

2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tested with Tier 2 Fuel – NCAT Test Report

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**Test:** 2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tested with Tier 2 Fuel – NCAT Test Report

**Program:** Light-Duty Greenhouse Gas Test Program

**Project:** Mid Term Evaluation (MTE) Engine Benchmarking

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# Purpose of Test

The purpose of this test is to characterize the performance of a 2014 Chevrolet 4.3L EcoTec3 LV3 V6 engine operated with Tier 2 fuel, in particular to generate fuel map data that may be used in the ALPHA model. During the course of this testing, test methods for use in characterizations of future engines were also developed.

Although we intended to gather test data from this engine while it operated on Tier 2 fuel with cylinder deactivation enabled, due to testing resource constraints we were unable to collect this data set before this engine’s test program ended.  Therefore, this test Tier 2 data package contains only engine data with cylinder deactivation disabled.  Conversely, the available LEV III test data package includes engine test data with and without cylinder deactivation enabled.  Using the LEV III benchmarking data gathered with cylinder deactivation enabled, we estimated a complete Tier 2 ALPHA engine map with cylinder deactivation enabled.

# Definitions

|  |  |
| --- | --- |
| Fuel map | Engine operating map that displays contours of brake specific fuel consumption (in g/kWh) on a grid of engine speeds (RPM) and engine torques (Nm). |
| Coefficient of Variation (COV) | A measure of variability defined as the ratio of standard deviation to mean (σ/μ) |
| Protection mode | An engine operation mode where the ECU retards ignition timing, limits load and/or runs excess fuel (λ<1) due to exhaust temperature limits being reached |

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# Description of Test Article

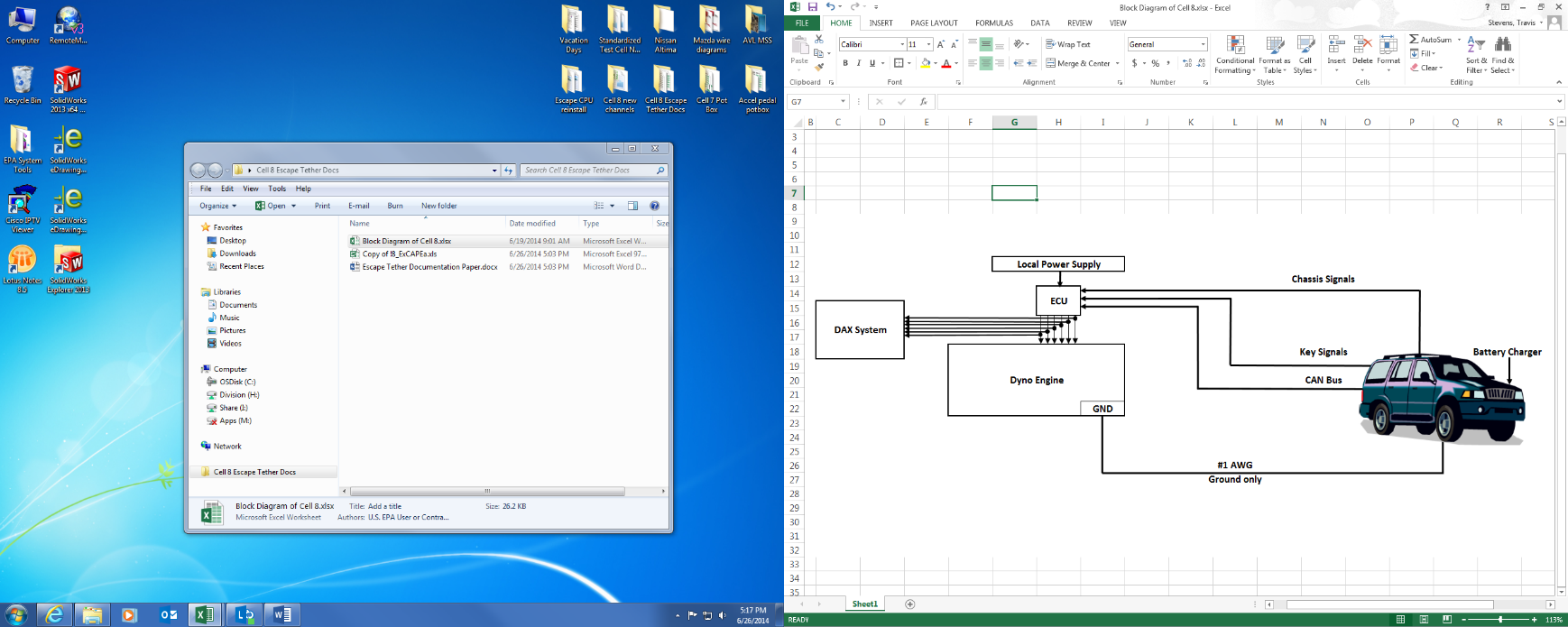
The engine used in this project was a 2014 Chevrolet 4.3L EcoTec3 LV3 V6, which is a direct-injection gasoline engine from a Chevrolet Silverado vehicle. Table 1 summarizes information that describes the vehicle and engine used in this test program.

**Table 1: Summary of Vehicle and Engine Identification Information**

|  |  |
| --- | --- |
| Vehicle (MY, Make, Model) | 2014 Chevrolet Silverado |
| Vehicle Identification Number | 1GCNCPEH2EZ171727 |
| Engine (displacement, name) | 4.3L EcoTec3 LV3 V6 |
| Rated Power | 285 hp (213 kw) @ 5300 RPM |
| Rated Torque | 305 lb.-ft (413 Nm) @ 3900 RPM |
| Recommended Fuel | Regular unleaded or E85 |
| Engine Features of Interest for MTE | Side mount direct-injection, cylinder deactivation, continuously variable valve timing, pushrod, single cam and active fuel management |

The engine with its associated controller is subject to manufacturer specific protection modes that cannot be controlled in the test cell. These protection modes may limit operation of the engine, particularly at higher loads where the engine temperatures can reach critical thresholds.

The objective of this benchmarking was to characterize the engine while operating in an engine dynamometer test cell as though the engine were operating in the vehicle. The ECU in today’s vehicles requires communication with other control modules to monitor the entire vehicle’s operation (security, entry, key on, dashboard signals, etc.). Because the ECU needs signals from these modules to operate, the signals need to be extended into the test cell so the ECU can send and receive signals indicating correct vehicle operation. For this benchmark testing, the wiring harnesses were lengthened connecting the ECU in the test cell to the rest of the vehicle. As a result, the engine located in the dynamometer cell was then tethered to its vehicle chassis located outside the cell. The ECU signals were monitored by the data acquisition system. Figure 1 illustrates the tethered wiring harness.

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**Figure 1. Vehicle and Engine Tethered Wire Harness**

# Test Site

This test was performed in National Center for Advanced Technology (NCAT) Test Cell 9, but the procedure is applicable in various NCAT test cells using iTest controls and RPECS data collection.

# Test Cell Capabilities

The following instrumentation, listed in Table 2, exists in Test Cell 9 although not all instrumentation listed may have been utilized during this testing.

**Table 2: Instrumentation in NCAT Test Cell 9**

|  |  |  |
| --- | --- | --- |
| Instrument Name | Purpose/Measurement Capabilities | Manufacturer |
| Dynamometer | Motoring and absorbing AC dyno | Meidensha |
| Torque Sensor | Measures engine torque | HBM |
| CVS dilution tunnel | Exhaust flow system | EPA |
| Coriolis fuel meter | Measures fuel flow rate | Micromotion |
| Laminar flow element | Measures air flow rate | Merriman |
| Methane cutter | Removes methane | Horiba |
| Emissions bench | Raw and dilute exhaust gases:  CO, THC, NOx, CH4, CO2 | MEXA |

# Data Collection Systems

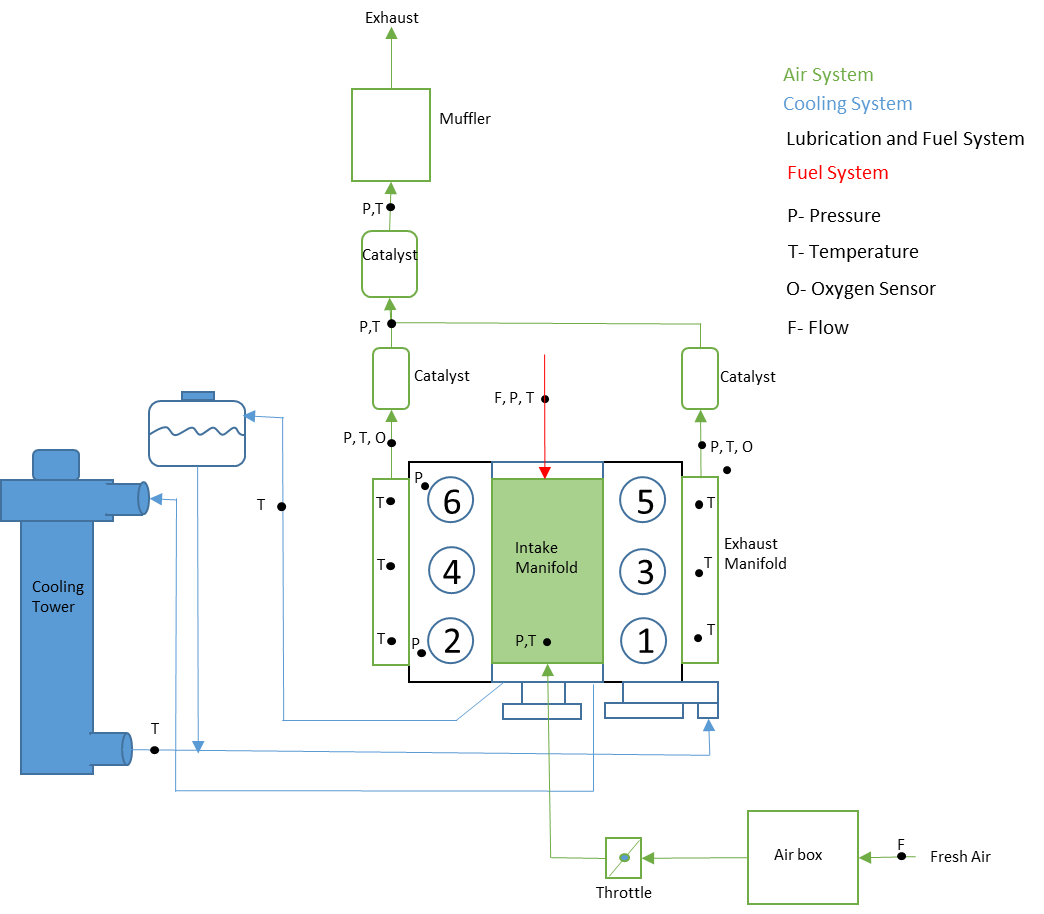
Test cell data acquisition and dynamometer control are performed by iTest, a data acquisition system developed by A&D Technology, Inc. Test cell data including temperatures, pressures, speed and torque are logged by iTest. Combustion data is analyzed by the MTS Combustion Analysis System (CAS). Engine and transmission ECU inputs and outputs are measured using the Rapid Prototyping Engine Control System (RPECS), a hardware/software package for engine control and supplemental data acquisition developed by Southwest Research Institute (SwRI). RPECS data is logged by iTest via an Ethernet connection and combined into a single output file. The engine control and data acquisition software packages are summarized below in Table 3.

**Table 3: Engine Control and Data Acquisition Systems**

|  |  |  |  |
| --- | --- | --- | --- |
| **System** | **Developer** | **Description** | **Data Rate** |
| CAS | MTS Systems Corporation | Combustion analyzer | 3600/rev |
| iTest | A&D Technology Inc., Ann Arbor, MI | Test cell automation hardware and software system that controls the dynamometer and some engine controls; collects test cell data; master data logger. | 10-100 Hz |
| MATLAB | MathWorks, Natick, MA | Software used for development of data processing algorithms for transient testing | -- |
| RPECS | Southwest Research Institute, San Antonio, TX | Crank angle based engine control and data acquisition system that collects ECU analog and CAN data, TCU analog and CAN data, and controls torque converter lock up solenoid. | 1/engine cycle |

# Engine Setup

Figure 2 illustrates the engine setup along with the added sensor locations and instrumentation in Test Cell 9. The engine sensor locations of the systems being monitored are indicated on the diagram corresponding to the system colors. A description of the monitored systems is also provided in the upper right corner of the figure.



**Figure 2: Testing Schematic with Engine Sensor Locations & Monitored Systems**

**Engine-Dynamometer Setup**

In the test setup for this testing. the engine is coupled to the dynamometer via the drive shaft.  In this test method the engine accessory loads are minimized by modifying the alternator to not provide any output electrical load.  The only possible accessory loads are from the serpentine belts, water pump, idler pulleys, and alternator pulley and bearings.

# Engine Systems

1. *Intake:* Stock airbox and plumbing with laminar flow element (LFE) connected to airbox inlet.
2. *Exhaust:* Factory exhaust system was used including catalyst and mufflers. The exhaust system outlet connected to the emissions tunnel via 2-inch diameter tubing. Emission tunnel pressure was controlled to Patm +/- 1.2 kPa.
3. *Cooling system:* Stock cooling system except the radiator was replaced with a cooling tower. The stock engine thermostat was used to control engine coolant temperature and the cooling tower was controlled to 85 °C by iTest.
4. *Front End Accessory Drive (FEAD):* Stock belt and pulley FEAD system.
5. *Oil system:* An oil cooler was connected to a chilled water system and controlled to 90 °C by iTest.
6. *Alternator:* The alternator was modified for no electrical output by removing the field coils.
7. *Flywheel and housing:* Engine used a stock manual flywheel with an aluminum adapter plate connected to the dynamometer driveshaft. Flywheel housing was a fabricated housing with mounting pads for rear mounts.

# Test Methodology

## Test Fuel

The primary properties of the Tier 2 fuel used in this test program are shown in Table 4 below. A detailed summary of the fuel analysis performed and results measured for the Tier 2 fuel utilized in the test program can be found in the file: *6- NVFEL Fuel Analysis Report 24693.pdf*.

**Table 4. Fuel Properties for FTAG 24693**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter Description | Test Fuel Specifications  (40 CFR §86.113-04) | Reference Procedure | Measured Results | Units |
| Research Octane (optional) | 93 (minimum) | ASTM D2699; ASTM D2700 | 96.2 | RON |
| Octane Sensitivity (optional) | 7.5 | ASTM D2699; ASTM D2700 | 7.8 | RON-MON |
| Hydrocarbon Composition (vol %) | | | | |
| Olefins | 10% Maximum | ASTM D1319 | 0.7 | Vol % |
| Aromatics | 35% Maximum | ASTM D1319 | 30.4 | Vol % |
| Total Sulfur, wt.% | 0.0015-0.008 | ASTM D2622 | 36.2 | ppm |
| Dry Vapor Pressure Equivalent, psi (kPa) | 8.7–9.2 (60.0-63.4) | ASTM D5191 | 9.14 | psi |
| The following are provided for Reference Only and are not specified in the CFR | | | | |
| Antiknock | None | N/A | 92.3 | (RON+MON)/2 |
| Net Heating Value | None | ASTM D3338 | 18439 | BTU/lb |
| None | N/A | 42.9 | MJ/kg |
| Alcohol Content | None | ASTM D5599 | 0.00 | Vol % |
| Carbon Content | None | ASTM D3343 | 0.86680 | Weight Fraction |

# Quality Procedures

This test program is covered by the Light-Duty Greenhouse Gas Test Program: Evaluating Potential Future Vehicle Technologies Quality Assurance Project Plan (QAPP).

# Engine Safeties

Table 5 lists the limits that exist for several engine parameters. These variables were monitored to ensure component durability and operator safety.

**Table 5: Engine Safety Limits**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Test Parameter Name** | **Units** | **Minimum** | **Maximum** |
| Oil Pressure |  | kPag | 175 |  |
| Coolant Temperature | Coolant Temp | oC |  | 120 |
| Engine Speed | Speed | RPM |  | 6500 |

# Pre-Conditioning and Common Mode Check

Before testing began, the engine was warmed up. The engine was considered “warm” when the fuel flow rate and exhaust temperatures stabilized and the coolant and oil temperatures were a minimum of 90 oC and 80 oC respectfully. A common mode, run with the parameters given in Table 6, was repeated at the beginning of each test to expose any potential inconsistencies that could indicate equipment wear or improper instrument calibration. For each common mode, the parameters in Table 7 were examined to check for any deviation from the norm.

**Table 6: Common Mode Test Conditions and Criteria for Achieving “Warmed” State**

|  |  |  |
| --- | --- | --- |
| Parameter | Test Parameter Name | Condition |
| Engine Speed Setting | Speed | 2000 RPM |
| Pedal Command Setting |  | 50% |
| Coolant Temperature Criteria | Coolant Temp | 90 oC min |
| Oil Temperature Criteria | Oil Sump Temp | 80 oC min |

**Table 7: Common Mode Test Parameters**

|  |  |  |
| --- | --- | --- |
| Parameter | Test Parameter Name | Unit |
| Brake Mean Effective Pressure | BMEP | Bar |
| Thermal Efficiency | BTE | % |
| Intake Manifold Pressure | Intake Manifold Press | kPa |

# Data Set Definition

The data logged included torque, fuel flow, emissions, temperatures, pressures, in-cylinder pressure and OBD/epid CAN data. The steady-state data were recorded by the iTest data acquisition system. Each steady-state mode was logged to a single output file. The final data set containing the engine mapping test parameters is provided in the file: *4- 2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tier 2 Fuel - Test Data.xlsx.*

# Test Data Points

The test data points for this engine map covered the torque and speed range of the engine according to the Test Data Points shown in Figure 3. The steady state testing was conducted by operating the engine at a fixed speed and setting the engine load with the pedal (accelerator) input from iTest.

Each engine mapping data point was established by setting the engine’s speed with the dyno and then nominal torque value was requested by setting the pedal to a position from 0 to 100%. Once the engine torque value at that data point stabilized, the data was then recorded. The speed values were selected in 200-250 rpm increments at the lower engine speeds and 500 rpm increments at higher engine speeds. The pedal inputs range from 0 to 100% and were incremented to gradually increase load until the engine torque reaches the next higher load point.

The engine mapping process incremented through the torque column starting with the engine’s lowest speed in the map. Once the load range was completed for a specific engine speed by increasing the pedal position from 0% to 100%, the engine speed was then increased to the next predetermined speed and the process was repeated. The zero pedal (0%) point for each speed setting established the minimum torque value utilized in the construction of the full engine map. The torque and speed values measured for this engine are shown in Figure 3, note the speed points were limited to not exceed 4000 rpm.

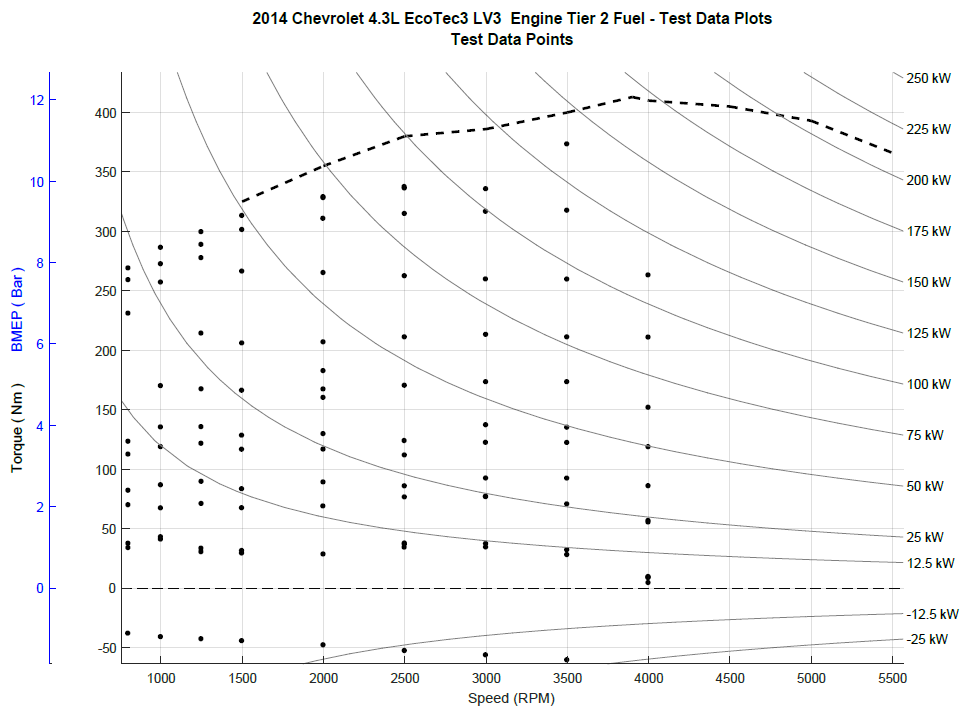


Figure 3. Test Data Points

# Data Collection Procedure

The test procedure steps through an array of data points based upon the specified speed and torques described above. At each speed and torque combination a set of stability criteria are applied prior to recording the single mode log point data for 10 seconds at 10 hz. Stability is determined by fuel flow and torque. The iTest control system logs data from Horiba MEXA, CAS, RPECS and the engine controller.

**Test Procedure**

The engine and vehicle are tested in the engine dyno cell with a tethered wire harness as described previously. The speed of the engine is controlled by the dyno speed set point. The load of the engine is controlled by the ECU which is set by the vehicle pedal input. The pedal input signal was generated by disconnecting the vehicle’s pedal and replacing it with an iTest controller. The transmission PRNDL was set in the neutral position to allow for starter cranking, starting and setting desired engine load.

The test procedure used to gather both idle speed data and fuel data at or near idle, includes measuring the fuel flow conditions in the engine dyno test cell. The test setup has the transmission installed with an inline torque sensor between the engine and transmission. This enables the engine to operate at idle conditions similar to the chassis with the transmission in drive, zero pedal, and torque converter unlocked. In this test method the engine accessory loads are minimized by modifying the alternator to not provide any output electrical load. The only possible accessory loads are from the serpentine belts, water pump, idler pulleys, and alternator pulley and bearings.

The procedure for starting up and shutting down the test cell is outlined in the file: *3b- 2014 Chevrolet 4.3L EcoTec3 LV3 Engine - Test Cell 9 Startup & Shutdown Procedure.docx*. This procedure describes how to activate and operate the test cell components required to run the engine. This procedure was developed during the installation of the engine and associated hardware needed for testing prior to conducting any recorded engine mapping and testing. This procedure ensures the correct start up and shutdown of the engine, the vehicle, and the test cell equipment for the engine to operate as expected in the test cell.

# Data Set Processing

The iTest data collection system logs each single mode at 10 hz for 10 seconds and the data is subsequently averaged and written to the data file. The variable list also includes statistical information for selected variables such as standard deviation, coefficient of variation, minimum & maximum. Also within iTest, certain parameters are calculated as described below.

# Data Processing

Brake specific fuel consumption (BSFC) in g/kW-hr was calculated according to the equation below using the values obtained from iTest.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | |  |
|  | | | |
| Where: | |  | |

Brake thermal efficiency (BTE) was calculated according to the equation below using the known heating value of the test fuel.

Where: Net Heating Value of the fuel is provided in Table 4

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# Data Quality Control

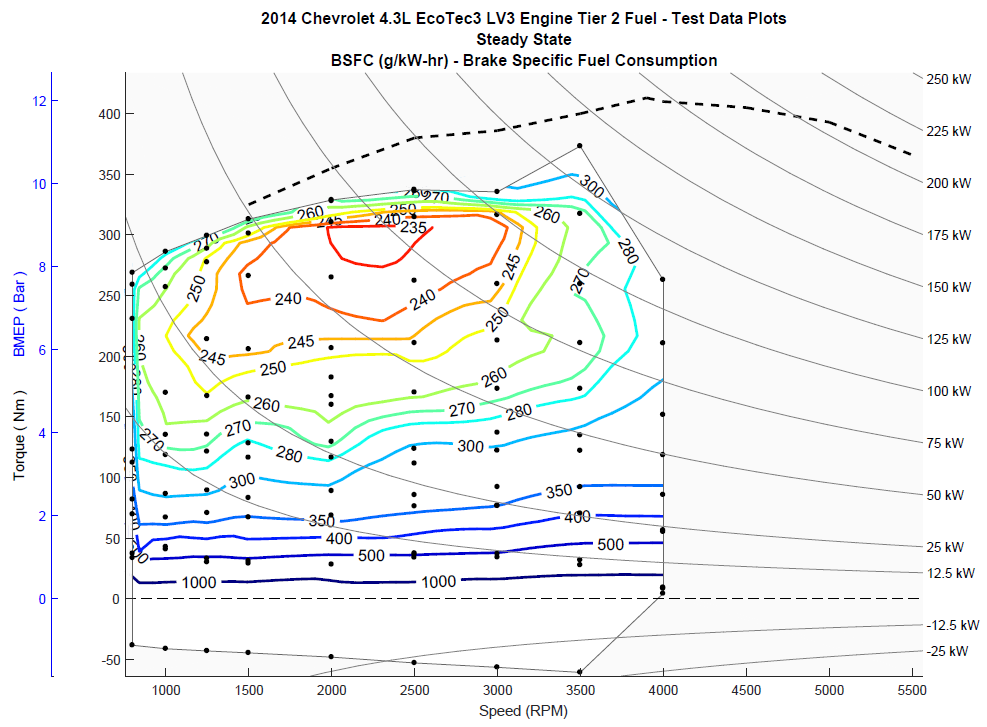
A test parameter subset of data focused on engine efficiency was extracted from the iTest data log for review. Descriptions for the test parameter list are provided in the test data set for reference. The data set is analyzed for outlier data based on the statistical data included in the iTest data logger file. In addition, the data set is plotted and reviewed using an NCAT developed contour plotting routine. During these reviews, any outliers may be removed as needed based upon the discretion of the internal review team.

# Results

The final data set containing the engine mapping test parameters is provided in the file: *4- 2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tier 2 Fuel - Test Data.xlsx.* The Chevrolet 4.3L EcoTec3 LV3 engine uses cylinder deactivation to improve thermal efficiency by reducing pumping losses during low-load operation by deactivating cylinders 3 and 6 simultaneously. When testing this engine using Tier 2 fuel, the cylinder deactivation feature was deactivated (not allowed to operate), so therefore no mapping data was gathered about the engine’s cylinder deactivation operation. Information regarding the results of the cylinder deactivation feature activation are provided in the NCAT Package *2014 Chevrolet 4.3L EcoTec3 LV3 Engine LEV III Fuel – Test Data Package.*

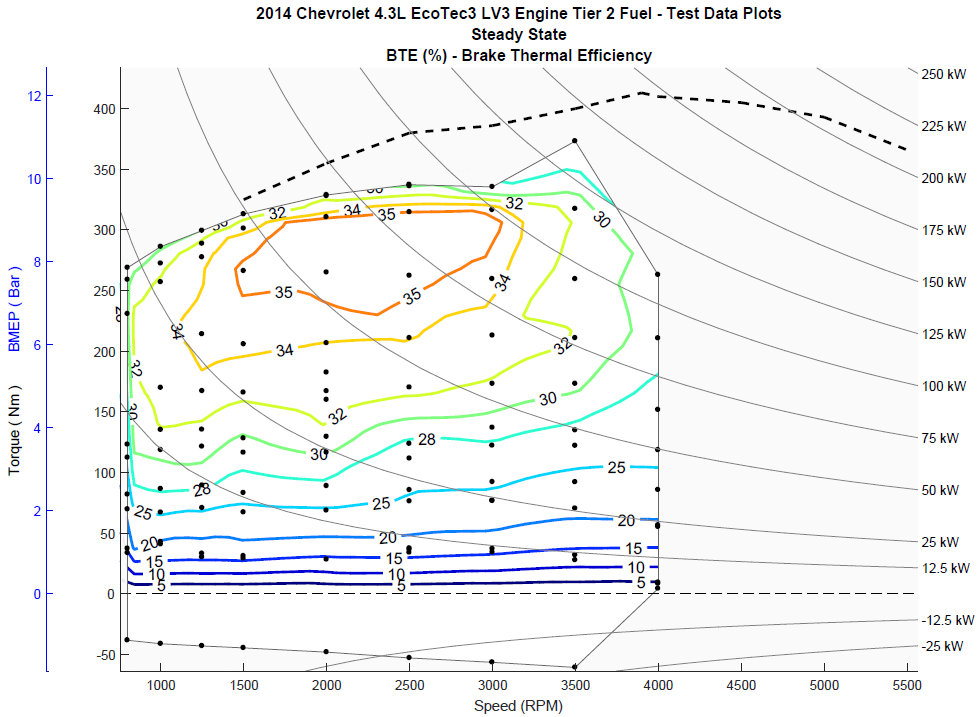
The data in this report were also used in the development of a full engine map that estimates the engine’s fuel consumption over its complete operating range as described in detail in the *2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tier 2 Fuel – ALPHA Map Package*. Additional details are also provided in SAE paper *SAE 2016-01-0662 Fuel Efficiency Mapping of a 2016 6-Cylinder GM EcoTec 4.3L Engine with Cylinder Deactivation* [1] included in this test package for reference.

The average torque, speed, and fuel flow measurements were used to determine a grid and generate fuel contour maps for Brake Specific Fuel Consumption (BSFC), shown in Figure 4, and Brake Thermal Efficiency (BTE), shown in Figure 5. These plots represent the engine mapping results without the cylinder deactivation feature enabled. The black dots in the figures above indicate the speed/load points at which steady state data were acquired. The dashed line is the Wide Open Throttle (WOT) curve plotted using published data. Additional contour maps for the test data measurements with the cylinder deactivation operation disabled are provided in *5- 2014 Chevrolet 4.3L EcoTec3 LV3 Engine Tier 2 Fuel – Test Data Plots.pdf.*



**Figure 4. 2014 Chevrolet 4.3L EcoTec3 – BSFC (g/kWh) Cylinder Deactivation Disabled**

[1] http://media.gm.com/content/dam/Media/images/US/Vehicles/Chevrolet/Other/2014-silverado-release/061813-sae-2014-silverado-torque-chart.jpg (2013-06-19)



**Figure 5. 2014 Chevrolet 4.3L EcoTec3 – BTE (%) Cylinder Deactivation Disabled**

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# Uncertainty

Sensor/signal Uncertainties

The uncertainties of the signals [u(signal)] in the data set can be based on (a) the uncertainty associated with the calibration standard, (b) the uncertainty of the sensor calibration [u(calibration)], and (c) the uncertainty of the signal during operation [u(operation)]. The uncertainty associated with the calibration standard is assumed to be negligible when compared to other uncertainties and thus this uncertainty is not considered for this calculation.

To determine the uncertainty of the sensor calibration, past calibration records were assessed and the difference between the standard and measured quantities were used to calculate uncertainty. To determine the uncertainty of the signal during operation, the standard deviations for each signal were calculated from the testing data and the average was used to calculate the variance of the mean, and thus the uncertainty,

Where n is the number of data points in a mode. Assuming n = 70 (a minimum number), the standard uncertainty for each signal is given in Table 8.

**Table 8: Standard Uncertainties for Signals**

|  |  |  |  |
| --- | --- | --- | --- |
| Signal | u(calibration) | u(operation) | u(signal) |
| Temperature (deg C) | 0.549 | 0.225 | 0.593 |
| Pressure (kPa) | 0.321 | 0.0053 | 0.321 |
| Speed (rpm) | 1.183 | 0.178 | 1.197 |
| Torque (Nm) | 0.0808 | 0.137 | 0.159 |
| Fuel (g/sec) | 0.00640 | 0.00365 | 0.00737 |

Testing Uncertainty

In addition to the uncertainties associated with each signal, there may be an overall uncertainty associated with the repeatability of the testing procedure and the engine operation. To estimate this uncertainty, common mode data taken during earlier testing (reference the section “Pre-Conditioning and Common Mode Check”) were examined. Due to a limited number of common mode data for the Tier 2 testing, the common mode data collected on this same engine fueled with LEV III fuel was used for this analysis.

**Figure 6. BSFC versus Engine Oil Temperature for LEV III Common Modes**

Uncertainty of BSFC

The variation of engine BSFC in the common modes correlated with engine oil temperature. As a result, engine oil temperature was considered to be a reasonable proxy for the test procedure uncertainty. The standard deviation of the engine oil temperature was 2.38 °C, which corresponds to 2.11 g/kWh BSFC based upon the linear relationship between these two values as shown in Figure 6. The total uncertainty for BSFC is thus calculated by:

or

The individual uncertainties are, from above,

*u(q)* = 0.00737 g/sec fuel flow

*u(T)* = 0.159 Nm

*u(ω)* = 1.197 rpm

*ue(BSFC)* = 2.11 g/kWh

**Figure 7. BTE versus Engine Oil Temperature for LEV III Common Modes**

Uncertainty of BTE

The derivation of the uncertainty of thermal efficiency is similar, with a testing uncertainty (related to the 2.38 °C standard deviation of the engine oil temperature) of 0.25% efficiency based on the linear relationship between these two values as shown in Figure 7. The uncertainty in measurement of the fuel heating value is assumed to be small compared to other uncertainties. Assuming *u(HV)* = 10 BTU/lb,

Low Speed Uncertainty

During testing, it was observed that engine operation and torque cell data tended to have more variability at speeds below about 1250 rpm, with the variability most noticeable at the lowest tested speed (800 rpm). Although not enough data were taken to fully characterize the increase in uncertainty at low speeds, the uncertainty at 1000 rpm may be up to two times the values calculated in the equations above, and the uncertainty at 800 rpm may be up to four times the values calculated.

Standard uncertainties are analogous to standard deviations, such that it would be expected that, for a given set of data, the “true” value of a parameter would fall within +/-1*uc* for 68% of the data points, the “true” value of a parameter would fall within +/-2*uc* for 95% of the data points, and the “true” value of a parameter would fall within +/-3*uc* for 99.7% of the data points. The calculated uncertainty for both the BSFC and BTE measurements are shown in Figures 8 and 9.

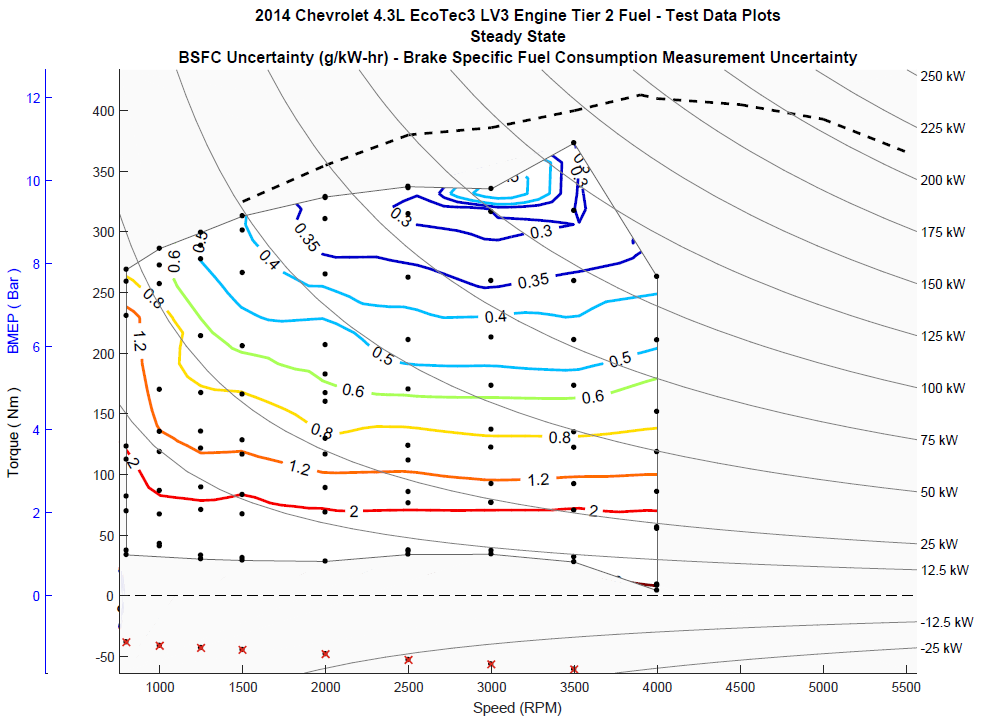
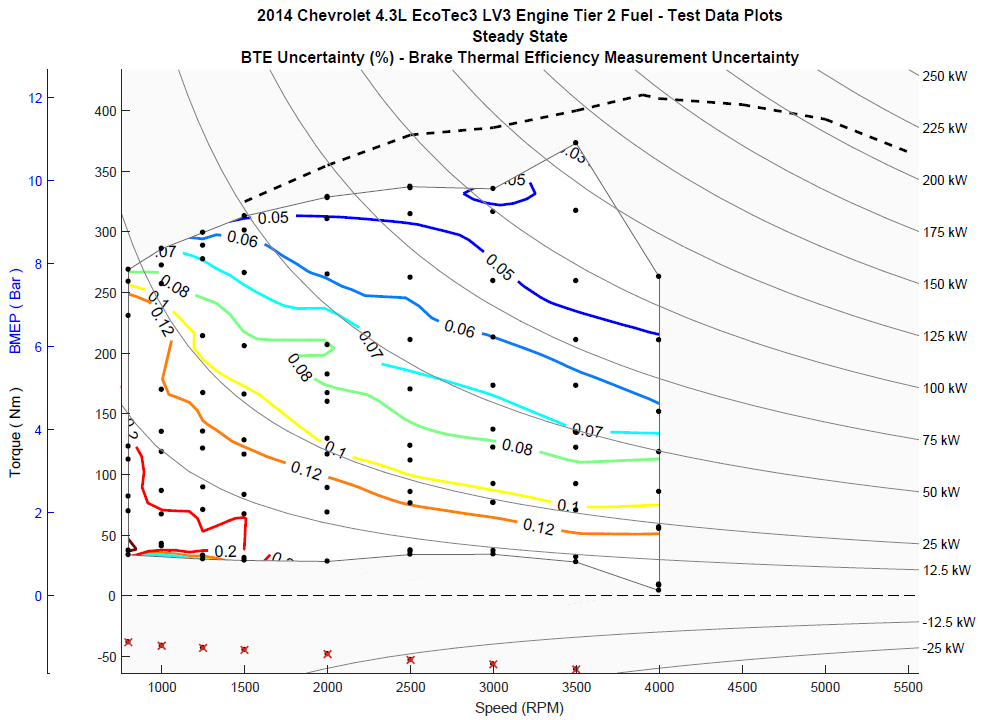


Figure 8. BSFC (g/kWh) Uncertainty



**Figure 9. BTE (%) Uncertainty**

# References

[1] Stuhldreher, M., “*Fuel Efficiency Mapping of a 2016 6-Cylinder GM EcoTec 4.3L Engine with Cylinder Deactivation*,” SAE Technical Paper 2016-01-0662, 2016, doi:10-4271/2016-01-0662.