

Fuel Economy Beyond ILSAC GF-5: Correlation of Modern Engine Oil Tests to Real World Performance

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ABSTRACT

A host of bench and engine tests have historically been used by formulators to assess fuel economy when developing engine oils for gasoline-powered passenger cars and light trucks. Some of these methods assess basic lubricant physical properties such as hydrodynamic, boundary and thin-film friction, and are useful for quickly screening experimental components and formulations. Some methods assess rotational drag of a motored engine and offer insights into the friction of various engine parts. Still other methods directly measure the energy consumption in a test engine running in a research laboratory and thus come the closest to simulating a consumer-operated vehicle. Each test method has inherent limitations and is based on underlying assumptions, producing artifacts that must first be understood and then analyzed for relevance to either industry lubricant specifications or real world fuel economy performance. In this paper the authors compare the response of the various test methods to typical engine oil formulation approaches, and evaluate the correlation between test response and real world fuel economy performance as measured in a specially designed vehicle fuel economy test. The authors show that correlation may be established between research tests and standardized fuel economy tests such as the Sequence VID, but the correlation is not as straightforward when applied to performance in a real world vehicle fuel economy test due to the myriad engine and vehicle types available in today's market. Therefore, engine oil formulation approaches for GF-6 and beyond will need to take into account both performance in standard engine tests and response in various types of consumer vehicles in order to achieve maximum fuel efficiency in real world driving.

CITATION: Styer, J. and Guinther, G., "Fuel Economy Beyond ILSAC GF-5: Correlation of Modern Engine Oil Tests to Real World Performance," *SAE Int. J. Fuels Lubr.* 5(3):2012, doi:10.4271/2012-01-1618.

INTRODUCTION

Due to increasingly stringent vehicle fuel economy mandates over the past two decades, fuel economy improvement continues to be a focal point in all aspects of engine and vehicle design and operation[†]. This includes engine oil formulation, whose fuel economy improvement potential can be estimated to be anywhere from 1 to 4%¹, depending on the chosen baseline. In response, all major global regions have established standard engine oil fuel economy tests, whether through industry groups (such as ILSAC, API, or ACEA), or through individual OEMs. Currently, most of the standard tests are engine dynamometer tests (such as the Sequence VID and M111E fuel economy

tests), but others, particularly European OEM tests, have recently been directed more toward vehicle testing.

In addition to the standardized fuel economy tests that oils are required to pass to meet specifications, several other test methods have historically been used to screen and/or further assess the fuel economy performance of these oils. These tests include bench tests that evaluate frictional and viscometric properties, motored research engine tests, fired research engine tests, and various non-standard vehicle fuel economy tests. A brief overview of these test types follows.

Bench tests

It is generally accepted for engine oils that fuel economy improvement is influenced by reductions in kinematic viscosity, high shear viscosity, boundary friction, thin-film

[†]In 2010 the U.S. Department of Transportation and the Environmental Protection Agency jointly established new federal rules that established national greenhouse gas emissions standards and a significant increase in fuel economy for all new passenger cars and light trucks sold in the United States. These rules progressively increase Corporate Average Fuel Economy (CAFE) from the 2011 base of 27.6 mpg to 34.1 by the year 2016. Individually, passenger cars will go from the base of 30.4 mpg to 37.8 and light trucks will go from 24.4 mpg to 28.8 mpg.

The details of this new rulemaking may be found in the Federal Register (http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE-GHG_MY_2012-2016_Final_Rule_FR.pdf).

friction, and pressure-viscosity coefficient^{2,3,4,5,6,7,8,9,10,11}. These measurements are relatively quick and easy to obtain compared to the more sophisticated engine performance tests. However, they are also highly specific and fundamental in nature. They necessitate detailed correlation equations to be established before they can be reliably used to predict fuel economy performance.

Motored engine tests

These tests have been described in the literature^{12,13,14} and generally involve a fully assembled engine of the researcher's choosing, with the engine being connected through a torque meter to a separate electric motor. The electric motor is used to spin the test engine while the torque meter measures the amount of effort required to do so. In addition to flexibility in the choice of test engine, this method offers several other advantages, including flexibility of test conditions (such as oil and coolant temperature and speed), test time, and test cost compared to standard and research fired engine tests. The method provides a very good estimate of overall internal engine friction, which negates the need to establish rigorous correlation equations. However, it also has several drawbacks, including the inability to test aged oils (unless a sufficient quantity of aged oil has been generated elsewhere), the absence of the combustion process (including the generation of combustion byproducts and fuel dilution effects), and a different set of forces applied to the engine parts due to the pistons being driven from below rather than being thrust from above.

Standardized and research fired engine tests

Fired engine tests offer the closest approximation to vehicle tests. The standardized tests are rigorously controlled and widely available. Fired research engine tests are more flexible and can be designed to vary temperature, speed, torque, and engine type. In addition, they can be designed to operate under steady-state or transient conditions.

Vehicle tests

Vehicle tests offer the opportunity to measure total vehicle fuel economy, however there are significant challenges to be addressed with these tests. These include (but are not limited to) fluctuations in ambient conditions, consistency of variables such as tie-down forces, yaw, fuel temperature, and tire pressure, driver repeatability, other driveline variables (such as transmission, axle, and transaxle impacts), identification of appropriate drive cycles, and vehicle mileage impacts¹⁵. However, if these challenges can be overcome vehicle testing provides the most comprehensive measure of real world fuel economy possible.

Figure 1 shows a comparison of each of the test methods described above based on several relative factors:

- Test cost (“cost”),
- Test throughput (“speed”),

- Test repeatability (“repeatability”),
- Ability to operate under transient conditions (“transient operation”),
- Flexibility of apparatus and/or procedure (“flexibility”),
- Responsiveness to known fuel economy drivers (“response”),
- The ability to evaluate aged oil (“aged oil”), and
- The ability to predict OEM or vehicle-specific fuel economy (“real-world”).

The comparison is based on a 1-5 scale, with 5 indicating the best possible scenario and 1 indicating the worst. As can be seen, there is no perfect fuel economy test for all situations and needs. A combination/correlation approach to engine oil fuel economy research offers the best opportunity to thoroughly understand formulation influences on performance and most effectively predict response in standard fuel economy tests and real-world applications.

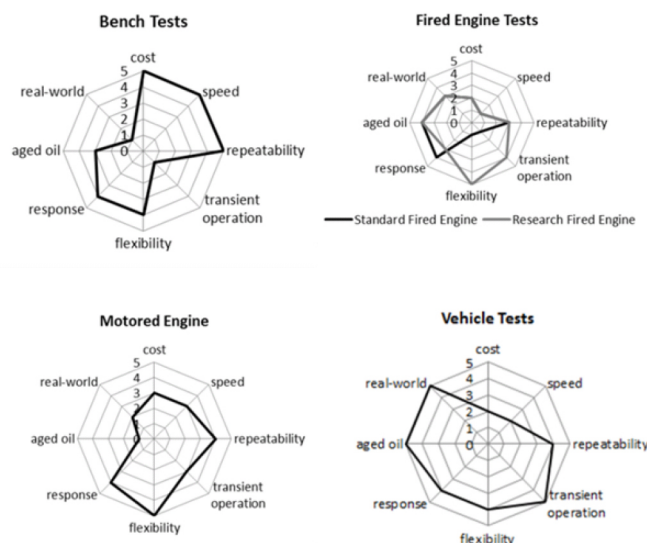


Figure 1. Relative performance attributes of various fuel economy test methods (5 = best scenario)

TESTING APPARATUS AND CONDITIONS

For the current research effort, testing was performed using all of the above fuel economy evaluation methods. Details of the test equipment and conditions are as follows:

Bench tests

Boundary regime friction coefficient (BFC): Evaluated using a PCS Instruments High Frequency Reciprocating Rig (HFRR) with an ANSI 52100 steel ball and ANSI 52100 steel disk. Typical conditions used for evaluation consisted of a 1

mm path length, frequency of 20 Hz, applied load of 4 to 10 N, and temperatures ranging from 50-150°C.

Thin-film/EHD regime friction coefficient (TFFC): Evaluated using a PCS Instruments Mini-Traction Machine (MTM) with an ANSI 52100 steel ball and ANSI 52100 steel disk. Friction coefficients were measured at various temperatures (50-150°C) as oil was being pulled through the contact zone at entrainment speeds between 100 and 2000 mm/s. Applied loads ranged from 20-50 N and slide-to-roll ratios were 20-50%.

High temperature high shear viscosities (HTHS): Evaluated using a PCS Instruments USD Viscometer. Viscosities were measured at 50-150°C and a shear rate of 1×10^6 1/s.

Motored engine tests

A 2008 General Motors 3.6L V6 engine (LY7) was used as the test engine, the same engine platform currently used for the Sequence VID fuel economy test. The test engine was driven by way of a Siemens Three-phase electric motor with torque measurements determined using an HBM T10F Torque Meter. Typically, two test schemes were used to compare fluids. These consisted of a temperature ramp, in which the speed was held constant (usually 1000 or 2000 rpm) and the temperature was increased from about 20 to 120°C, and a speed sweep, in which the temperature was held constant and the speed was ramped from about 500 to 3000 rpm.

Standard fired engine tests

Sequence VID tests were performed by the standard test method ASTM D7589, "Standard Test Method for Measurement of Effects of Automotive Engine Oils on Fuel Economy of Passenger Cars and Light-Duty Trucks in Sequence VID Spark Ignition Engine". The method compares the fuel consumption of a candidate oil to a 20W-30 baseline oil using a set of six measurement stages. The candidate oil is aged in the engine for 100 hours with the 6-stage fuel consumption measurement being performed after 16 hours ("FEI 1") and 100 hours ("FEI 2") of aging. FEI 1 and FEI 2 fuel consumption measurements are compared to baseline values obtained before and after the candidate run.

Research fired engine tests

A 2008 General Motors 3.6L V6 engine (LY7) was used for these tests. This is the same engine platform used for the current Sequence VID fuel economy test. Tests were performed using a proprietary test method which measures fuel consumption continuously as oils are aged under conditions similar to those used in the Sequence VID method (2250 rpm, 120°C oil temperature)¹⁶.

Vehicle tests

Vehicle tests were performed on a specially modified Mileage Accumulation Dynamometer using a transient test cycle. Acquisition of real-time fuel consumption and ambient

data allowed for direct fuel economy calculations concurrent with oil aging¹⁸. The vehicles used for these tests varied and are described in subsequent sections.

INVESTIGATIVE APPROACH AND RESULTS

Approach

A significant element in understanding the response of the various fuel economy test methods to formulation approaches involved the application of a common test platform from which to build a correlation. Understanding that engine design may have a significant impact on formulation response, the authors chose to use of the same engine platform in various tests, thereby minimizing engine-specific variables. During the course of the research, engine oils of similar formulation style were tested by multiple methods in order to compare the formulation impact.

Formulation approaches were chosen in order to 1) compare the response of the tests to known fuel economy drivers, such as viscometrics and friction modifier content and 2) evaluate the impact of formulation style on aged oil fuel economy trends (limited to fired engine and vehicle tests). Ultimately, an attempt was made to correlate the response in motored and fired research engine tests to the response in Sequence VID and vehicle tests.

Test Oils

The engine oils used to evaluate test method correlation have been described in each section below. It should be noted that it was not always practical to use identical formulations in all of the tests, which resulted in instances where comparisons were made between oils of similar formulation style. This situation occurred because the tests were often performed as a subset of larger, self-contained experimental designs that may or may not have contained the exact same supplemental components as those of other designs. Formulations used for comparison, however, are considered to be similar enough to justifiably make direct comparisons.

Test Results and Discussion

Bench test data was primarily used to rapidly screen formulations for estimated fuel economy performance prior to scaling up to other test methods. Although past efforts have resulted in decent correlation equations that may be used to predict Sequence VID performance from bench test data, it can reasonably be assumed that any significant reduction in boundary and thin-film friction would result in improved fuel economy. For the purpose of this paper, the bench test data was included primarily for comparison to the performance observed in the other tests, and not for prediction of Sequence VID or real world performance.