

On-Road and Dynamometer Evaluation of Vehicle Auxiliary Loads

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ABSTRACT

Laboratory and on-road vehicle evaluation is conducted on four vehicle models to evaluate and characterize the impacts to fuel economy of real-world auxiliary loads.

The four vehicle models in this study include the Volkswagen Jetta TDI, Mazda 3 i-ELOOP, Chevrolet Cruze Diesel, and Honda Civic GX (CNG). Four vehicles of each model are included in this; sixteen vehicles in total. Evaluation was conducted using a chassis dynamometer over standard drive cycles as well as twelve months of on-road driving across a wide range of road and environmental conditions.

The information gathered in the study serves as a baseline to quantify future improvements in auxiliary load reduction technology. The results from this study directly support automotive manufacturers in regards to potential “off-cycle” fuel economy credits as part of the Corporate Average Fuel Economy (CAFE) regulations, in which credit is provided for advanced technologies in which reduction of energy consumption from vehicle auxiliary loads can be demonstrated.

The observed on-road auxiliary load varied from 135 W to over 1200 W across a wide range of ambient conditions and utilization patterns. The annual average auxiliary load varied across vehicle models from 310 W to 640 W. Ambient temperature was the most predominant factor to impact auxiliary load since air conditioner (A/C) operation is prevalent at high ambient temperature and heating system operation is prevalent at cold ambient temperatures. Additionally the impact of auxiliary load on vehicle fuel economy was determined to be typically between 7.5% and 18% of the fuel consumed during onroad operation of the four vehicle models in this study.

During dynamometer testing, auxiliary loads were captured from several key locations along the low-voltage bus, including the alternator output, the low-voltage battery, and select other locations dependent upon the vehicle configuration. Dynamometer testing was then conducted on both certification and custom constant-speed drive cycles at three ambient temperatures (-7 °C, 23 °C, as well as 35 °C with 850 W/m² of solar emulation). This instrumentation and test methodology provides an accurate understanding of the energy use by the accessory system from these four vehicle technologies.

This paper details and discusses the dynamometer and on-road evaluation results of the auxiliary load from the sixteen vehicles over the twelve month period.

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INTRODUCTION

As part of the testing and data collection support to the U.S. Department of Energy's (DOE) Advanced Vehicle Testing Activity (AVTA) [1], Idaho National Laboratory, Argonne National Laboratory, and Intertek Center for Evaluation of Clean Energy Technology (CECET) test advanced technology vehicles in on-road fleets, on test tracks, and in laboratory settings in order to determine

the real-world petroleum consumption reduction potential of various advanced vehicle technologies. One strategy for petroleum consumption reduction is to reduce the auxiliary, 12 V loads of the vehicle. This strategy has been explored in recent research [2,3,4,5] and several U.S. automotive manufacturers are also interested in developing novel methods for improved fuel economy.

Vehicle auxiliary load data collection, analysis, and characterization were conducted on sixteen non-electrified vehicles as part of the AVTA on-road vehicle evaluation. This auxiliary load characterization study directly supports automotive manufacturers in regards to potential “off-cycle” fuel economy credits that are part of the U.S. CAFE regulations, in which credit is provided for advanced technologies that reduce the energy consumption from vehicle auxiliary loads. A few examples of these advanced technologies are advanced alternators, HVAC systems, active aerodynamics systems (such as movable grille shutters that close at high speeds), and lighting systems. The data collection and analysis details the auxiliary load data collected during the on-road operation of 126,000 miles of 16 non-electrified vehicles (four Volkswagen Jetta TDI, four Mazda 3 i-ELOOP, four Chevrolet Cruze Diesel, and four Honda Civic GX (CNG) vehicles).

Chassis dynamometer testing was conducted on the same four vehicle models noted above, over several standard drive cycles (e.g., UDDS, HWFET, and US06) at three separate temperatures of -7 °C, 23 °C, as well as 35 °C with 850 W/m² of solar emulation. Instrumentation was installed on each vehicle prior to dynamometer evaluation in order to capture 12 V power flow and energy consumption by the vehicle accessories. This was used to correlate and cross reference the on-road data collection across varying ambient conditions and temperatures.

VEHICLE MODELS EVALUATED

The sixteen vehicles in this study include four 2013 Volkswagen Jetta TDI, four 2012 Honda Civic CNG, four 2014 Mazda 3 i-ELOOP, and four 2014 Chevrolet Cruze Diesel vehicles. The vehicles are operated on-road in document delivery courier fleets and taxi fleets in Arizona, Texas, and Oklahoma. Routine maintenance is performed on the vehicles per the manufacturer’s maintenance schedule.

The test vehicles selected for the project were diesel vehicles (Jetta TDI and Cruze Diesel), natural gas vehicles ((NGVs) Civic CNG), and an advanced conventional vehicle (3 i-ELOOP). The vehicles were chosen because of automotive OEM requests to study non-electrified vehicles auxiliary load characteristics during on-road operation. The ultra-capacitor of the Mazda 3 i-ELOOP helps reduce demand on the 12 V battery, but the vehicle architecture was deemed sufficiently conventional to be included in the study. Furthermore, each vehicle model has unique features which are of interest and are shown in Table 1. The Jetta TDI and Chevy Cruze Diesel both utilize a four-cylinder, turbo diesel engine. The Jetta TDI has a six-speed, dual-clutch transmission, whereas the Cruze Diesel has a conventional six-speed, automatic transmission. The Honda Civic CNG utilizes compressed natural gas (CNG) as the sole fuel source. Of importance, the Civic CNG does not use a fuel pump, which is important with respect to auxiliary load. The Mazda 3 i-ELOOP utilizes a direct-injection, gasoline engine and a six-speed transmission. Additionally, the Mazda 3 i-ELOOP uses a 25 V capacitor and power electronics to supplement and aid the alternator system in providing electrical power to the auxiliary loads to improve operating efficiency.

Table 1. Test vehicle descriptions

Vehicle Model	Notable Characteristics and Features
2013 VW Jetta TDI	Turbo diesel engine with dual clutch transmission
2014 Chevrolet Cruze Diesel	Turbo diesel engine with automatic transmission
2012 Honda Civic CNG	CNG naturally aspirated engine with automatic transmission
2014 Mazda 3 i-ELOOP	25 V capacitor and power electronics system to aid alternator efficiency performance

TESTING OVERVIEW

The sixteen vehicles (four of each vehicle model) were instrumented with current and voltage sensors as well as controller area network (CAN) message monitoring equipment. On-board data acquisition (DAQ) systems from Isaac Instruments were installed in the vehicles to record the current, voltage, and CAN messages. This information was used to determine the vehicle operating conditions, utilization patterns and the auxiliary loads during those conditions.

Prior to testing, all features of the tests vehicles which can apply a substantial load to the 12 V system were identified. For each feature identified, the amperage rating for the fuse through which power flows to that feature’s hardware was also documented. The vehicle state (i.e., key on, engine off/key on, engine on) during which each feature becomes functional was also determined.

In order to conduct the characterization of the loads on the 12 V system, the vehicle was instrumented using current sensors on the cables leading to the various feature hardware. The current sensors were connected to the Isaac Instruments DAQ systems, and the data were set to capture at a 1 Hz rate. The current sensor data were also corroborated using signals that were deciphered from the vehicle CAN system.

The 12 V power draws were separated into two categories: (1) power draws during engine off, and (2) power draws during engine on. There was some overlap between the two groups, with some power draws occurring in both cases, while other power draws occurring only with the engine on because the engine power is required. The power draws that were measured are shown in Table 2 (power draw occurring only with the engine on are indicated by blue shading).

Table 2. Tested individual power draws

Parking lights	Cabin fan (at all available speeds)
Dashboard lights	Radio (at high volume)
Headlights (low and high beam)	Windshield wipers (low and high speed)
Dome lights	Windshield washer (front and rear)
Moon roof (open and close)	Driver’s window
Taxi light and meter*	DAQ power draw
Driver and passenger seat heaters	Air conditioning (ECO, Normal, and MAX, with varying fan speeds)
Front and Rear defrosters	Electric power steering
Brake lights	Reverse lights

* Some of the test vehicles are in taxi fleets

The test vehicles were deployed into AVTA project partner fleets in several locations:

- Phoenix, AZ: VW Jetta TDI
- Dallas and Houston, TX: Chevrolet Cruze Diesel
- Oklahoma City, OK: Honda Civic CNG
- Phoenix, AZ: Mazda 3 i-ELOOP

The vehicles operate within these fleets in the same manner as other vehicles within the same fleet, except that the drivers maintain a log of all refueling, and all maintenance is recorded.

The fleets are couriers that accumulate up to 500 miles per day, and this rapid accumulation helps provide a large amount of on-road operation data in a condensed period of time. The vehicles are driven by multiple drivers to avoid driver bias, and the vehicles are driven in a wide variety of drive cycles, from intra-city to urban to highway to interstate roads, with topographical variation, although there is no pre-determined driving pattern that is forced upon the fleets. Further, the vehicles are driven year-round, with results in significant temperature variation.

The Isaac DAQ systems capture the on-road operation data, and the base of operations for each fleet is equipped with Wi-Fi routers that allow for automatic data upload whenever the vehicle is in the vicinity. In this way, the 12 V load characterization data were uploaded on a nearly a daily basis to ensure data continuity and data completeness.

INDIVIDUAL LOAD BENCHMARK EVALUATION

A specific auxiliary load test was completed on each vehicle model to measure the load of individual accessories and components. Additionally, the base auxiliary load of the vehicle was measured with all driver controlled accessories in the off position with the engine off and with the engine idling. Figure 1 shows the measured values for the individual auxiliary loads. Note the Honda Civic CNG is not equipped with seat heaters, rear defroster, or electric power steering.

Table 3. Minimum auxiliary load with Engine idling (all accessories off)

Vehicle Model	Steady State Auxiliary Load with Engine Idling and All Accessories Off (W)
2013 VW Jetta TDI	258
2014 Chevy Cruze Diesel	256
2012 Honda Civic CNG	136
2014 Mazda 3 i-ELOOP	206

Table 3 shows the minimum auxiliary load when the engine is idling and all driver controlled accessories are in the off position. Note the wide range of auxiliary load across the vehicle models. The Honda Civic CNG has the lowest auxiliary load of the four vehicle models in

part due to not having a fuel pump. Also of note, the two vehicles with turbo diesel powertrains have quite similar auxiliary loads at idle (256 W and 258 W) when all accessories are turned off.

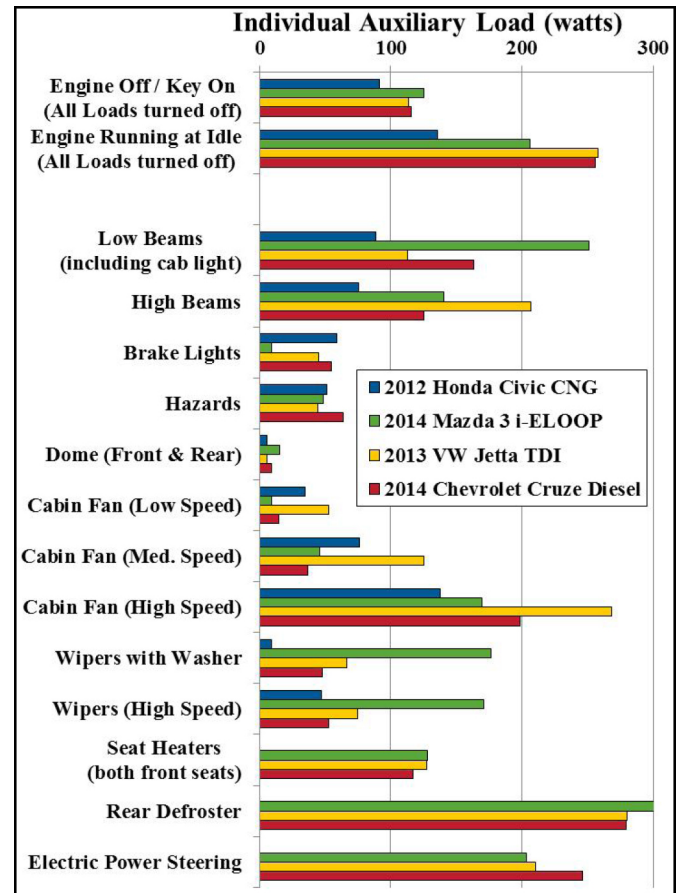


Figure 1. Individual auxiliary load characterization

CHASSIS DYNAMOMETER TESTING

Three of the vehicles were also tested on a chassis dynamometer in order to provide a thorough evaluation while under controlled, repeatable conditions within a temperature controlled environmental chamber. The standard U.S. certification drive cycles were run, as well as customized drive cycles to capture the steady-state vehicle accessory load. This testing was conducted at Argonne National Lab's Advanced Powertrain Research Facility as shown in Figure 2.



Figure 2. Vehicle during Chassis Dynamometer Testing at Argonne National Lab's Advanced Powertrain Research Facility