00	8.64E+00
NOx[ppm dry]	1.29E+02	1.33E+02	1.31E+02	1.28E+02	1.33E+02

NO[ppm dry]	7.06E+01	7.37E+01	7.10E+01	6.97E+01	7.11E+01
NO2[ppm dry]	5.88E+01	5.97E+01	6.04E+01	5.84E+01	6.16E+01
CO2[% dry]	7.11E+00	7.10E+00	7.10E+00	7.08E+00	7.09E+00
CO[ppm dry]	5.45E+02	5.45E+02	5.45E+02	5.45E+02	5.46E+02
Supercharger Speed	3.06E+01	3.06E+01	3.06E+01	3.06E+01	3.06E+01
SC IC CV Pos.	7.04E+01	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Steam Valve Position	1.67E+01	1.50E+01	1.50E+01	1.68E+01	1.65E+01
ICW CV Pos.	4.06E+01	3.81E+01	3.66E+01	3.57E+01	3.78E+01
Exh Back Pres CV	6.41E+01	6.42E+01	6.37E+01	6.36E+01	6.41E+01
JW Temp Valve Pos.	6.13E+01	6.26E+01	6.18E+01	6.36E+01	6.00E+01
Jacket Water Flow Control Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	1.33E+02	1.33E+02	1.33E+02	1.32E+02	1.33E+02
Intercooler Flow [gpm]	1.37E+02	1.37E+02	1.37E+02	1.37E+02	1.37E+02
Dyno Water Flow [gpm]	7.22E+01	7.23E+01	7.22E+01	7.22E+01	7.23E+01
Boiler Return Temp [C]	6.70E+01	6.58E+01	6.46E+01	6.23E+01	6.12E+01
Boiler Supply Temp [C]	6.69E+01	6.58E+01	6.46E+01	6.21E+01	6.14E+01
BMEP[psi]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.85E+02
Ambient Pressure[psia]	1.24E+01	1.24E+01	1.24E+01	1.24E+01	1.24E+01
Propane Flow[lb/hr]	2.85E+01	2.84E+01	2.87E+01	2.83E+01	2.88E+01
Propane Valve Pos	6.19E+00	6.08E+00	6.33E+00	6.19E+00	6.42E+00
Propane VFD speed	6.45E+01	6.40E+01	6.51E+01	6.34E+01	6.62E+01
Propane Pressure[psig]	2.50E+01	2.49E+01	2.51E+01	2.49E+01	2.50E+01
Blowby Flow[acfm]	5.86E+00	5.84E+00	5.81E+00	5.76E+00	5.74E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data					
PHI Comb.	~~0.00E+00~~	6.27E-01	6.27E-01	0.00E+00	6.26E-01
BSFC [BTU/BHP_hr]	7.00E+03	7.02E+03	7.03E+03	6.99E+03	7.03E+03
Stoich. A/F	~~0.00E+00~~	1.68E+01	1.68E+01	0.00E+00	1.68E+01
U & S A/F	~~0.00E+00~~	2.68E+01	2.68E+01	0.00E+00	2.69E+01
U & S Total A/F	~~0.00E+00~~	2.52E+01	2.53E+01	0.00E+00	2.53E+01
Mass Flow A/F	~~0.00E+00~~	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	3.71E+03	3.72E+03	3.73E+03	3.72E+03	3.74E+03
BMEP [psi]	1.85E+02	1.85E+02	1.85E+02	1.85E+02	1.85E+02
Thermal Eff. [%]	3.63E+01	3.63E+01	3.62E+01	3.64E+01	3.62E+01
Wobbe Index [BTU/cuft]	1.26E+03	1.26E+03	1.26E+03	1.27E+03	1.27E+03
Methane [%]	8.54E+01	8.48E+01	8.48E+01	8.43E+01	8.41E+01
LHV [BTU/cuft]	1.03E+03	1.04E+03	1.04E+03	1.05E+03	1.05E+03

Abs. Humidity	1.59E+02	1.59E+02	1.59E+02	1.57E+02	1.56E+02
NOx @ 15% O2 [BHP-hr]	6.20E+01	6.40E+01	6.30E+01	6.16E+01	6.38E+01
BS THC [g/BHP-hr]	4.72E+00	4.74E+00	4.74E+00	4.77E+00	4.74E+00
BS NOx Actual [g/BHP-hr]	6.40E-01	6.60E-01	6.56E-01	6.37E-01	6.65E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	7.90E-01	8.17E-01	8.08E-01	7.86E-01	8.17E-01
BS NO FTIR [g/BHP-hr]	2.81E-01	2.94E-01	2.85E-01	2.79E-01	2.85E-01
BS NO2 FTIR [g/BHP-hr]	3.59E-01	3.66E-01	3.71E-01	3.58E-01	3.79E-01
BS CO [g/BHP-hr]	2.02E+00	2.03E+00	2.04E+00	2.04E+00	2.04E+00
BS CO2 [g/BHP-hr]	4.15E+02	4.16E+02	4.17E+02	4.16E+02	4.18E+02
PHI Total	~~0.00E+00~~	6.33E-01	6.33E-01	0.00E+00	6.31E-01
H2O MF	3.56E+02	3.57E+02	3.58E+02	3.55E+02	3.56E+02
Exh MF	3.85E+03	3.86E+03	3.88E+03	3.86E+03	3.88E+03
BS O2 [g/BHP-hr]	~~3.65E+02~~	3.67E+02	3.68E+02	3.68E+02	3.70E+02
Gas Density [lbm/1000cuft]	5.46E+01	5.49E+01	5.49E+01	5.52E+01	5.52E+01
Vapor Pressure[kPa]	1.14E+00	1.13E+00	1.14E+00	1.12E+00	1.11E+00
Combustion Data					
FMEP [psi]	1.85E+01	1.85E+01	1.84E+01	1.85E+01	1.84E+01

Data Point Name	**QSK-90-1500-SAE40-06**	**QSK-75-1500-SAE40-07**	**QSK-75-1500-SAE40-08**	**QSK-75-1500-SAE40-09**	**QSK-50-1500-SAE40-10**
Engine Data					
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	4.06E+02	3.38E+02	3.38E+02	3.38E+02	2.25E+02
Torque[ft-lb]	1.42E+03	1.18E+03	1.18E+03	1.18E+03	7.89E+02
Fuel Flow[#ph]	1.42E+02	1.21E+02	1.21E+02	1.21E+02	8.70E+01
Fuel Pressure[psig]	4.86E+00	4.88E+00	4.88E+00	4.88E+00	4.95E+00
Fuel Temp[F]	8.72E+01	8.75E+01	8.74E+01	8.73E+01	8.64E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.61E+00
IMAP[psia]	3.22E+01	2.74E+01	2.74E+01	2.73E+01	1.93E+01
IC Diff Pressure[inH2O]	-8.45E-01	-1.57E+00	-1.57E+00	-1.53E+00	-1.11E+00
Boost Pressure[psig]	2.90E+01	2.71E+01	2.70E+01	2.70E+01	1.74E+01
Inlet Air Temperature[F]	9.94E+01	9.89E+01	9.86E+01	9.84E+01	9.99E+01
Intake Manifold Temp[F]	1.30E+02	1.30E+02	1.30E+02	1.29E+02	1.32E+02
Boost Temp[F]	3.42E+02	3.30E+02	3.29E+02	3.29E+02	2.61E+02
Inlet Air RH[%]	5.05E+01	5.09E+01	5.22E+01	5.32E+01	5.06E+01
Exhaust Back Pres[inHg]	4.69E+00	4.70E+00	4.71E+00	4.70E+00	4.65E+00

EMAP[psia]	3.71E+01	3.34E+01	3.35E+01	3.34E+01	2.55E+01
Exhaust Temp[F]	9.63E+02	9.53E+02	9.52E+02	9.53E+02	9.87E+02
Turbine In Temp[F]	1.19E+03	1.18E+03	1.18E+03	1.18E+03	1.15E+03
Exh Port 1[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.08E+03
Exh Port 2[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.08E+03
Exh Port 3[F]	1.09E+03	1.09E+03	1.09E+03	1.09E+03	1.07E+03
Exh Port 4[F]	1.10E+03	1.08E+03	1.08E+03	1.08E+03	1.06E+03
Exh Port 5[F]	1.10E+03	1.09E+03	1.09E+03	1.09E+03	1.08E+03
Exh Port 6[F]	1.07E+03	1.06E+03	1.06E+03	1.06E+03	1.05E+03
JW In Temp[F]	1.77E+02	1.78E+02	1.79E+02	1.80E+02	1.87E+02
JW Out Temp[F]	1.87E+02	1.88E+02	1.89E+02	1.89E+02	1.95E+02
ACW In Temp[F]	1.16E+02	1.17E+02	1.17E+02	1.16E+02	1.22E+02
ACW Out Temp[F]	1.25E+02	1.24E+02	1.24E+02	1.24E+02	1.25E+02
Dyno In Temp[F]	7.83E+01	7.76E+01	7.69E+01	7.68E+01	7.49E+01
Dyno Out Temp[F]	1.12E+02	1.06E+02	1.05E+02	1.05E+02	9.38E+01
Oil Sump Temp[F]	2.11E+02	2.10E+02	2.11E+02	2.11E+02	2.11E+02
Oil Rifle Temp[F]	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.07E+02
Oil Pressure[psig]	7.00E+01	7.15E+01	7.07E+01	7.11E+01	7.13E+01
THC[ppm dry]	1.84E+03	1.84E+03	1.84E+03	1.83E+03	1.99E+03
O2[%dry]	8.60E+00	8.38E+00	8.38E+00	8.34E+00	8.21E+00
NOx[ppm dry]	1.30E+02	1.37E+02	1.42E+02	1.51E+02	9.52E+01
NO[ppm dry]	7.00E+01	7.72E+01	8.34E+01	8.06E+01	3.74E+01
NO2[ppm dry]	6.00E+01	5.95E+01	5.90E+01	7.02E+01	5.78E+01
CO2[% dry]	7.11E+00	7.20E+00	7.20E+00	7.24E+00	7.42E+00
CO[ppm dry]	5.48E+02	5.32E+02	5.36E+02	5.41E+02	5.28E+02
Supercharger Speed	3.06E+01	2.71E+01	2.71E+01	2.71E+01	2.21E+01
SC IC CV Pos.	1.00E+02	1.00E+02	1.00E+02	1.00E+02	4.26E+01
Steam Valve Position	1.52E+01	1.50E+01	1.50E+01	1.50E+01	1.28E+01
ICW CV Pos.	3.86E+01	4.40E+01	4.40E+01	4.40E+01	4.04E+01
Exh Back Pres CV	6.41E+01	6.81E+01	6.85E+01	6.84E+01	7.75E+01
JW Temp Valve Pos.	6.35E+01	6.46E+01	6.21E+01	6.32E+01	6.18E+01
Jacket Water Flow Control Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	1.33E+02	1.33E+02	1.32E+02	1.32E+02	1.32E+02
Intercooler Flow [gpm]	1.37E+02	1.37E+02	1.37E+02	1.37E+02	1.38E+02
Dyno Water Flow [gpm]	7.21E+01	7.20E+01	7.21E+01	7.21E+01	7.20E+01
Boiler Return Temp [C]	6.07E+01	5.66E+01	5.56E+01	5.55E+01	7.22E+01
Boiler Supply Temp [C]	6.09E+01	5.65E+01	5.61E+01	5.53E+01	6.77E+01
BMEP[psi]	1.85E+02	1.54E+02	1.54E+02	1.54E+02	1.03E+02
Ambient Pressure[psia]	1.24E+01	1.24E+01	1.24E+01	1.24E+01	1.24E+01

Propane Flow[lb/hr]	2.85E+01	1.79E+01	1.90E+01	1.90E+01	2.82E+01
Propane Valve Pos	6.40E+00	4.14E+00	4.69E+00	4.58E+00	7.86E+00
Propane VFD speed	6.49E+01	5.07E+01	5.32E+01	5.20E+01	6.35E+01
Propane Pressure[psig]	2.50E+01	2.51E+01	2.50E+01	2.50E+01	2.51E+01
Blowby Flow[acfm]	5.73E+00	5.98E+00	6.13E+00	6.05E+00	5.88E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data					
PHI Comb.	6.27E-01	6.38E-01	6.38E-01	6.40E-01	6.44E-01
BSFC [BTU/BHP_hr]	7.01E+03	7.16E+03	7.14E+03	7.16E+03	7.75E+03
Stoich. A/F	1.68E+01	1.69E+01	1.69E+01	1.69E+01	1.66E+01
U & S A/F	2.68E+01	2.65E+01	2.65E+01	2.64E+01	2.58E+01
U & S Total A/F	2.53E+01	2.49E+01	2.49E+01	2.48E+01	2.46E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	3.72E+03	3.13E+03	3.13E+03	3.12E+03	2.26E+03
BMEP [psi]	1.85E+02	1.54E+02	1.54E+02	1.54E+02	1.03E+02
Thermal Eff. [%]	3.63E+01	3.55E+01	3.56E+01	3.55E+01	3.28E+01
Wobbe Index [BTU/cuft]	1.27E+03	1.25E+03	1.25E+03	1.26E+03	1.32E+03
Methane [%]	8.41E+01	8.52E+01	8.49E+01	8.46E+01	7.76E+01
LHV [BTU/cuft]	1.05E+03	1.02E+03	1.03E+03	1.03E+03	1.14E+03
Abs. Humidity	1.58E+02	1.87E+02	1.91E+02	1.94E+02	2.84E+02
NOx @ 15% O2 [BHP-hr]	6.23E+01	6.44E+01	6.71E+01	7.08E+01	4.43E+01
BS THC [g/BHP-hr]	4.73E+00	4.65E+00	4.64E+00	4.62E+00	6.03E+00
BS NOx Actual [g/BHP-hr]	6.47E-01	6.77E-01	6.98E-01	7.54E-01	5.42E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	7.96E-01	8.42E-01	8.76E-01	9.26E-01	6.27E-01
BS NO FTIR [g/BHP-hr]	2.80E-01	3.10E-01	3.35E-01	3.23E-01	1.61E-01
BS NO2 FTIR [g/BHP-hr]	3.67E-01	3.67E-01	3.63E-01	4.31E-01	3.81E-01
BS CO [g/BHP-hr]	2.04E+00	2.00E+00	2.01E+00	2.02E+00	2.12E+00
BS CO2 [g/BHP-hr]	4.17E+02	4.24E+02	4.24E+02	4.25E+02	4.68E+02
PHI Total	6.32E-01	6.42E-01	6.42E-01	6.44E-01	6.48E-01
H2O MF	3.55E+02	3.16E+02	3.17E+02	3.18E+02	2.51E+02
Exh MF	3.86E+03	3.25E+03	3.25E+03	3.24E+03	2.35E+03
BS O2 [g/BHP-hr]	3.67E+02	3.59E+02	3.59E+02	3.56E+02	3.76E+02
Gas Density [lbm/1000cuft]	5.53E+01	5.41E+01	5.42E+01	5.44E+01	6.01E+01
Vapor Pressure[kPa]	1.12E+00	1.13E+00	1.15E+00	1.16E+00	1.18E+00
Combustion Data					
FMEP [psi]	1.84E+01	1.70E+01	1.70E+01	1.70E+01	1.37E+01

Data Point Name	QSK-50-1500-SAE40-11	QSK-50-1500-SAE40-12	QSK-25-1500-SAE40-13	QSK-25-1500-SAE40-14	QSK-25-1500-SAE40-15
Engine Data					
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	2.25E+02	2.25E+02	1.13E+02	1.13E+02	1.13E+02
Torque[ft-lb]	7.89E+02	7.89E+02	3.94E+02	3.94E+02	3.94E+02
Fuel Flow[#ph]	8.61E+01	8.66E+01	5.00E+01	5.11E+01	5.04E+01
Fuel Pressure[psig]	4.94E+00	4.94E+00	5.00E+00	5.01E+00	5.01E+00
Fuel Temp[F]	8.65E+01	8.65E+01	8.51E+01	8.51E+01	8.49E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	1.93E+01	1.93E+01	1.11E+01	1.12E+01	1.12E+01
IC Diff Pressure[inH2O]	-1.13E+00	-1.15E+00	-4.97E-01	-5.07E-01	-5.14E-01
Boost Pressure[psig]	1.75E+01	1.75E+01	6.81E+00	6.94E+00	7.05E+00
Inlet Air Temperature[F]	9.93E+01	9.93E+01	9.77E+01	9.76E+01	9.74E+01
Intake Manifold Temp[F]	1.30E+02	1.27E+02	1.29E+02	1.29E+02	1.30E+02
Boost Temp[F]	2.60E+02	2.60E+02	1.62E+02	1.64E+02	1.65E+02
Inlet Air RH[%]	5.04E+01	5.02E+01	6.06E+01	6.11E+01	6.08E+01
Exhaust Back Pres[inHg]	4.67E+00	4.69E+00	4.70E+00	4.74E+00	4.66E+00
EMAP[psia]	2.56E+01	2.56E+01	1.84E+01	1.85E+01	1.85E+01
Exhaust Temp[F]	9.86E+02	9.85E+02	1.02E+03	1.03E+03	1.03E+03
Turbine In Temp[F]	1.15E+03	1.15E+03	1.08E+03	1.09E+03	1.10E+03
Exh Port 1[F]	1.08E+03	1.08E+03	1.07E+03	1.08E+03	1.09E+03
Exh Port 2[F]	1.08E+03	1.07E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 3[F]	1.07E+03	1.06E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 4[F]	1.06E+03	1.06E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 5[F]	1.08E+03	1.07E+03	1.08E+03	1.09E+03	1.10E+03
Exh Port 6[F]	1.04E+03	1.04E+03	1.05E+03	1.06E+03	1.06E+03
JW In Temp[F]	1.87E+02	1.86E+02	1.92E+02	1.91E+02	1.90E+02
JW Out Temp[F]	1.94E+02	1.94E+02	1.98E+02	1.97E+02	1.96E+02
ACW In Temp[F]	1.18E+02	1.15E+02	1.17E+02	1.18E+02	1.19E+02
ACW Out Temp[F]	1.22E+02	1.19E+02	1.18E+02	1.19E+02	1.20E+02
Dyno In Temp[F]	7.51E+01	7.54E+01	7.40E+01	7.39E+01	7.39E+01
Dyno Out Temp[F]	9.38E+01	9.42E+01	8.34E+01	8.33E+01	8.32E+01
Oil Sump Temp[F]	2.11E+02	2.12E+02	2.11E+02	2.11E+02	2.11E+02
Oil Rifle Temp[F]	2.07E+02	2.07E+02	2.08E+02	2.08E+02	2.07E+02
Oil Pressure[psig]	7.17E+01	7.11E+01	7.12E+01	7.16E+01	7.17E+01
THC[ppm dry]	1.98E+03	2.00E+03	2.02E+03	1.98E+03	1.93E+03
O2[%dry]	8.22E+00	8.23E+00	6.82E+00	6.87E+00	6.88E+00
NOx[ppm dry]	8.35E+01	9.48E+01	2.16E+02	1.63E+02	1.50E+02
NO[ppm dry]	4.41E+01	3.76E+01	1.05E+02	6.56E+01	5.47E+01

NO2[ppm dry]	3.94E+01	5.71E+01	1.11E+02	9.76E+01	9.50E+01
CO2[% dry]	7.42E+00	7.42E+00	8.50E+00	8.48E+00	8.50E+00
CO[ppm dry]	5.31E+02	5.34E+02	6.98E+02	6.54E+02	6.42E+02
Supercharger Speed	2.21E+01	2.21E+01	1.60E+01	1.60E+01	1.60E+01
SC IC CV Pos.	9.80E+01	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Steam Valve Position	1.17E+01	1.14E+01	7.00E+00	8.00E+00	8.00E+00
ICW CV Pos.	3.87E+01	4.80E+01	7.20E+01	7.20E+01	7.20E+01
Exh Back Pres CV	7.73E+01	7.72E+01	8.76E+01	8.73E+01	8.77E+01
JW Temp Valve Pos.	6.41E+01	6.43E+01	6.35E+01	6.53E+01	6.66E+01
Jacket Water Flow Control Valve	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Jacket Water Flow [gpm]	1.32E+02	1.32E+02	1.31E+02	1.31E+02	1.32E+02
Intercooler Flow [gpm]	1.37E+02	1.38E+02	1.39E+02	1.39E+02	1.39E+02
Dyno Water Flow [gpm]	7.20E+01	7.21E+01	7.20E+01	7.19E+01	7.18E+01
Boiler Return Temp [C]	6.94E+01	6.75E+01	5.86E+01	5.82E+01	5.72E+01
Boiler Supply Temp [C]	6.95E+01	6.73E+01	5.90E+01	5.80E+01	5.76E+01
BMEP[psi]	1.03E+02	1.03E+02	5.13E+01	5.13E+01	5.12E+01
Ambient Pressure[psia]	1.24E+01	1.24E+01	1.24E+01	1.24E+01	1.24E+01
Propane Flow[lb/hr]	2.81E+01	3.02E+01	3.69E+01	3.52E+01	3.30E+01
Propane Valve Pos	7.32E+00	7.48E+00	2.36E+01	2.13E+01	1.87E+01
Propane VFD speed	6.11E+01	6.67E+01	4.39E+01	4.17E+01	3.90E+01
Propane Pressure[psig]	2.50E+01	2.50E+01	2.51E+01	2.50E+01	2.50E+01
Blowby Flow[acfm]	6.00E+00	5.96E+00	5.96E+00	5.94E+00	5.94E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data					
PHI Comb.	6.44E-01	6.43E-01	7.25E-01	7.22E-01	7.22E-01
BSFC [BTU/BHP_hr]	7.67E+03	7.71E+03	8.90E+03	9.10E+03	8.97E+03
Stoich. A/F	1.66E+01	1.66E+01	1.70E+01	1.70E+01	1.70E+01
U & S A/F	2.58E+01	2.59E+01	2.35E+01	2.35E+01	2.35E+01
U & S Total A/F	2.46E+01	2.46E+01	2.19E+01	2.20E+01	2.20E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	2.23E+03	2.24E+03	1.16E+03	1.19E+03	1.18E+03
BMEP [psi]	1.03E+02	1.03E+02	5.12E+01	5.12E+01	5.12E+01
Thermal Eff. [%]	3.32E+01	3.30E+01	2.86E+01	2.80E+01	2.84E+01
Wobbe Index [BTU/cuft]	1.32E+03	1.33E+03	1.22E+03	1.22E+03	1.22E+03
Methane [%]	7.77E+01	7.71E+01	8.93E+01	8.90E+01	8.88E+01
LHV [BTU/cuft]	1.14E+03	1.15E+03	9.65E+02	9.70E+02	9.70E+02
Abs. Humidity	2.66E+02	2.46E+02	5.81E+02	5.92E+02	5.97E+02

NOx @ 15% O2 [BHP-hr]	3.88E+01	4.41E+01	9.05E+01	6.86E+01	6.30E+01
BS THC [g/BHP-hr]	5.93E+00	6.07E+00	4.98E+00	5.05E+00	4.84E+00
BS NOx Actual [g/BHP-hr]	4.44E-01	5.37E-01	1.15E+00	9.25E-01	8.48E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	5.44E-01	6.23E-01	1.39E+00	1.07E+00	9.72E-01
BS NO FTIR [g/BHP-hr]	1.88E-01	1.61E-01	4.38E-01	2.82E-01	2.32E-01
BS NO2 FTIR [g/BHP-hr]	2.57E-01	3.75E-01	7.14E-01	6.43E-01	6.16E-01
BS CO [g/BHP-hr]	2.11E+00	2.14E+00	2.73E+00	2.62E+00	2.54E+00
BS CO2 [g/BHP-hr]	4.63E+02	4.66E+02	5.22E+02	5.34E+02	5.27E+02
PHI Total	6.48E-01	6.47E-01	7.31E-01	7.29E-01	7.28E-01
H2O MF	2.43E+02	2.38E+02	1.88E+02	1.94E+02	1.92E+02
Exh MF	2.32E+03	2.33E+03	1.21E+03	1.25E+03	1.23E+03
BS O2 [g/BHP-hr]	3.73E+02	3.76E+02	3.05E+02	3.15E+02	3.10E+02
Gas Density [lbm/1000cuft]	6.01E+01	6.05E+01	5.10E+01	5.12E+01	5.13E+01
Vapor Pressure[kPa]	1.11E+00	1.03E+00	1.31E+00	1.34E+00	1.35E+00
Combustion Data					
FMEP [psi]	1.67E+01	1.37E+01	1.18E+01	1.18E+01	1.18E+01

Data Point Name	**QSK-90-1800-SAE40-1**	**QSK-90-1800-SAE40-2**	**QSK-90-1800-SAE40-3**	**QSK-75-1800-SAE40-4**	**QSK-75-1800-SAE40-5**	**QSK-75-1800-SAE40-6**
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	4.24E+02	4.24E+02	4.24E+02	3.54E+02	3.54E+02	3.54E+02
Torque[ft-lb]	1.24E+03	1.24E+03	1.24E+03	1.03E+03	1.03E+03	1.03E+03
Fuel Flow[#ph]	1.59E+02	1.59E+02	1.59E+02	1.36E+02	1.36E+02	1.37E+02
Fuel Pressure[psig]	4.83E+00	4.82E+00	4.83E+00	4.86E+00	4.87E+00	4.86E+00
Fuel Temp[F]	9.28E+01	9.30E+01	9.31E+01	9.32E+01	9.32E+01	9.33E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.61E+00	3.60E+00
IMAP[psia]	3.06E+01	3.08E+01	3.09E+01	2.65E+01	2.64E+01	2.65E+01
IC Diff Pressure[inH2O]	-1.05E+00	-9.79E-01	-9.44E-01	-1.87E+00	-1.86E+00	-1.84E+00
Boost Pressure[psig]	2.96E+01	2.96E+01	2.97E+01	2.83E+01	2.83E+01	2.83E+01
Inlet Air Temperature[F]	1.03E+02	1.03E+02	1.03E+02	1.03E+02	1.03E+02	1.03E+02
Intake Manifold Temp[F]	1.30E+02	1.30E+02	1.30E+02	1.28E+02	1.31E+02	1.32E+02
Boost Temp[F]	3.63E+02	3.66E+02	3.64E+02	3.80E+02	3.69E+02	3.65E+02
Inlet Air RH[%]	5.08E+01	5.05E+01	5.14E+01	4.81E+01	4.90E+01	5.18E+01
Exhaust Back Pres[inHg]	4.67E+00	4.72E+00	4.70E+00	4.75E+00	4.69E+00	4.75E+00
EMAP[psia]	3.97E+01	3.99E+01	4.00E+01	3.59E+01	3.57E+01	3.58E+01
Exhaust Temp[F]	1.01E+03	1.01E+03	1.01E+03	9.94E+02	1.00E+03	9.96E+02

Turbine In Temp[F]	1.24E+03	1.24E+03	1.24E+03	1.22E+03	1.23E+03	1.22E+03
Exh Port 1[F]	1.15E+03	1.15E+03	1.15E+03	1.14E+03	1.15E+03	1.14E+03
Exh Port 2[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.13E+03
Exh Port 3[F]	1.15E+03	1.15E+03	1.15E+03	1.13E+03	1.14E+03	1.13E+03
Exh Port 4[F]	1.16E+03	1.16E+03	1.16E+03	1.14E+03	1.15E+03	1.14E+03
Exh Port 5[F]	1.17E+03	1.17E+03	1.17E+03	1.15E+03	1.15E+03	1.15E+03
Exh Port 6[F]	1.14E+03	1.14E+03	1.14E+03	1.12E+03	1.12E+03	1.12E+03
JW In Temp[F]	1.76E+02	1.77E+02	1.74E+02	1.80E+02	1.82E+02	1.79E+02
JW Out Temp[F]	1.84E+02	1.85E+02	1.83E+02	1.87E+02	1.89E+02	1.87E+02
ACW In Temp[F]	1.14E+02	1.14E+02	1.14E+02	1.14E+02	1.18E+02	1.18E+02
ACW Out Temp[F]	1.25E+02	1.25E+02	1.25E+02	1.23E+02	1.26E+02	1.27E+02
Dyno In Temp[F]	1.03E+02	1.02E+02	1.03E+02	1.02E+02	1.02E+02	1.01E+02
Dyno Out Temp[F]	1.37E+02	1.37E+02	1.37E+02	1.31E+02	1.31E+02	1.30E+02
Oil Sump Temp[F]	2.12E+02	2.12E+02	2.12E+02	2.12E+02	2.13E+02	2.13E+02
Oil Rifle Temp[F]	2.04E+02	2.04E+02	2.04E+02	2.05E+02	2.06E+02	2.06E+02
Oil Pressure[psig]	7.63E+01	7.78E+01	7.63E+01	7.65E+01	7.56E+01	7.69E+01
THC[ppm dry]	1.58E+03	1.59E+03	1.61E+03	1.73E+03	1.70E+03	1.75E+03
O2[%dry]	8.28E+00	8.31E+00	8.31E+00	8.37E+00	8.34E+00	8.31E+00
NOx[ppm dry]	1.22E+02	1.16E+02	1.14E+02	9.91E+01	9.33E+01	1.01E+02
NO[ppm dry]	6.03E+01	5.61E+01	5.42E+01	4.49E+01	3.92E+01	4.43E+01
NO2[ppm dry]	6.16E+01	6.00E+01	5.96E+01	5.42E+01	5.42E+01	5.71E+01
CO2[% dry]	7.27E+00	7.24E+00	7.23E+00	7.22E+00	7.25E+00	7.25E+00
CO[ppm dry]	5.52E+02	5.49E+02	5.49E+02	5.41E+02	5.36E+02	5.42E+02
Supercharger Speed	3.41E+01	3.42E+01	3.42E+01	3.07E+01	3.06E+01	3.06E+01
SC IC CV Pos.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Steam Valve Position	2.10E+01	2.34E+01	2.10E+01	1.93E+01	1.94E+01	1.80E+01
ICW CV Pos.	3.01E+01	3.26E+01	3.36E+01	3.99E+01	4.20E+01	3.20E+01
Exh Back Pres CV	6.15E+01	6.14E+01	6.06E+01	6.51E+01	6.54E+01	6.50E+01
JW Temp Valve Pos.	6.28E+01	6.18E+01	6.19E+01	6.40E+01	6.16E+01	6.38E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.99E+02	1.99E+02	1.99E+02	1.99E+02	1.99E+02	1.99E+02
Intercooler Flow [gpm]	1.36E+02	1.36E+02	1.36E+02	1.36E+02	1.37E+02	1.37E+02
Dyno Water Flow [gpm]	7.21E+01	7.22E+01	7.22E+01	7.21E+01	7.22E+01	7.21E+01
Boiler Return Temp [C]	5.70E+01	5.58E+01	5.58E+01	5.64E+01	5.89E+01	6.59E+01
Boiler Supply Temp [C]	5.67E+01	5.60E+01	5.56E+01	5.56E+01	5.66E+01	6.22E+01
BMEP[psi]	1.61E+02	1.61E+02	1.61E+02	1.34E+02	1.34E+02	1.34E+02
Ambient Pressure[psia]	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Propane Flow[lb/hr]	1.06E+01	9.88E+00	9.56E+00	9.74E+00	1.07E+01	9.55E+00
Propane Valve Pos	2.03E+00	1.90E+00	2.02E+00	1.98E+00	2.48E+00	2.04E+00

Propane VFD speed	1.62E+01	1.56E+01	1.60E+01	1.57E+01	1.76E+01	1.55E+01
Propane Pressure[psig]	2.63E+01	2.61E+01	2.64E+01	2.62E+01	2.65E+01	2.66E+01
Blowby Flow[acfm]	4.91E+00	4.99E+00	5.00E+00	5.06E+00	5.10E+00	5.05E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	7.22E-01	6.41E-01	6.40E-01	6.37E-01	6.39E-01	6.40E-01
BSFC [BTU/BHP_hr]	7.51E+03	7.50E+03	7.49E+03	7.70E+03	7.72E+03	7.74E+03
Stoich. A/F	1.70E+01	1.69E+01	1.69E+01	1.69E+01	1.69E+01	1.69E+01
U & S A/F	2.35E+01	2.63E+01	2.64E+01	2.65E+01	2.64E+01	2.63E+01
U & S Total A/F	2.20E+01	2.49E+01	2.50E+01	2.51E+01	2.50E+01	2.49E+01
Mass Flow A/F	4.10E+03	4.11E+03	4.11E+03	3.53E+03	3.53E+03	3.54E+03
Air Flow [lb/hr]	1.61E+02	1.61E+02	1.61E+02	1.34E+02	1.34E+02	1.34E+02
BMEP [psi]	3.39E+01	3.39E+01	3.40E+01	3.31E+01	3.30E+01	3.29E+01
Thermal Eff. [%]	1.25E+03	1.25E+03	1.25E+03	1.25E+03	1.26E+03	1.25E+03
Wobbe Index [BTU/cuft]	8.31E+01	8.29E+01	8.33E+01	8.26E+01	8.25E+01	8.27E+01
Methane [%]	1.02E+03	1.02E+03	1.02E+03	1.03E+03	1.03E+03	1.03E+03
LHV [BTU/cuft]	1.67E+02	1.65E+02	1.67E+02	1.74E+02	1.91E+02	2.08E+02
Abs. Humidity	5.70E+01	5.44E+01	5.33E+01	4.67E+01	4.38E+01	4.75E+01
NOx @ 15% O2 [BHP-hr]	4.15E+00	4.21E+00	4.23E+00	4.72E+00	4.64E+00	4.78E+00
BS THC [g/BHP-hr]	6.50E-01	6.25E-01	6.13E-01	5.55E-01	5.29E-01	5.71E-01
BS NOx Actual [g/BHP-hr]	7.85E-01	7.51E-01	7.34E-01	6.59E-01	6.20E-01	6.73E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	2.53E-01	2.37E-01	2.28E-01	1.95E-01	1.70E-01	1.92E-01
BS NO FTIR [g/BHP-hr]	3.97E-01	3.88E-01	3.85E-01	3.60E-01	3.60E-01	3.79E-01
BS NO2 FTIR [g/BHP-hr]	2.17E+00	2.16E+00	2.16E+00	2.19E+00	2.17E+00	2.19E+00
BS CO [g/BHP-hr]	4.48E+02	4.48E+02	4.46E+02	4.59E+02	4.60E+02	4.61E+02
BS CO2 [g/BHP-hr]	7.28E-01	6.41E-01	6.39E-01	6.37E-01	6.39E-01	6.40E-01
PHI Total	4.06E+02	4.05E+02	4.06E+02	3.50E+02	3.58E+02	3.67E+02
H2O MF	4.26E+03	4.27E+03	4.26E+03	3.66E+03	3.67E+03	3.68E+03
Exh MF	3.71E+02	3.74E+02	3.73E+02	3.87E+02	3.85E+02	3.84E+02
BS O2 [g/BHP-hr]	5.39E+01	5.41E+01	5.38E+01	5.44E+01	5.45E+01	5.43E+01
Gas Density [lbm/1000cuft]	7.61E+01	6.79E+01	6.74E+01	6.68E+01	6.68E+01	6.65E+01
Vapor Pressure[kPa]	1.13E+00	1.12E+00	1.14E+00	1.02E+00	1.11E+00	1.21E+00
Combustion Data						
FMEP [psi]	1.75E+01	1.74E+01	1.75E+01	1.61E+01	1.60E+01	1.60E+01

Data Point Name	QSK-50-1800-SAE40-7	QSK-50-1800-SAE40-8	QSK-50-1800-SAE40-9	QSK-25-1800-SAE40-10	QSK-25-1800-SAE40-11	QSK-25-1800-SAE40-12
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.36E+02	2.36E+02	2.36E+02	1.18E+02	1.18E+02	1.18E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	3.43E+02	3.43E+02	3.43E+02
Fuel Flow[#ph]	9.98E+01	9.86E+01	9.88E+01	6.22E+01	6.28E+01	6.23E+01
Fuel Pressure[psig]	4.92E+00	4.92E+00	4.92E+00	4.97E+00	4.97E+00	4.97E+00
Fuel Temp[F]	9.36E+01	9.37E+01	9.37E+01	9.39E+01	9.38E+01	9.37E+01
Inlet Air Pres[inHg]	3.60E+00	3.61E+00	3.59E+00	3.60E+00	3.59E+00	3.59E+00
IMAP[psia]	1.93E+01	1.91E+01	1.93E+01	1.26E+01	1.26E+01	1.26E+01
IC Diff Pressure[inH2O]	-1.92E+00	-1.89E+00	-1.92E+00	-8.97E-01	-8.68E-01	-9.33E-01
Boost Pressure[psig]	2.17E+01	2.12E+01	2.17E+01	1.11E+01	1.10E+01	1.11E+01
Inlet Air Temperature[F]	1.02E+02	1.02E+02	1.02E+02	1.00E+02	1.00E+02	9.98E+01
Intake Manifold Temp[F]	1.30E+02	1.27E+02	1.29E+02	1.31E+02	1.31E+02	1.29E+02
Boost Temp[F]	3.24E+02	3.13E+02	3.26E+02	2.36E+02	2.36E+02	2.31E+02
Inlet Air RH[%]	4.85E+01	4.81E+01	4.90E+01	4.87E+01	4.86E+01	4.88E+01
Exhaust Back Pres[inHg]	4.70E+00	4.70E+00	4.71E+00	4.68E+00	4.76E+00	4.71E+00
EMAP[psia]	2.85E+01	2.82E+01	2.85E+01	2.09E+01	2.09E+01	2.10E+01
Exhaust Temp[F]	1.01E+03	1.01E+03	1.01E+03	1.05E+03	1.05E+03	1.05E+03
Turbine In Temp[F]	1.20E+03	1.20E+03	1.20E+03	1.15E+03	1.15E+03	1.15E+03
Exh Port 1[F]	1.14E+03	1.13E+03	1.14E+03	1.12E+03	1.12E+03	1.12E+03
Exh Port 2[F]	1.14E+03	1.13E+03	1.14E+03	1.13E+03	1.12E+03	1.13E+03
Exh Port 3[F]	1.13E+03	1.12E+03	1.13E+03	1.12E+03	1.11E+03	1.12E+03
Exh Port 4[F]	1.12E+03	1.12E+03	1.13E+03	1.11E+03	1.10E+03	1.11E+03
Exh Port 5[F]	1.13E+03	1.13E+03	1.14E+03	1.13E+03	1.12E+03	1.13E+03
Exh Port 6[F]	1.11E+03	1.10E+03	1.11E+03	1.09E+03	1.09E+03	1.09E+03
JW In Temp[F]	1.81E+02	1.82E+02	1.84E+02	1.89E+02	1.91E+02	1.87E+02
JW Out Temp[F]	1.88E+02	1.88E+02	1.90E+02	1.94E+02	1.96E+02	1.92E+02
ACW In Temp[F]	1.18E+02	1.14E+02	1.18E+02	1.21E+02	1.20E+02	1.16E+02
ACW Out Temp[F]	1.23E+02	1.20E+02	1.23E+02	1.23E+02	1.22E+02	1.18E+02
Dyno In Temp[F]	9.94E+01	9.90E+01	9.89E+01	9.62E+01	9.55E+01	9.53E+01
Dyno Out Temp[F]	1.19E+02	1.19E+02	1.18E+02	1.06E+02	1.05E+02	1.05E+02
Oil Sump Temp[F]	2.13E+02	2.12E+02	2.12E+02	2.11E+02	2.13E+02	2.12E+02
Oil Rifle Temp[F]	2.05E+02	2.05E+02	2.06E+02	2.06E+02	2.08E+02	2.07E+02
Oil Pressure[psig]	7.78E+01	7.72E+01	7.73E+01	7.75E+01	7.63E+01	7.80E+01
THC[ppm dry]	1.90E+03	1.92E+03	1.90E+03	2.22E+03	2.25E+03	2.22E+03
O2[%dry]	8.26E+00	8.22E+00	8.21E+00	8.33E+00	8.32E+00	8.32E+00
NOx[ppm dry]	5.96E+01	7.21E+01	6.98E+01	3.39E+01	3.44E+01	3.36E+01

NO[ppm dry]	2.57E+01	2.41E+01	3.09E+01	4.09E+00	4.10E+00	3.16E+00
NO2[ppm dry]	3.39E+01	4.80E+01	3.89E+01	2.98E+01	3.03E+01	3.05E+01
CO2[% dry]	7.37E+00	7.38E+00	7.39E+00	7.44E+00	7.44E+00	7.48E+00
CO[ppm dry]	5.34E+02	5.37E+02	5.35E+02	5.98E+02	5.96E+02	6.04E+02
Supercharger Speed	2.49E+01	2.47E+01	2.49E+01	1.91E+01	1.90E+01	1.91E+01
SC IC CV Pos.	0.00E+00	0.00E+00	1.60E-04	1.28E-02	8.54E-02	1.32E+01
Steam Valve Position	1.45E+01	1.42E+01	1.41E+01	9.01E+00	9.00E+00	9.76E+00
ICW CV Pos.	3.33E+01	4.35E+01	4.71E+01	4.89E+01	3.92E+01	4.46E+01
Exh Back Pres CV	7.36E+01	7.40E+01	7.36E+01	8.28E+01	8.28E+01	8.24E+01
JW Temp Valve Pos.	6.46E+01	6.53E+01	6.31E+01	6.62E+01	6.38E+01	6.59E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.99E+02	1.99E+02	1.99E+02	1.99E+02	1.99E+02	1.99E+02
Intercooler Flow [gpm]	1.37E+02	1.37E+02	1.38E+02	1.38E+02	1.37E+02	1.37E+02
Dyno Water Flow [gpm]	7.19E+01	7.19E+01	7.19E+01	7.16E+01	7.17E+01	7.16E+01
Boiler Return Temp [C]	6.64E+01	6.53E+01	6.42E+01	5.96E+01	5.85E+01	5.79E+01
Boiler Supply Temp [C]	6.64E+01	6.52E+01	6.40E+01	5.94E+01	5.85E+01	5.82E+01
BMEP[psi]	8.95E+01	8.95E+01	8.95E+01	4.47E+01	4.47E+01	4.47E+01
Ambient Pressure[psia]	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01	1.23E+01
Propane Flow[lb/hr]	1.65E+01	1.63E+01	1.74E+01	2.23E+01	2.83E+01	3.19E+01
Propane Valve Pos	4.48E+00	4.34E+00	4.71E+00	8.37E+00	9.80E+00	8.88E+00
Propane VFD speed	2.21E+01	2.19E+01	2.25E+01	2.76E+01	3.59E+01	4.11E+01
Propane Pressure[psig]	2.67E+01	2.59E+01	2.60E+01	2.59E+01	2.57E+01	2.53E+01
Blowby Flow[acfm]	5.23E+00	5.31E+00	5.25E+00	5.56E+00	5.58E+00	5.57E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	6.44E-01	6.44E-01	6.45E-01	6.46E-01	6.42E-01	6.42E-01
BSFC [BTU/BHP_hr]	8.48E+03	8.39E+03	8.39E+03	1.06E+04	1.07E+04	1.06E+04
Stoich. A/F	1.68E+01	1.68E+01	1.68E+01	1.68E+01	1.66E+01	1.65E+01
U & S A/F	2.60E+01	2.60E+01	2.60E+01	2.59E+01	2.58E+01	2.58E+01
U & S Total A/F	2.48E+01	2.48E+01	2.47E+01	2.47E+01	2.48E+01	2.48E+01
Mass Flow A/F	2.58E+03	2.54E+03	2.55E+03	1.65E+03	1.66E+03	1.64E+03
Air Flow [lb/hr]	8.94E+01	8.94E+01	8.94E+01	4.46E+01	4.46E+01	4.46E+01
BMEP [psi]	3.00E+01	3.03E+01	3.03E+01	2.40E+01	2.38E+01	2.39E+01
Thermal Eff. [%]	1.28E+03	1.29E+03	1.29E+03	1.35E+03	1.35E+03	1.36E+03
Wobbe Index [BTU/cuft]	7.99E+01	7.94E+01	7.92E+01	7.32E+01	7.24E+01	7.18E+01
Methane [%]	1.07E+03	1.08E+03	1.08E+03	1.18E+03	1.19E+03	1.20E+03
LHV [BTU/cuft]	2.62E+02	2.40E+02	2.54E+02	4.26E+02	4.26E+02	3.95E+02

Abs. Humidity	2.78E+01	3.36E+01	3.25E+01	1.59E+01	1.61E+01	1.58E+01
NOx @ 15% O2 [BHP-hr]	5.89E+00	5.93E+00	5.86E+00	9.56E+00	9.87E+00	9.73E+00
BS THC [g/BHP-hr]	3.65E-01	4.54E-01	4.21E-01	2.93E-01	3.01E-01	2.94E-01
BS NOx Actual [g/BHP-hr]	4.30E-01	5.14E-01	4.97E-01	3.06E-01	3.14E-01	3.04E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	1.21E-01	1.12E-01	1.44E-01	2.40E-02	2.44E-02	1.86E-02
BS NO FTIR [g/BHP-hr]	2.45E-01	3.42E-01	2.77E-01	2.69E-01	2.77E-01	2.75E-01
BS NO2 FTIR [g/BHP-hr]	2.34E+00	2.33E+00	2.32E+00	3.28E+00	3.31E+00	3.32E+00
BS CO [g/BHP-hr]	5.08E+02	5.03E+02	5.04E+02	6.42E+02	6.50E+02	6.46E+02
BS CO2 [g/BHP-hr]	6.44E-01	6.44E-01	6.45E-01	6.46E-01	6.42E-01	6.43E-01
PHI Total	2.84E+02	2.73E+02	2.78E+02	2.09E+02	2.11E+02	2.02E+02
H2O MF	2.68E+03	2.64E+03	2.65E+03	1.71E+03	1.73E+03	1.70E+03
Exh MF	4.14E+02	4.08E+02	4.07E+02	5.22E+02	5.28E+02	5.22E+02
BS O2 [g/BHP-hr]	5.67E+01	5.71E+01	5.72E+01	6.23E+01	6.29E+01	6.34E+01
Gas Density [lbm/1000cuft]	6.70E+01	6.20E+01	6.14E+01	6.12E+01	5.44E+01	5.38E+01
Vapor Pressure[kPa]	1.10E+00	9.97E-01	1.06E+00	1.12E+00	1.12E+00	1.05E+00
Combustion Data						
FMEP [psi]	1.38E+01	1.37E+01	1.37E+01	1.25E+01	1.24E+01	1.26E+01

Data Point Name	**QSK-90-1500-SAE30-13**	**QSK-90-1500-SAE30-14**	**QSK-90-1500-SAE30-15**	**QSK-75-1500-SAE30-16**	**QSK-75-1500-SAE30-17**	**QSK-75-1500-SAE30-18**
Engine Data						
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	4.06E+02	4.06E+02	4.06E+02	3.38E+02	3.38E+02	3.38E+02
Torque[ft-lb]	1.42E+03	1.42E+03	1.42E+03	1.18E+03	1.18E+03	1.18E+03
Fuel Flow[#ph]	1.39E+02	1.40E+02	1.39E+02	1.19E+02	1.18E+02	1.19E+02
Fuel Pressure[psig]	4.86E+00	4.86E+00	4.86E+00	4.89E+00	4.89E+00	4.89E+00
Fuel Temp[F]	8.41E+01	8.40E+01	8.42E+01	8.41E+01	8.43E+01	8.43E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.23E+01	3.23E+01	3.23E+01	2.75E+01	2.76E+01	2.76E+01
IC Diff Pressure[inH2O]	-8.47E-01	-8.60E-01	-8.50E-01	-1.54E+00	-1.56E+00	-1.56E+00
Boost Pressure[psig]	2.90E+01	2.90E+01	2.90E+01	2.70E+01	2.71E+01	2.71E+01
Inlet Air Temperature[F]	9.88E+01	9.88E+01	9.96E+01	9.89E+01	9.88E+01	9.87E+01
Intake Manifold Temp[F]	1.31E+02	1.31E+02	1.31E+02	1.31E+02	1.30E+02	1.30E+02
Boost Temp[F]	3.44E+02	3.60E+02	3.55E+02	3.65E+02	3.99E+02	3.66E+02
Inlet Air RH[%]	4.64E+01	4.46E+01	4.31E+01	4.86E+01	4.64E+01	4.49E+01
Exhaust Back Pres[inHg]	4.72E+00	4.67E+00	4.70E+00	4.71E+00	4.71E+00	4.67E+00

EMAP[psia]	3.72E+01	3.72E+01	3.72E+01	3.35E+01	3.35E+01	3.35E+01
Exhaust Temp[F]	9.54E+02	9.52E+02	9.52E+02	9.47E+02	9.47E+02	9.46E+02
Turbine In Temp[F]	1.18E+03	1.18E+03	1.18E+03	1.17E+03	1.17E+03	1.17E+03
Exh Port 1[F]	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
Exh Port 2[F]	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
Exh Port 3[F]	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
Exh Port 4[F]	1.09E+03	1.09E+03	1.09E+03	1.07E+03	1.07E+03	1.07E+03
Exh Port 5[F]	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03	1.08E+03
Exh Port 6[F]	1.07E+03	1.07E+03	1.07E+03	1.06E+03	1.06E+03	1.06E+03
JW In Temp[F]	1.86E+02	1.86E+02	1.87E+02	1.88E+02	1.89E+02	1.87E+02
JW Out Temp[F]	1.93E+02	1.94E+02	1.94E+02	1.94E+02	1.96E+02	1.94E+02
ACW In Temp[F]	1.17E+02	1.16E+02	1.16E+02	1.18E+02	1.17E+02	1.16E+02
ACW Out Temp[F]	1.26E+02	1.26E+02	1.25E+02	1.25E+02	1.24E+02	1.23E+02
Dyno In Temp[F]	7.53E+01	7.58E+01	7.61E+01	7.59E+01	7.62E+01	7.59E+01
Dyno Out Temp[F]	1.08E+02	1.09E+02	1.09E+02	1.03E+02	1.04E+02	1.04E+02
Oil Sump Temp[F]	2.11E+02	2.12E+02	2.12E+02	2.12E+02	2.13E+02	2.12E+02
Oil Rifle Temp[F]	2.05E+02	2.05E+02	2.06E+02	2.06E+02	2.07E+02	2.06E+02
Oil Pressure[psig]	5.57E+01	5.70E+01	5.62E+01	5.75E+01	5.66E+01	5.78E+01
THC[ppm dry]	1.82E+03	1.81E+03	1.80E+03	1.90E+03	1.89E+03	1.89E+03
O2[%dry]	8.77E+00	8.77E+00	8.79E+00	8.54E+00	8.58E+00	8.60E+00
NOx[ppm dry]	1.21E+02	1.25E+02	1.23E+02	1.23E+02	1.18E+02	1.15E+02
NO[ppm dry]	6.29E+01	6.49E+01	6.40E+01	6.31E+01	5.88E+01	5.87E+01
NO2[ppm dry]	5.84E+01	6.05E+01	5.94E+01	5.99E+01	5.90E+01	5.65E+01
CO2[% dry]	6.99E+00	6.98E+00	6.98E+00	7.14E+00	7.11E+00	7.09E+00
CO[ppm dry]	5.17E+02	5.17E+02	5.16E+02	5.26E+02	5.22E+02	5.21E+02
Supercharger Speed	3.05E+01	3.05E+01	3.05E+01	2.70E+01	2.70E+01	2.71E+01
SC IC CV Pos.	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Steam Valve Position	1.80E+01	1.80E+01	1.80E+01	2.62E+01	2.70E+01	2.74E+01
ICW CV Pos.	3.50E+01	3.50E+01	3.50E+01	4.04E+01	3.50E+01	3.68E+01
Exh Back Pres CV	6.36E+01	6.40E+01	6.41E+01	6.80E+01	6.82E+01	6.80E+01
JW Temp Valve Pos.	6.50E+01	6.50E+01	6.44E+01	6.57E+01	6.23E+01	6.57E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.36E+02	1.36E+02	1.36E+02	1.37E+02	1.36E+02	1.36E+02
Dyno Water Flow [gpm]	7.24E+01	7.25E+01	7.25E+01	7.24E+01	7.25E+01	7.24E+01
Boiler Return Temp [C]	5.70E+01	6.58E+01	6.35E+01	6.36E+01	6.22E+01	6.12E+01
Boiler Supply Temp [C]	5.51E+01	5.88E+01	6.18E+01	6.35E+01	6.23E+01	6.11E+01
BMEP[psi]	1.85E+02	1.85E+02	1.85E+02	1.54E+02	1.54E+02	1.54E+02
Ambient Pressure[psia]	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01

Propane Flow[lb/hr]	1.10E+01	1.12E+01	9.90E+00	1.48E+01	1.57E+01	1.54E+01
Propane Valve Pos	2.17E+00	2.13E+00	1.72E+00	3.34E+00	3.66E+00	3.63E+00
Propane VFD speed	1.63E+01	1.58E+01	1.41E+01	1.95E+01	1.99E+01	2.07E+01
Propane Pressure[psig]	2.59E+01	2.61E+01	2.59E+01	2.66E+01	2.66E+01	2.60E+01
Blowby Flow[acfm]	3.23E+00	2.64E+00	3.30E+00	4.38E+00	4.56E+00	4.44E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	6.20E-01	6.20E-01	6.19E-01	6.30E-01	6.28E-01	6.27E-01
BSFC [BTU/BHP_hr]	6.88E+03	6.93E+03	6.89E+03	7.04E+03	7.02E+03	7.06E+03
Stoich. A/F	1.69E+01	1.69E+01	1.69E+01	1.68E+01	1.68E+01	1.68E+01
U & S A/F	2.72E+01	2.73E+01	2.73E+01	2.67E+01	2.68E+01	2.68E+01
U & S Total A/F	2.58E+01	2.58E+01	2.59E+01	2.54E+01	2.55E+01	2.56E+01
Air Flow [lb/hr]	3.70E+03	3.73E+03	3.71E+03	3.11E+03	3.12E+03	3.13E+03
BMEP [psi]	1.85E+02	1.85E+02	1.85E+02	1.54E+02	1.54E+02	1.54E+02
Thermal Eff. [%]	3.70E+01	3.67E+01	3.69E+01	3.61E+01	3.62E+01	3.60E+01
Wobbe Index [BTU/cuft]	1.25E+03	1.25E+03	1.25E+03	1.27E+03	1.27E+03	1.27E+03
Methane [%]	8.34E+01	8.39E+01	8.35E+01	8.21E+01	8.16E+01	8.22E+01
LHV [BTU/cuft]	1.02E+03	1.02E+03	1.02E+03	1.04E+03	1.05E+03	1.05E+03
Abs. Humidity	1.48E+02	1.42E+02	1.36E+02	1.82E+02	1.71E+02	1.62E+02
NOx @ 15% O2 [BHP-hr]	5.90E+01	6.10E+01	6.01E+01	5.87E+01	5.64E+01	5.53E+01
BS THC [g/BHP-hr]	4.54E+00	4.53E+00	4.51E+00	4.86E+00	4.89E+00	4.90E+00
BS NOx Actual [g/BHP-hr]	6.08E-01	6.33E-01	6.20E-01	6.21E-01	5.99E-01	5.88E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	7.41E-01	7.72E-01	7.56E-01	7.55E-01	7.25E-01	7.14E-01
BS NO FTIR [g/BHP-hr]	2.51E-01	2.61E-01	2.56E-01	2.53E-01	2.36E-01	2.37E-01
BS NO2 FTIR [g/BHP-hr]	3.57E-01	3.73E-01	3.64E-01	3.68E-01	3.63E-01	3.50E-01
BS CO [g/BHP-hr]	1.92E+00	1.94E+00	1.93E+00	1.97E+00	1.96E+00	1.97E+00
BS CO2 [g/BHP-hr]	4.08E+02	4.11E+02	4.09E+02	4.19E+02	4.19E+02	4.21E+02
PHI Total	6.19E-01	6.19E-01	6.18E-01	6.30E-01	6.28E-01	6.27E-01
H2O MF	3.47E+02	3.47E+02	3.42E+02	3.08E+02	3.02E+02	3.00E+02
Exh MF	3.84E+03	3.87E+03	3.85E+03	3.23E+03	3.23E+03	3.25E+03
BS O2 [g/BHP-hr]	3.73E+02	3.76E+02	3.75E+02	3.65E+02	3.68E+02	3.71E+02
Gas Density [lbm/1000cuft]	5.41E+01	5.37E+01	5.40E+01	5.51E+01	5.56E+01	5.52E+01
Vapor Pressure[kPa]	1.06E+00	1.02E+00	9.79E-01	1.11E+00	1.04E+00	9.87E-01
Combustion Data						
FMEP [psi]	1.55E+01	1.54E+01	1.54E+01	1.38E+01	1.37E+01	1.38E+01

Data Point Name	QSK-50-1500-SAE30-20	QSK-50-1500-SAE30-21	QSK-50-1500-SAE30-22	QSK-25-1500-SAE30-23	QSK-25-1500-SAE30-24	QSK-25-1500-SAE30-25
Engine Data						
RPM	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03	1.50E+03
Power[hp]	2.25E+02	2.25E+02	2.25E+02	1.13E+02	1.13E+02	1.13E+02
Torque[ft-lb]	7.89E+02	7.89E+02	7.89E+02	3.94E+02	3.94E+02	3.94E+02
Fuel Flow[#ph]	8.47E+01	8.24E+01	8.28E+01	4.82E+01	4.84E+01	4.90E+01
Fuel Pressure[psig]	4.95E+00	4.95E+00	4.95E+00	5.00E+00	5.00E+00	5.01E+00
Fuel Temp[F]	8.46E+01	8.45E+01	8.46E+01	8.46E+01	8.42E+01	8.40E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.61E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	1.94E+01	1.94E+01	1.95E+01	1.05E+01	1.05E+01	1.06E+01
IC Diff Pressure[inH2O]	-1.08E+00	-1.12E+00	-1.16E+00	-5.23E-01	-5.36E-01	-5.44E-01
Boost Pressure[psig]	1.73E+01	1.74E+01	1.76E+01	6.18E+00	6.27E+00	6.33E+00
Inlet Air Temperature[F]	9.86E+01	9.92E+01	9.95E+01	9.83E+01	9.81E+01	9.78E+01
Intake Manifold Temp[F]	1.31E+02	1.30E+02	1.27E+02	1.30E+02	1.30E+02	1.30E+02
Boost Temp[F]	3.40E+02	3.61E+02	3.99E+02	1.63E+03	7.53E+02	8.39E+02
Inlet Air RH[%]	2.21E+01	1.85E+01	1.87E+01	1.82E+01	1.77E+01	1.69E+01
Exhaust Back Pres[inHg]	4.73E+00	4.73E+00	4.68E+00	4.73E+00	4.72E+00	4.69E+00
EMAP[psia]	2.56E+01	2.57E+01	2.57E+01	1.80E+01	1.80E+01	1.80E+01
Exhaust Temp[F]	9.66E+02	9.64E+02	9.65E+02	1.02E+03	1.02E+03	1.03E+03
Turbine In Temp[F]	1.12E+03	1.12E+03	1.12E+03	1.08E+03	1.08E+03	1.09E+03
Exh Port 1[F]	1.05E+03	1.06E+03	1.06E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 2[F]	1.05E+03	1.06E+03	1.06E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 3[F]	1.04E+03	1.04E+03	1.04E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 4[F]	1.04E+03	1.04E+03	1.04E+03	1.07E+03	1.08E+03	1.08E+03
Exh Port 5[F]	1.05E+03	1.05E+03	1.05E+03	1.08E+03	1.09E+03	1.09E+03
Exh Port 6[F]	1.03E+03	1.03E+03	1.03E+03	1.05E+03	1.06E+03	1.06E+03
JW In Temp[F]	1.91E+02	1.90E+02	1.90E+02	1.97E+02	1.98E+02	1.93E+02
JW Out Temp[F]	1.97E+02	1.96E+02	1.96E+02	2.01E+02	2.02E+02	1.98E+02
ACW In Temp[F]	1.20E+02	1.18E+02	1.15E+02	1.16E+02	1.16E+02	1.16E+02
ACW Out Temp[F]	1.24E+02	1.21E+02	1.19E+02	1.17E+02	1.17E+02	1.17E+02
Dyno In Temp[F]	7.53E+01	7.50E+01	7.54E+01	7.47E+01	7.44E+01	7.40E+01
Dyno Out Temp[F]	9.37E+01	9.35E+01	9.38E+01	8.40E+01	8.36E+01	8.33E+01
Oil Sump Temp[F]	2.12E+02	2.12E+02	2.12E+02	2.11E+02	2.12E+02	2.12E+02
Oil Rifle Temp[F]	2.06E+02	2.06E+02	2.06E+02	2.08E+02	2.09E+02	2.07E+02
Oil Pressure[psig]	5.94E+01	5.95E+01	5.95E+01	5.98E+01	5.93E+01	5.98E+01
THC[ppm dry]	1.98E+03	1.95E+03	1.98E+03	1.66E+03	1.62E+03	1.59E+03
O2[%dry]	8.71E+00	8.81E+00	8.84E+00	6.48E+00	6.50E+00	6.53E+00
NOx[ppm dry]	9.35E+01	8.23E+01	7.79E+01	6.57E+02	5.83E+02	5.06E+02

NO[ppm dry]	3.38E+01	3.31E+01	2.71E+01	4.71E+02	4.39E+02	3.58E+02
NO2[ppm dry]	5.97E+01	4.92E+01	5.09E+01	1.86E+02	1.44E+02	1.48E+02
CO2[% dry]	7.15E+00	7.13E+00	7.10E+00	8.52E+00	8.54E+00	8.56E+00
CO[ppm dry]	5.11E+02	5.13E+02	5.12E+02	8.34E+02	8.24E+02	8.09E+02
Supercharger Speed	2.22E+01	2.23E+01	2.24E+01	1.56E+01	1.56E+01	1.56E+01
SC IC CV Pos.	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Steam Valve Position	3.40E+01	3.68E+01	4.70E+01	4.70E+01	4.70E+01	4.70E+01
ICW CV Pos.	4.53E+01	3.59E+01	4.59E+01	4.86E+01	4.88E+01	5.04E+01
Exh Back Pres CV	7.81E+01	7.74E+01	7.74E+01	8.93E+01	8.84E+01	8.91E+01
JW Temp Valve Pos.	6.62E+01	6.54E+01	6.63E+01	6.66E+01	6.40E+01	6.57E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02	1.87E+02
Intercooler Flow [gpm]	1.37E+02	1.36E+02	1.37E+02	1.37E+02	1.37E+02	1.37E+02
Dyno Water Flow [gpm]	7.21E+01	7.21E+01	7.22E+01	7.22E+01	7.21E+01	7.22E+01
Boiler Return Temp [C]	6.70E+01	6.45E+01	6.36E+01	5.93E+01	5.85E+01	5.82E+01
Boiler Supply Temp [C]	6.49E+01	6.45E+01	6.37E+01	5.92E+01	5.89E+01	5.80E+01
BMEP[psi]	1.03E+02	1.03E+02	1.03E+02	5.13E+01	5.13E+01	5.13E+01
Ambient Pressure[psia]	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01
Propane Flow[lb/hr]	2.90E+01	2.01E+01	2.04E+01	2.67E+01	2.73E+01	2.89E+01
Propane Valve Pos	6.54E+00	6.11E+00	5.89E+00	1.33E+01	1.19E+01	1.22E+01
Propane VFD speed	3.59E+01	2.29E+01	2.34E+01	3.01E+01	3.13E+01	3.45E+01
Propane Pressure[psig]	2.50E+01	2.57E+01	2.58E+01	2.54E+01	2.53E+01	2.49E+01
Blowby Flow[acfm]	5.21E+00	5.28E+00	5.34E+00	4.65E+00	4.67E+00	4.68E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	6.21E-01	6.16E-01	6.15E-01	7.23E-01	7.21E-01	7.20E-01
BSFC [BTU/BHP_hr]	7.55E+03	7.34E+03	7.37E+03	8.59E+03	8.64E+03	8.73E+03
Stoich. A/F	1.66E+01	1.66E+01	1.66E+01	1.66E+01	1.65E+01	1.65E+01
U & S A/F	2.68E+01	2.69E+01	2.70E+01	2.29E+01	2.29E+01	2.29E+01
U & S Total A/F	2.57E+01	2.59E+01	2.59E+01	2.20E+01	2.20E+01	2.21E+01
Mass Flow A/F	2.23E+03	2.18E+03	2.19E+03	1.10E+03	1.10E+03	1.12E+03
Air Flow [lb/hr]	1.03E+02	1.03E+02	1.03E+02	5.12E+01	5.12E+01	5.12E+01
BMEP [psi]	3.37E+01	3.47E+01	3.45E+01	2.96E+01	2.95E+01	2.92E+01
Thermal Eff. [%]	1.33E+03	1.34E+03	1.34E+03	1.36E+03	1.37E+03	1.38E+03
Wobbe Index [BTU/cuft]	7.55E+01	7.36E+01	7.42E+01	7.22E+01	7.05E+01	6.90E+01
Methane [%]	1.15E+03	1.18E+03	1.17E+03	1.20E+03	1.22E+03	1.25E+03
LHV [BTU/cuft]	1.16E+02	9.35E+01	8.82E+01	1.76E+02	1.69E+02	1.60E+02

Abs. Humidity	4.53E+01	4.01E+01	3.81E+01	2.69E+02	2.39E+02	2.08E+02
NOx @ 15% O2 [BHP-hr]	6.14E+00	6.06E+00	6.13E+00	5.19E+00	5.19E+00	5.27E+00
BS THC [g/BHP-hr]	5.46E-01	4.63E-01	4.51E-01	3.18E+00	2.79E+00	2.50E+00
BS NOx Actual [g/BHP-hr]	6.24E-01	5.38E-01	5.13E-01	4.24E+00	3.78E+00	3.32E+00
BS NOx EPA Meth. 20 [g/BHP-hr]	1.47E-01	1.41E-01	1.16E-01	1.98E+00	1.86E+00	1.53E+00
BS NO FTIR [g/BHP-hr]	3.99E-01	3.22E-01	3.35E-01	1.20E+00	9.33E-01	9.71E-01
BS NO2 FTIR [g/BHP-hr]	2.08E+00	2.04E+00	2.05E+00	3.28E+00	3.26E+00	3.24E+00
BS CO [g/BHP-hr]	4.57E+02	4.46E+02	4.47E+02	5.26E+02	5.30E+02	5.38E+02
BS CO2 [g/BHP-hr]	6.21E-01	6.16E-01	6.15E-01	7.23E-01	7.22E-01	7.20E-01
PHI Total	1.95E+02	1.82E+02	1.81E+02	1.17E+02	1.16E+02	1.15E+02
H2O MF	2.32E+03	2.26E+03	2.27E+03	1.15E+03	1.15E+03	1.16E+03
Exh MF	4.04E+02	4.01E+02	4.05E+02	2.91E+02	2.94E+02	2.98E+02
BS O2 [g/BHP-hr]	6.07E+01	6.21E+01	6.16E+01	6.32E+01	6.46E+01	6.58E+01
Gas Density [lbm/1000cuft]	5.01E-01	4.09E-01	3.86E-01	4.07E-01	3.94E-01	3.74E-01
Vapor Pressure[kPa]						
Combustion Data						
FMEP [psi]	1.08E+01	1.08E+01	1.09E+01	8.98E+00	8.93E+00	9.01E+00

Data Point Name	**QSK-90-1800-SAE30-01**	**QSK-90-1800-SAE30-02**	**QSK-90-1800-SAE30-03**	**QSK-75-1800-SAE30-04**	**QSK-75-1800-SAE30-05**	**QSK-75-1800-SAE30-06**
Engine Data						
RPM	1.80E+03	1.79E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	4.24E+02	4.23E+02	4.24E+02	3.54E+02	3.54E+02	3.54E+02
Torque[ft-lb]	1.24E+03	1.24E+03	1.24E+03	1.03E+03	1.03E+03	1.03E+03
Fuel Flow[#ph]	1.56E+02	1.56E+02	1.56E+02	1.35E+02	1.35E+02	1.35E+02
Fuel Pressure[psig]	4.84E+00	4.84E+00	4.84E+00	4.87E+00	4.87E+00	4.87E+00
Fuel Temp[F]	8.15E+01	8.18E+01	8.19E+01	8.21E+01	8.23E+01	8.23E+01
Inlet Air Pres[inHg]	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00	3.60E+00
IMAP[psia]	3.07E+01	3.07E+01	3.07E+01	2.64E+01	2.64E+01	2.67E+01
IC Diff Pressure[inH2O]	-9.73E-01	-1.01E+00	-9.77E-01	-1.86E+00	-1.87E+00	- 1.86E+00
Boost Pressure[psig]	2.99E+01	2.99E+01	2.99E+01	2.85E+01	2.86E+01	2.88E+01
Inlet Air Temperature[F]	9.77E+01	9.77E+01	9.88E+01	9.96E+01	9.94E+01	9.95E+01
Intake Manifold Temp[F]	1.32E+02	1.31E+02	1.31E+02	1.30E+02	1.31E+02	1.30E+02
Boost Temp[F]	4.78E+02	4.11E+02	5.13E+02	4.38E+02	4.46E+02	4.46E+02
Inlet Air RH[%]	4.84E+01	4.89E+01	4.84E+01	4.82E+01	4.84E+01	4.80E+01
Exhaust Back Pres[inHg]	4.72E+00	4.67E+00	4.71E+00	4.73E+00	4.69E+00	4.67E+00

EMAP[psia]	3.97E+01	3.96E+01	3.97E+01	3.57E+01	3.57E+01	3.60E+01
Exhaust Temp[F]	1.01E+03	1.01E+03	1.01E+03	9.98E+02	1.00E+03	1.00E+03
Turbine In Temp[F]	1.23E+03	1.23E+03	1.23E+03	1.22E+03	1.23E+03	1.23E+03
Exh Port 1[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.15E+03	1.15E+03
Exh Port 2[F]	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.14E+03	1.14E+03
Exh Port 3[F]	1.14E+03	1.14E+03	1.14E+03	1.13E+03	1.14E+03	1.14E+03
Exh Port 4[F]	1.16E+03	1.16E+03	1.16E+03	1.14E+03	1.15E+03	1.15E+03
Exh Port 5[F]	1.16E+03	1.16E+03	1.16E+03	1.15E+03	1.15E+03	1.16E+03
Exh Port 6[F]	1.14E+03	1.13E+03	1.14E+03	1.12E+03	1.13E+03	1.13E+03
JW In Temp[F]	1.81E+02	1.80E+02	1.81E+02	1.80E+02	1.82E+02	1.81E+02
JW Out Temp[F]	1.89E+02	1.89E+02	1.89E+02	1.88E+02	1.90E+02	1.88E+02
ACW In Temp[F]	1.17E+02	1.16E+02	1.16E+02	1.16E+02	1.19E+02	1.17E+02
ACW Out Temp[F]	1.27E+02	1.26E+02	1.26E+02	1.25E+02	1.27E+02	1.25E+02
Dyno In Temp[F]	6.92E+01	6.95E+01	6.97E+01	7.00E+01	6.95E+01	6.92E+01
Dyno Out Temp[F]	1.04E+02	1.05E+02	1.05E+02	9.96E+01	9.89E+01	9.87E+01
Oil Sump Temp[F]	2.13E+02	2.13E+02	2.12E+02	2.12E+02	2.12E+02	2.12E+02
Oil Rifle Temp[F]	2.05E+02	2.05E+02	2.05E+02	2.04E+02	2.05E+02	2.04E+02
Oil Pressure[psig]	6.47E+01	6.67E+01	6.50E+01	6.77E+01	6.65E+01	6.68E+01
THC[ppm dry]	1.57E+03	1.57E+03	1.58E+03	1.72E+03	1.68E+03	1.72E+03
O2[%dry]	8.42E+00	8.43E+00	8.45E+00	8.38E+00	8.38E+00	8.45E+00
NOx[ppm dry]	1.25E+02	1.22E+02	1.19E+02	1.01E+02	9.66E+01	8.88E+01
NO[ppm dry]	6.47E+01	6.23E+01	5.91E+01	4.83E+01	4.45E+01	4.02E+01
NO2[ppm dry]	6.06E+01	6.01E+01	6.01E+01	5.29E+01	5.21E+01	4.86E+01
CO2[% dry]	7.22E+00	7.21E+00	7.21E+00	7.25E+00	7.25E+00	7.20E+00
CO[ppm dry]	5.36E+02	5.34E+02	5.32E+02	5.26E+02	5.21E+02	5.24E+02
Supercharger Speed	3.20E+01	3.20E+01	3.20E+01	2.88E+01	2.88E+01	2.90E+01
SC IC CV Pos.	1.00E+02	1.00E+02	1.00E+02	6.23E+01	1.00E+02	1.00E+02
Steam Valve Position	1.55E+01	1.64E+01	1.63E+01	1.57E+01	1.54E+01	1.61E+01
ICW CV Pos.	3.36E+01	3.35E+01	3.35E+01	4.30E+01	3.56E+01	3.36E+01
Exh Back Pres CV	6.15E+01	6.11E+01	6.14E+01	6.53E+01	6.54E+01	6.50E+01
JW Temp Valve Pos.	5.97E+01	6.23E+01	6.48E+01	6.54E+01	6.15E+01	6.39E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.97E+02	1.97E+02	1.97E+02	1.97E+02	1.97E+02	1.97E+02
Intercooler Flow [gpm]	1.36E+02	1.36E+02	1.36E+02	1.36E+02	1.36E+02	1.36E+02
Dyno Water Flow [gpm]	7.16E+01	7.16E+01	7.16E+01	7.17E+01	7.16E+01	7.16E+01
Boiler Return Temp [C]	5.57E+01	6.26E+01	6.51E+01	6.49E+01	6.29E+01	6.17E+01
Boiler Supply Temp [C]	5.53E+01	6.06E+01	6.25E+01	6.48E+01	6.33E+01	6.18E+01
BMEP[psi]	1.61E+02	1.61E+02	1.61E+02	1.34E+02	1.34E+02	1.34E+02
Ambient Pressure[psia]	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01

Propane Flow[lb/hr]	9.63E+00	9.66E+00	9.27E+00	9.30E+00	9.62E+00	9.66E+00
Propane Valve Pos	1.50E+00	1.50E+00	1.50E+00	1.50E+00	1.50E+00	1.50E+00
Propane VFD speed	1.33E+01	1.41E+01	1.40E+01	1.34E+01	1.36E+01	1.35E+01
Propane Pressure[psig]	2.55E+01	2.51E+01	2.51E+01	2.51E+01	2.54E+01	2.54E+01
Blowby Flow[acfm]	5.81E+00	5.53E+00	5.05E+00	4.82E+00	4.47E+00	4.05E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	6.35E-01	6.35E-01	6.34E-01	6.39E-01	6.38E-01	6.35E-01
BSFC [BTU/BHP_hr]	7.34E+03	7.38E+03	7.37E+03	7.60E+03	7.60E+03	7.66E+03
Stoich. A/F	1.69E+01	1.69E+01	1.69E+01	1.69E+01	1.69E+01	1.69E+01
U & S A/F	2.66E+01	2.66E+01	2.66E+01	2.65E+01	2.65E+01	2.66E+01
U & S Total A/F	2.51E+01	2.52E+01	2.52E+01	2.50E+01	2.50E+01	2.52E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	4.04E+03	4.04E+03	4.05E+03	3.47E+03	3.48E+03	3.52E+03
BMEP [psi]	1.61E+02	1.61E+02	1.61E+02	1.34E+02	1.34E+02	1.34E+02
Thermal Eff. [%]	3.46E+01	3.45E+01	3.45E+01	3.35E+01	3.35E+01	3.32E+01
Wobbe Index [BTU/cuft]	1.25E+03	1.25E+03	1.25E+03	1.25E+03	1.25E+03	1.25E+03
Methane [%]	8.31E+01	8.35E+01	8.34E+01	8.34E+01	8.32E+01	8.33E+01
LHV [BTU/cuft]	1.02E+03	1.01E+03	1.01E+03	1.02E+03	1.02E+03	1.02E+03
Abs. Humidity	1.66E+02	1.65E+02	1.62E+02	1.83E+02	1.93E+02	1.84E+02
NOx @ 15% O2 [BHP-hr]	5.92E+01	5.79E+01	5.65E+01	4.77E+01	4.55E+01	4.21E+01
BS THC [g/BHP-hr]	4.05E+00	4.06E+00	4.07E+00	4.56E+00	4.47E+00	4.62E+00
BS NOx Actual [g/BHP-hr]	6.52E-01	6.42E-01	6.29E-01	5.51E-01	5.30E-01	4.95E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	7.95E-01	7.80E-01	7.59E-01	6.61E-01	6.31E-01	5.87E-01
BS NO FTIR [g/BHP-hr]	2.68E-01	2.59E-01	2.45E-01	2.06E-01	1.90E-01	1.74E-01
BS NO2 FTIR [g/BHP-hr]	3.84E-01	3.83E-01	3.83E-01	3.45E-01	3.40E-01	3.21E-01
BS CO [g/BHP-hr]	2.07E+00	2.07E+00	2.06E+00	2.09E+00	2.07E+00	2.11E+00
BS CO2 [g/BHP-hr]	4.38E+02	4.40E+02	4.39E+02	4.52E+02	4.53E+02	4.56E+02
PHI Total	6.35E-01	6.35E-01	6.34E-01	6.38E-01	6.38E-01	6.35E-01
H2O MF	3.97E+02	3.97E+02	3.97E+02	3.50E+02	3.55E+02	3.54E+02
Exh MF	4.19E+03	4.20E+03	4.21E+03	3.61E+03	3.62E+03	3.65E+03
BS O2 [g/BHP-hr]	3.72E+02	3.74E+02	3.74E+02	3.81E+02	3.81E+02	3.89E+02
Gas Density [lbm/1000cuft]	5.39E+01	5.37E+01	5.37E+01	5.38E+01	5.39E+01	5.39E+01
Vapor Pressure[kPa]	1.13E+00	1.12E+00	1.10E+00	1.06E+00	1.12E+00	1.08E+00
Combustion Data						
FMEP [psi]	1.60E+01	1.60E+01	1.59E+01	1.48E+01	1.46E+01	1.47E+01

Data Point Name	QSK-50-1800-SAE30-07	QSK-50-1800-SAE30-08	QSK-50-1800-SAE30-09	QSK-25-1800-SAE30-10	QSK-25-1800-SAE30-11	QSK-25-1800-SAE30-12
Engine Data						
RPM	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03	1.80E+03
Power[hp]	2.36E+02	2.36E+02	2.36E+02	1.18E+02	1.18E+02	1.18E+02
Torque[ft-lb]	6.88E+02	6.88E+02	6.88E+02	3.43E+02	3.43E+02	3.43E+02
Fuel Flow[#ph]	9.75E+01	9.68E+01	9.64E+01	6.02E+01	5.85E+01	6.04E+01
Fuel Pressure[psig]	4.92E+00	4.92E+00	4.92E+00	4.96E+00	4.97E+00	4.97E+00
Fuel Temp[F]	8.27E+01	8.29E+01	8.29E+01	8.28E+01	8.29E+01	8.28E+01
Inlet Air Pres[inHg]	3.60E+00	3.59E+00	3.61E+00	3.58E+00	3.60E+00	3.61E+00
IMAP[psia]	1.92E+01	1.91E+01	1.89E+01	1.26E+01	1.23E+01	1.26E+01
IC Diff Pressure[inH2O]	-1.88E+00	-1.84E+00	-1.83E+00	-8.76E-01	-8.15E-01	-8.91E-01
Boost Pressure[psig]	2.18E+01	2.14E+01	2.12E+01	1.12E+01	1.04E+01	1.12E+01
Inlet Air Temperature[F]	9.94E+01	9.95E+01	9.95E+01	9.91E+01	9.90E+01	9.88E+01
Intake Manifold Temp[F]	1.28E+02	1.29E+02	1.30E+02	1.30E+02	1.31E+02	1.31E+02
Boost Temp[F]	3.83E+02	3.68E+02	5.84E+02	3.72E+02	7.34E+02	2.42E+02
Inlet Air RH[%]	5.33E+01	5.01E+01	5.17E+01	4.65E+01	4.83E+01	4.67E+01
Exhaust Back Pres[inHg]	4.70E+00	4.73E+00	4.67E+00	4.75E+00	4.73E+00	4.68E+00
EMAP[psia]	2.85E+01	2.83E+01	2.81E+01	2.12E+01	2.07E+01	2.11E+01
Exhaust Temp[F]	1.01E+03	1.01E+03	1.01E+03	1.04E+03	1.04E+03	1.05E+03
Turbine In Temp[F]	1.20E+03	1.20E+03	1.20E+03	1.14E+03	1.14E+03	1.15E+03
Exh Port 1[F]	1.14E+03	1.14E+03	1.14E+03	1.11E+03	1.10E+03	1.13E+03
Exh Port 2[F]	1.14E+03	1.13E+03	1.13E+03	1.11E+03	1.10E+03	1.13E+03
Exh Port 3[F]	1.13E+03	1.13E+03	1.13E+03	1.12E+03	1.10E+03	1.12E+03
Exh Port 4[F]	1.12E+03	1.12E+03	1.12E+03	1.10E+03	1.09E+03	1.12E+03
Exh Port 5[F]	1.14E+03	1.13E+03	1.13E+03	1.11E+03	1.10E+03	1.13E+03
Exh Port 6[F]	1.11E+03	1.10E+03	1.10E+03	1.08E+03	1.08E+03	1.10E+03
JW In Temp[F]	1.90E+02	1.87E+02	1.88E+02	1.94E+02	1.95E+02	1.95E+02
JW Out Temp[F]	1.96E+02	1.94E+02	1.95E+02	1.99E+02	2.00E+02	2.00E+02
ACW In Temp[F]	1.17E+02	1.17E+02	1.19E+02	1.19E+02	1.20E+02	1.20E+02
ACW Out Temp[F]	1.22E+02	1.22E+02	1.24E+02	1.21E+02	1.22E+02	1.22E+02
Dyno In Temp[F]	6.79E+01	6.81E+01	6.80E+01	6.67E+01	6.67E+01	6.69E+01
Dyno Out Temp[F]	8.76E+01	8.78E+01	8.77E+01	7.64E+01	7.64E+01	7.66E+01
Oil Sump Temp[F]	2.12E+02	2.13E+02	2.13E+02	2.13E+02	2.14E+02	2.14E+02
Oil Rifle Temp[F]	2.07E+02	2.07E+02	2.07E+02	2.09E+02	2.09E+02	2.10E+02
Oil Pressure[psig]	6.67E+01	6.71E+01	6.76E+01	6.69E+01	6.63E+01	6.64E+01
THC[ppm dry]	1.95E+03	1.92E+03	1.92E+03	2.36E+03	2.29E+03	2.23E+03
O2[%dry]	8.26E+00	8.21E+00	8.15E+00	8.39E+00	8.26E+00	8.40E+00
NOx[ppm dry]	6.89E+01	8.35E+01	8.27E+01	3.49E+01	3.73E+01	2.90E+01

NO[ppm dry]	2.58E+01	2.98E+01	2.85E+01	6.25E+00	7.61E+00	3.78E+00
NO2[ppm dry]	4.30E+01	5.37E+01	5.43E+01	2.86E+01	2.96E+01	2.52E+01
CO2[% dry]	7.32E+00	7.36E+00	7.38E+00	7.23E+00	7.32E+00	7.27E+00
CO[ppm dry]	5.15E+02	5.11E+02	5.10E+02	5.73E+02	5.45E+02	5.65E+02
Supercharger Speed	2.36E+01	2.34E+01	2.33E+01	1.80E+01	1.77E+01	1.80E+01
SC IC CV Pos.	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02
Steam Valve Position	1.28E+01	1.24E+01	1.21E+01	1.03E+01	1.03E+01	1.09E+01
ICW CV Pos.	4.55E+01	4.55E+01	4.55E+01	5.06E+01	4.65E+01	3.98E+01
Exh Back Pres CV	7.41E+01	7.45E+01	7.48E+01	8.31E+01	8.37E+01	8.32E+01
JW Temp Valve Pos.	6.44E+01	6.53E+01	6.58E+01	6.67E+01	6.57E+01	6.56E+01
Jacket Water Flow Control Valve	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01	9.94E+01
Jacket Water Flow [gpm]	1.96E+02	1.96E+02	1.96E+02	1.96E+02	1.96E+02	1.96E+02
Intercooler Flow [gpm]	1.37E+02	1.37E+02	1.37E+02	1.38E+02	1.38E+02	1.37E+02
Dyno Water Flow [gpm]	7.14E+01	7.14E+01	7.14E+01	7.13E+01	7.12E+01	7.12E+01
Boiler Return Temp [C]	5.56E+01	5.62E+01	6.56E+01	5.86E+01	5.75E+01	5.73E+01
Boiler Supply Temp [C]	5.58E+01	5.52E+01	6.01E+01	5.85E+01	5.79E+01	5.72E+01
BMEP[psi]	8.95E+01	8.95E+01	8.95E+01	4.47E+01	4.47E+01	4.47E+01
Ambient Pressure[psia]	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01	1.25E+01
Propane Flow[lb/hr]	9.40E+00	8.65E+00	9.19E+00	9.69E+00	8.61E+00	9.05E+00
Propane Valve Pos	1.50E+00	1.50E+00	1.50E+00	1.50E+00	1.50E+00	1.50E+00
Propane VFD speed	1.38E+01	1.38E+01	1.42E+01	1.34E+01	1.43E+01	1.35E+01
Propane Pressure[psig]	2.52E+01	2.55E+01	2.56E+01	2.52E+01	2.55E+01	2.56E+01
Blowby Flow[acfm]	2.20E+00	2.51E+00	2.27E+00	4.20E+00	4.26E+00	4.31E+00
Time[sec]	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09	3.43E+09
Calculated Data						
PHI Comb.	6.45E-01	6.48E-01	6.50E-01	6.41E-01	6.47E-01	6.41E-01
BSFC [BTU/BHP_hr]	8.27E+03	8.21E+03	8.18E+03	1.02E+04	9.96E+03	1.03E+04
Stoich. A/F	1.69E+01	1.69E+01	1.69E+01	1.68E+01	1.68E+01	1.68E+01
U & S A/F	2.61E+01	2.60E+01	2.59E+01	2.62E+01	2.60E+01	2.62E+01
U & S Total A/F	2.47E+01	2.46E+01	2.45E+01	2.49E+01	2.47E+01	2.49E+01
Mass Flow A/F	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Air Flow [lb/hr]	2.52E+03	2.49E+03	2.48E+03	1.60E+03	1.54E+03	1.60E+03
BMEP [psi]	8.94E+01	8.94E+01	8.94E+01	4.46E+01	4.46E+01	4.46E+01
Thermal Eff. [%]	3.08E+01	3.10E+01	3.11E+01	2.49E+01	2.56E+01	2.48E+01
Wobbe Index [BTU/cuft]	1.26E+03	1.26E+03	1.26E+03	1.27E+03	1.27E+03	1.27E+03
Methane [%]	8.24E+01	8.25E+01	8.25E+01	8.09E+01	8.08E+01	8.07E+01
LHV [BTU/cuft]	1.03E+03	1.03E+03	1.03E+03	1.06E+03	1.06E+03	1.06E+03

Abs. Humidity	2.73E+02	2.62E+02	2.81E+02	3.91E+02	4.32E+02	4.08E+02
NOx @ 15% O2 [BHP-hr]	3.21E+01	3.88E+01	3.83E+01	1.64E+01	1.74E+01	1.37E+01
BS THC [g/BHP-hr]	5.64E+00	5.49E+00	5.47E+00	8.77E+00	8.20E+00	8.32E+00
BS NOx Actual [g/BHP-hr]	4.21E-01	5.08E-01	5.02E-01	2.87E-01	2.93E-01	2.43E-01
BS NOx EPA Meth. 20 [g/BHP-hr]	4.84E-01	5.80E-01	5.71E-01	3.06E-01	3.15E-01	2.55E-01
BS NO FTIR [g/BHP-hr]	1.18E-01	1.35E-01	1.28E-01	3.58E-02	4.20E-02	2.16E-02
BS NO2 FTIR [g/BHP-hr]	3.02E-01	3.73E-01	3.74E-01	2.51E-01	2.51E-01	2.21E-01
BS CO [g/BHP-hr]	2.20E+00	2.16E+00	2.14E+00	3.07E+00	2.81E+00	3.02E+00
BS CO2 [g/BHP-hr]	4.92E+02	4.89E+02	4.87E+02	6.07E+02	5.92E+02	6.10E+02
PHI Total	6.45E-01	6.47E-01	6.50E-01	6.40E-01	6.46E-01	6.40E-01
H2O MF	2.83E+02	2.77E+02	2.82E+02	1.99E+02	2.01E+02	2.03E+02
Exh MF	2.62E+03	2.59E+03	2.58E+03	1.66E+03	1.60E+03	1.66E+03
BS O2 [g/BHP-hr]	4.04E+02	3.97E+02	3.91E+02	5.12E+02	4.86E+02	5.13E+02
Gas Density [lbm/1000cuft]	5.46E+01	5.46E+01	5.46E+01	5.60E+01	5.60E+01	5.60E+01
Vapor Pressure[kPa]	1.13E+00	1.08E+00	1.15E+00	1.04E+00	1.11E+00	1.08E+00
Combustion Data						
FMEP [psi]	1.24E+01	1.24E+01	1.24E+01	1.12E+01	1.10E+01	1.11E+01