

2013 Chevrolet Malibu 1LS Vehicle Tested with Tier 2 and Tier 3 Fuels – NCAT Test Report

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**Test:** 2013 Chevrolet Malibu 1LS Vehicle Tested with Tier 2 & Tier 3 Fuels – NCAT Test Report

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# Purpose of Test

This test report describes the testing of a 2013 Chevrolet Malibu 1LS vehicle on TATD chassis dynamometers collecting data from CAN, discrete sensors, dynamometer control system, and emissions reports to determine vehicle behavior over standard vehicle cycles (FTP, HWFET, and US06), and to assist in validating the ALPHA (Advanced Light-Duty Powertrain & Hybrid Analysis) model. The project is further described in *SAE 2015-01-1140 Benchmarking & Modeling of a Conventional Mid-Size Car Using ALPHA.pdf* [1] and *SAE 2015-01-1142 Development & Testing an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation.pdf*. [2]

# Definitions

|  |  |
| --- | --- |
| CAN | Controller Area Network, method of communication for pertinent on-board vehicle information and conditions |

# Description of Test Article

The vehicle tested was a 2013 Chevrolet Malibu 1LS with a 4-cylinder, 2.5-liter I4 GDI engine which produces 197 HP (147 kW) and 191 ft-lbs (259 Nm). The powertrain includes a 6-speed automatic transmission with a torque converter. Table 1 below summarizes information that identifies the vehicle description and target dynamometer coefficients used in this test program.

The vehicle was tested at two different sets of Equivalent Test Weights (ETW), Target Dynamometer Coefficients (ABC’s) and Dynamometer Set Coefficients (ABC’s). The heavier 4000 lb. road load, NCAT MALIBU, replicates the weight used during emissions certification testing. The lighter 3625 lb. road load, FEV MALIBU, was chosen to evaluate EPA city and highway fuel consumption for the vehicle’s fuel economy label. The Test Identification names are only provided as reference names strictly for the testing conducted by NCAT. The test results provided in this data packet do not represent any testing conducted by the contractor, FEV. The test results were also used to support the ALPHA model validation as described in the SAE papers [1] and [2].

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

|  |  |  |
| --- | --- | --- |
| Vehicle (MY, Make, Model) | 2013 Chevrolet Malibu 1LS | |
| Vehicle Identification Number | 1G11B5SA2DF147935 | |
| Engine | Ecotec 2.5L DOHC I4 VVT DI | |
| Transmission | GM 6T40 FWD 6-Speed Automatic Transmission | |
| Tires | P215/60R 16 94H Goodyear Assurance | |
| Test Group | DGMXV02.5001 2.5L | |
| Test Identification | NCAT MALIBU | FEV MALIBU |
| Equivalent Test Weight | 4000 lb. | 3625 lb. |
| Target Coefficient A | 38.08 lbf | 28.62 lbf |
| Target Coefficient B | 0.2259 lbf/mph | 0.1872 lbf/mph |
| Target Coefficient C | 0.01944 lbf/mph2 | 0.01828 lbf/mph2 |

# Test Site

This testing was performed in the National Vehicle & Fuel Emissions Laboratory (NVFEL) Test Site Dynamometer #001 (D001) and the Cold Test Facility (CTF).

# Test Equipment

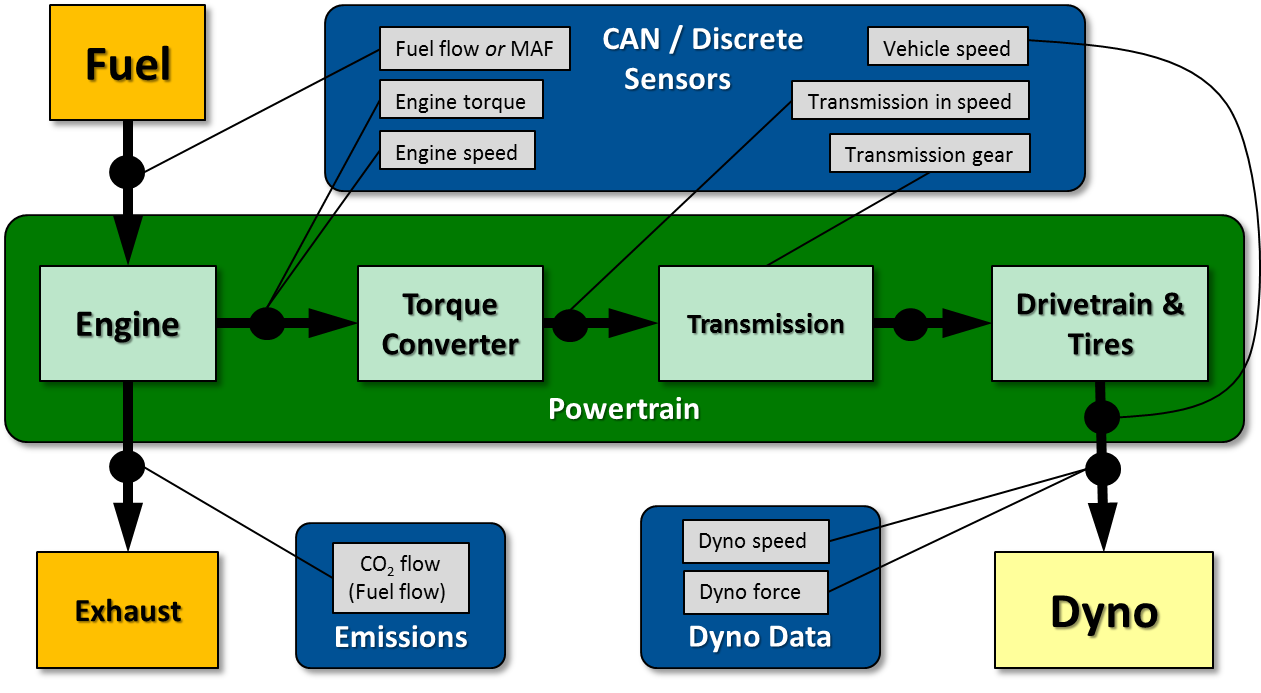
The test equipment installed in NVFEL Test Site includes a chassis dynamometer and an emissions bench. The D001 site includes a Horiba chassis dynamometer, a Horiba CVS sampling system and a Horiba Motor Exhaust Gas Analyzer MEXA-7200H emissions bench. The CTTF site includes a MAHA chassis dynamometer and an AVL emissions bench. This equipment is maintained and calibrated according to the testing requirements specified in 40CFR§86 and 40CFR§1065 referencing relevant work instructions documented in accordance with NVFEL’s ISO 17025 accredited quality system.

A DGE GatewayTK was installed to function as a stand-alone BUS gateway to allow the collection of specified vehicle CAN signals. The DGE GatewayTK captures broadcast CAN messages or creates PID requests as necessary and then broadcasts new messages on a second BUS that contains the same signal information. A .DBC file then defines the CAN messages being broadcast by the DGE GatewayTK for use in data analysis.

Vehicle operational data was obtained from discrete sensors and onboard vehicle CAN (via the DGE GatewayTK) using a RPECS IV system. Southwest Research Institute's® (SwRI®) Rapid Prototyping Electronic Control System IV (RPECS-IV) is an advanced programmable controller for custom control and data acquisition applications. The data recorded during testing included vehicle speed, engine speed and torque, wheel speeds, as well as other pressures and temperatures of interest at the time of testing.

# Vehicle and Engine Setup

Figure 1 illustrates the engine setup and data collection method utilized in the test cell. The signals shown in Figure 1 are not a complete set of the signals collected, but rather the most important signals used for component efficiency mapping.



**Figure 1: Schematic of the Vehicle on the Dynamometer**

## Vehicle Preparation

The vehicle was received new and after testing was completed on separate test stands on the removed powertrain components, the vehicle was reassembled and underwent further testing. The vehicle was put into dynamometer rolls mode using a procedure provided by the manufacturer to allow the vehicle to be tested in two-wheel drive mode. The dynamometer set coefficients were derived by performing a road load derivation and are listed below in Table 2.

**Table 2: Dynamometer Set Coefficients**

|  |  |  |
| --- | --- | --- |
| Vehicle | NCAT MALIBU | FEV MALIBU |
| Equivalent Test Weight | 4000 lb. | 3625 lb. |
| Set Coefficient A | 9.828 lbf | 3.260 lbf |
| Set Coefficient B | 0.2451 lbf/mph | 0.1710 lbf/mph |
| Set Coefficient C | 0.01728 lbf/mph2 | 0.01664 lbf/mph2 |

# Test Methodology

## Test Fuel

This testing used multiple fuels due to availability during testing as there was no intent to conduct a fuel comparison test. The primary properties for the fuels used in this test program are shown in Table 3 below. A detailed summary of the fuel analysis performed and results measured for the fuels utilized in this test program can be found in the files referenced below.

**Table 3: Fuel Properties**

|  |  |  |  |
| --- | --- | --- | --- |
| Report File | *5a– NVFEL Fuel Analysis Report 23945.pdf* | *5b– NVFEL Fuel Analysis Report 24054.pdf* | *5c– NVFEL Fuel Analysis Report 24293.pdf* |
| Antiknock | 92.65 AKI | 88.10 AKI | 90.05 AKI |
| Net Heating Value | 18438.07 BTU/lb. | 17913.00 BTU/lb. | 17709.00 BTU/lb. |
| Alcohol Content | 0.00 % | 10.18 % | 0.00 % |

# 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).

# Data Set Definition

There were multiple sources of data being logged during this testing. The test data sets are divided into several portions based upon the testing conducted and are provided for each type of test. Detailed descriptions of the data sources and the data results files are provided below.

# Data Sources

An overview description and examples of the various sources of test data being logged along with specifics on how they were sampled is provided below.

1. *Digital Parameters* - A Max 213-311 piston flow meter with a 295-000 pickoff was installed in-line with the fuel delivery system in the engine compartment. At each rising or falling edge of the flow meter signal a cumulative counter was incremented by one and at each log interval the most recent cumulative count was latched.

A 360-Pulse encoder provided a signal and with each rising or falling edge, a 66 MHz timer was latched and reset. The latched value was used to calculate an average period which corresponded to ½-CAD with a low-pass filter. This was then scaled to engine RPM and the most recent value was latched at each log interval.

Within the absolute FPGA time, the device used for digital signal acquisition, a 66 MHz counter ran continuously and the most recent value was latched at each log interval and then scaled to milliseconds.

1. *Analog Parameters* - Thermocouples were amplified and linearized using modules produced by Dataforth. Torques, pressures, voltages and currents were measured directly as they were produced by their corresponding transducers. These signals were sampled every 5ms and the latest sample was latched into the log buffer at each log interval.

1. *CAN Bus Parameters -* The DGE Gateway TK broadcasts data serially over a CAN bus at various rates. The RPECS IV system receives each message as they are transmitted from the gateway and parses them into their corresponding parameter values. At each log interval the latest value for each CAN parameter is latched into the log buffer.

Several Dataforth linearized thermocouple input modules (SCM5B47K-05) were also used in conjunction with the RPECS-IV system and the discrete temperature signals. Each module provides a single channel of thermocouple input which is filtered, isolated, amplified, linearized and converted to a high-level analog voltage output. Vehicle operational data was obtained from onboard vehicle CAN using a DashDAQ XL automotive data logger. The DashDAQ XL can work with any OBD II vehicle and was connected directly to the OBD II connector.

1. *ATi Half Shaft Sensors -* To permit in-vehicle wheel torque measurements, two ATi (Advanced Telemetrics International) torque sensing systems were installed on each half shaft. RF telemetry was used for data transfer, and an ATi Model 2125iR telemetry receiver, which produced a +/-5 VDC analog output, was also installed. Prior to testing, the torque sensing system was calibrated after being properly warmed up for 20 minutes. The zero and span potentiometers were adjusted until the desired outputs were indicated on the RPECS IV system. Given all of this, there is still concern with the final accuracy of the measurement due to thermal effects on the sensors.

# Test Data Set Overview

The data set results are provided for each of the tests conducted and include a list of the test parameters in each individual data file. The list includes a description, unit of measure, sampling rate, and source for each measured test parameter. Post-processing of the test data, including time alignment is described in the Data Set Processing section below. The data set files include:

1. *4a- 2013 Chevrolet Malibu 1LS Vehicle – Acceleration and Deceleration Test Data.xlsx*
2. *4b- 2013 Chevrolet Malibu 1LS Vehicle – TC Stall and Engine Spindown Test Data.xlsx*
3. *4c- 2013 Chevrolet Malibu 1LS Vehicle – Vehicle Cycle Test Data.xlsx*
4. *4d- 2013 Chevrolet Malibu 1LS Vehicle – Vehicle WOT Test Data.xlsx*
5. *4e- 2013 Chevrolet Malibu 1LS Vehicle – NVFEL Laboratory Test Data.xlsx*

# Data Collection Procedure

## Acceleration and Deceleration Testing

To assist in characterizing the transmission shifting and estimate some transmission spin losses, acceleration and deceleration testing was performed in the CTF using *FTAG 24293* test fuel*.* To perform these tests, the vehicle was warmed up with the dynamometer in a road simulation mode using the FEV MALIBU configuration. Next, the vehicle was brought to 0 kph and then very mildly accelerated (approximately 0.8 kph per second) to a speed near 130 kph. Subsequently the accelerator pedal was put at 0 % and the vehicle was allowed to coast down to a speed near 6.5 kph. The brake was then applied to bring the vehicle to 0 kph. The process was repeated three times with the transmission placed in both drive and neutral.

## Torque Converter Stall and Engine Spindown Testing

To help estimate the torque converter properties, the following test was performed in-vehicle. The vehicle was keyed on and put in drive. The brakes were applied to prevent any revolution of the wheels and, in turn, the transmission input shaft. The accelerator pedal was then fully depressed for approximately 3 seconds. This process was repeated several times. The DashDAQ XL device was used to record engine speed and engine torque at approximately 100 hz.

To estimate the combined inertia of the engine, its attached components, and the torque converter impeller, an engine spindown test was performed in-vehicle. The engine was revved with the transmission in park to the engine’s governed speed, then the ignition was keyed off, and the engine speed and torque were observed until the engine stopped. Engine speed and reported engine torque data (shown as negative during ignition off) were collected.

## Vehicle Cycle and Emission Testing

Multiple 3-bag and 4-bag FTP, HWFET and US06 tests were performed on the chassis dynamometer and the data was recorded. The tests were performed according to the test procedure requirements specified in 40CFR§86 and 40CFR§1065 referencing relevant work instructions documented in accordance with NVFEL’s ISO 17025 accredited quality system. The testing was conducted using both *FTAG 23945* and *FTAG 24054* fuelsas noted on each individual data sheet.

## Vehicle WOT Testing

To determine a more accurate engine maximum torque curve, a test was performed with the vehicle on a dynamometer. In this test the vehicle speed was held constant by the dynamometer and full pedal was applied. The test was repeated at multiple vehicle speeds that, in turn, produced a range of engine speeds.

# Data Set Processing

## Data Processing

Chassis dynamometer test data sets were processed in according to the test procedure requirements specified in 40CFR§86 and 40CFR§1065. A set of software applications retrieved, transmitted, processed and stored test data in a specified manner described in procedures developed in support of NVFEL’s ISO 17025 accredited quality system.

## Signal Collection and Time Alignment

The RPECS-IV was used to merge data from multiple sources at a fixed log rate of 20 ms to a comma-delimited file. Every row of data corresponds to one complete log interval and each column represents one variable that is being logged. Each source of data may be asynchronous to another and is sampled according to the type of data it is. When a timer within RPECS-IV expires, at the programmed log interval, the most recent value for every parameter is latched into a buffer.

Data were recorded from the vehicle CAN (via the DGE Gateway TK) and discrete sensors at a 50 Hz rate. Due to bandwidth limitations however, not all the CAN signals were being updated that frequently (i.e. points are repeating) on the DGE Gateway TK. As a result, the dynamometer controller and emissions bench data (DCEBD) were collected separately at a 10Hz rate.

The final data sets for the cycle testing contain 10Hz data that is a result of merging the RPECS IV data with a set of DCEBD. First, the time and vehicle speed found in the data set containing the DCEBD is statistically compared to the target vehicle time and speed of the associated cycle and shifted to align with the target time and speed. Second, an interpolation is performed on the DCEBD data so there is a time stamp starting at 0.0 seconds and ending at the exact time of the target cycle duration. Thirdly, the aforementioned two steps are repeated, comparing the vehicle speed in the RPECS IV data to the product created in the preceding steps and merging the data to create the final data set.

# Data Quality Control

NVFEL’s ISO 17025 accredited quality system uses quality control to ensure the accuracy and precision of laboratory tests to provide reliable, interpretable, repeatable and defendable results. In accordance with the ISO/IEC 17025 standard, there are established procedures for monitoring the validity of the testing conducted including auditing, corrective action and continuous improvement. Vehicle test packets are audited following approved processes prior to data release.

# Results

A summary of the vehicle cycle and emission testing is shown in the Table 4 below. The detailed test results for each test are provided in the files: *4c-* *2013 Chevrolet Malibu 1LS Vehicle – Vehicle Cycle Test Data.xlsx* and *4e-* *2013 Chevrolet Malibu 1LS Vehicle – NVFEL Laboratory Test Data.xlsx.* During each test, bag emissions and summary dynamometer data were recorded and used to determine cycle fuel economy. A summary of the fuel economy results for each test cycle is given in Table 5 below.

**Table 4: Summary of Standard Vehicle Cycle Testing**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Test Site** | **Vehicle I.D.** | **Fuel** | **Test Date** | **Test Number** | **Vehicle Cycle Results** | **Vehicle Emissions Results** |
| CTTF | NCATMALIBU | 23945 | 06/03/14 | 2014-0189-001 | Cold Start UDDS (Bag 1 & 2) | FTP3Bag Emissions |
| 06/13/14 | 505 | FTP3Bag Emissions |
| 06/03/14 | 2014-0189-002 | ----- | HWFET Emissions |
| 06/13/14 | 2014-0189-003 | ----- | US06 Emissions |
| Dyno 001 | FEV MALIBU | 24054 | 06/25/14 | 2014-0207-002 | Cold Start UDDS (Bag 1 & 2) | FTP4Bag Emissions |
| UDDS (Bags 3 & 4) |
| 06/25/14 | 2014-0207-003 | HWFET | HWFET Emissions |
| 06/25/14 | 2014-0207-004 | US06 | US06 Emissions |
| 07/23/14 | 2014-0207-007 | Cold Start UDDS (Bag 1 & 2) | FTP4Bag Emissions |
| UDDS (Bags 3 & 4) |
| 07/23/14 | 2014-0207-008 | HWFET | HWFET Emissions |
| 07/23/14 | 2014-0207-009 | US06 | US06 Emissions |
| 07/24/14 | 2014-0207-010 | Cold Start UDDS (Bag 1 & 2) | FTP4Bag Emissions |
| UDDS (Bags 3 & 4) |
| 07/24/14 | 2014-0207-011 | HWFET | HWFET Emissions |
| 07/24/14 | 2014-0207-012 | US06 | US06 Emissions |

**Table 5: Fuel Economy Test Results**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Test Site** | **Vehicle I.D.** | **FTP3Bag** | **FTP4Bag** | **HWFET** | **US06** |
| CTTF | NCATMALIBU | 26.22 | ----- | 42.53 | ----- |
| 26.54 |
| Dyno 001 | FEV MALIBU | ----- | 27.67 | 47.39 | 28.57 |
| 27.74 | 46.36 | 28.38 |
| 27.74 | 46.13 | 28.73 |

The results of the acceleration and deceleration testing were used to assist in characterizing the transmission shifting and estimate some transmission spin losses in the ALPHA model. In addition, the results of the torque converter stall and engine spindown testing were used to estimate the torque converter properties in the ALPHA model. [1] [2].

# Uncertainty

The dynamometer and emissions data were collected according to the test procedure requirements specified in 40CFR§86 and 40CFR§1065 referencing relevant work instructions documented in accordance with NVFEL’s ISO 17025 accredited quality system. Any uncertainty and test-to-test variation is controlled by adhering to the laboratory’s standard procedures.

The supporting data sets include CAN data as directly recorded from the test cell which have not been calibrated, checked, adjusted, or analyzed. This reported data may be valuable to use as reference parameters and should in general, be considered reference only. Users should exercise good engineering judgement when determining the extent to which they wish to rely on these reported values for any analysis purpose.

In addition, the data sets include measurements using discrete sensor signals including half-shaft torque transducers, a transmission line pressure transducer, and a fuel flow meter. The uncertainty of these signals is based upon the uncertainty associated with the sensor calibration and the uncertainty associated with the signal itself during operation.

To represent the uncertainty associated with the sensor calibration, the sensor calibration records were assessed and the standard deviation of the difference between the standard and measured quantities at each calibration point was calculated. To represent the uncertainty associated with operation, a ten-second steady-state mode was taken at vehicle idle and the standard deviation of the signal calculated. The results are provided in Table 6.

**Table 6. Standard Deviations Associated with Discrete Sensor Signals**

|  |  |  |
| --- | --- | --- |
| **Sensor Signal** | **Standard Deviation of Calibration** | **Nominal Standard Deviation of Signal** |
| Transmission Oil Pressure | 1.56 kPa | 2.98 kPa |
| Half-shaft Torque (Driver Side) | 0.357 Nm | 1.89 Nm |
| Half-shaft Torque (Passenger Side) | 0.455 Nm | 2.49 Nm |
| Fuel Flow | 0.00209 cc/sec | 0.0943 cc/min |

The actual uncertainty of the measurement would need to consider additional factors such as the application and the time frame (for example, instantaneous fuel flow, a running average of fuel flow, or totalized fuel over the cycle). The values provided above are intended to assist in determining an appropriate uncertainty and are provided as a reference only.

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.

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# Discussion and Data Usage

The intent of this testing was to determine vehicle behavior over standard vehicle cycles (UDDS, HWFET, and US06) and assist in validating the ALPHA (Advanced Light-Duty Powertrain & Hybrid Analysis) model. In general, the emissions and dynamometer data contained within this data set are good and can be used for multiple purposes.

The torque sensor data from the halfshafts are presented in uncorrected form and care should be taken to understand these issues before relying on data from these sensors. In addition, when using fuel flow, the user should be aware the fuel temperature was not recorded, and thus fuel density may vary throughout the test.  Although the volume flow recorded is likely accurate, subject to the discussion above in the Uncertainty Section, care should be taken when converting to mass flow.

The overall project and the results of the detailed analysis conducted is described in more detail in in *SAE 2015-01-1140 Benchmarking & Modeling of a Conventional Mid-Size Car Using ALPHA.pdf* [1] and *SAE 2015-01-1142 Development & Testing an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation.pdf*. [2]

# References

[1] Newman, K., Kargul, J., and Barba, D., "*Benchmarking and Modeling of a Conventional Mid-Size Car Using ALPHA*," SAE Technical Paper 2015-01-1140, 2015, doi: 10.4271/2015-01-1140.

[2] Newman, K., Kargul, J., and Barba, D., "*Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation*," *SAE Int. J. Engines* 8(3):2015, doi: 10.4271/2015-01-1142.