Sound Evidence of Change in Engine Performance
Due to the Use of a Device or Fuel Additive

Andrew Campbell
Fuel Technology Limited
14 June 2005

1. Background

The observed fuel economy of engines and vehicles can be affected by a great number of variables. Many such variables are often overlooked when people or organizations test engine-related devices or fuel additives. As a result claimed performance improvement due to the use of a device or additive, based on the results of specific testing, may not in fact provide sound evidence of the performance claims being made.

The following is intended to provide guidance to those wishing to test engines or vehicles for fuel economy, in a manner which should provide sound evidence of any performance changes being achieved.

2. Engine Performance

Engine related processes are extremely complex and providing detail on what can affect fuel preparation, combustion and other engine-related operation is beyond the scope of a book, let alone a short guideline. However, a sample of the complexities involved, and their follow on affects, is provided by the following examples:

- The specification (i.e. the minimum requirements) of fuels in New Zealand change on a seasonal basis. As well, there are batch-to-batch differences in quality (i.e. the actual measured properties of the fuel as apposed to the minimum requirements to meet). There can be reasonable changes in fuel economy and exhaust emissions between the use of fuel from different batches.
- For diesel engines, in particular, the temperature of the fuel at the fuel metering pump has a significant affect on the maximum engine power developed. There are many factors that can affect diesel temperature including ambient air temperature, weather conditions, level of fuel in the main tank, return line volume and engine load in the previous twenty minutes or more. An increase in fuel temperature of the order of 5°C can provide a measurable decrease in engine power and lower exhaust temperatures. For vehicle operation, this can also lead to fuel economy improvements in certain circumstances.
- The engine coolant system regulates the temperature of the engine. Small changes in coolant temperature can exhibit measurable (engine specific) changes in emissions, power, exhaust temperature and fuel economy.
- Engines of same model may respond quite differently to the use of a device or fuel additive.
A significant change in engine performance can be realized through “conditioning” the engine. For example, a 50% reduction in a diesel vehicle’s “snap acceleration” test result (provides an indication of how opaque the exhaust is on a fast acceleration of the engine) was found for many city-based vehicles after they had been operated at load on the open road. Improvements in engine performance can also be found through increasing the utilization of a vehicle.

Standardized vehicle fuel economy tests are designed to minimize test-method related variations (allowing results from testing at one facility to be compared with results from testing at another facility). However, there can be reasonable differences in results obtained even when keeping to within standardized test guidelines. For example, the difference in fuel economy results between two different drivers over the “IM240” drive cycle (a drive cycle used in light vehicle dynamometer testing) can be 5%.

There is also evidence of a placebo effect where drivers, believing there is a device fitted to their vehicles, report improved performance. Further, trials overseas have shown the act of fuel monitoring itself has provided reductions in reported fuel consumption.

The implication to providing evidence that a device or additive does provide performance change is care is required to neutralize or at least take account of any variables that may reasonably be involved in the operation of an engine or vehicle.

Perhaps also to be considered is whether the resulting change brought about by a device or additive is a clear advantage or whether the effect can be provided by an alternative means. For example, a fuel heating device on a diesel engine may bring about lowered fuel consumption, in some circumstances (due to lower power and follow on potential affects), but at the cost of reduced peak engine power. It has to be then asked whether higher peak power more desirable. A similar effect could also be realized by changing the pump setting.

3. Evidence of Device or Additive Performance

Performance claims require sound proof of the claimed performance and links to the use of the device or additive. Sound proof infers results cannot be contested, including:

- Claimed improvements are measurable (also inferring the magnitude of improvements are greater than experimental error)
- Claimed improvements are not due to other possible (reasonable) reasons (inferring other variables associated with an engine’s or vehicle’s operation have been accounted for).

The options for providing evidence of device or additive performance include engine dynamometer testing, vehicle dynamometer testing and on-road vehicle testing.

Testing on an engine dynamometer allows many of the variables associated with on-road conditions and vehicle operation to be avoided. The test conditions can also be,
generally, more carefully controlled and monitored in an engine dynamometer environment. Testing in such a controlled environment would ideally result in the only difference in comparative “base-engine” verses “device or additive” tests being the inclusion of the device or additive.

Vehicle testing on a dynamometer provides the next best option in terms of control or accountability of variables. Standard procedures cover the likes of tyre type and their inflation, vehicle preconditioning and setting up the dynamometer for taken the vehicle’s mass and inertia into consideration.

Compared to results from dynamometer testing, the results from on-road testing are expected to be influenced by a far greater number of variables. Ideally all significant variables would be taken into consideration and multi-variate statistical analysis of on-road results would be required to identify the true relationship between the use of a device or additive and performance change. The combination of test and analysis methodologies would need to provide a result that is statistically significant. This is no mean task for on-road operations due to the number of variables involved, even for on-road trials that are tightly controlled.

4. Testing Standards

Ideally results from which performance claims are based would be obtained from testing according to an appropriate, internationally recognized test standard. Such standards include:

FTP 75, a transient test cycle used in the US for light vehicles
IM240, a shortened test cycle used in the US for light vehicles
FTP Transient, a transient engine test cycle used in the USA for certification of heavy vehicle engines
ECE+EUDC, in various forms, a transient test sequence used for emissions testing certification of light vehicle in Europe (including deriving fuel consumption results)
ECE R49, in various forms, an engine test sequence of 13 modes used for certification of heavy duty engines in Europe
ECT, a transient engine test cycle used for certification of heavy duty engines in Europe
10-15 Mode Cycle, a transient cycle used for certification in Japan
13-Mode Cycle, an engine test sequence of 13 modes used for certification of heavy duty engines in Japan
JP05, a transient engine test cycle used for certification of heavy duty engine in Japan.

This list is by no means complete as there are also the likes of road-condition simulation drive cycles developed in the USA and Australia (for example, the Business Arterial Commuter cycle used in the US) which can also be used to derive emissions and fuel economy results which would be suitable for performance claims when test results are used on a comparative basis.

At issue with testing to such cycles is the cost involved for some of the tests listed (Southwest Research Institute in the US asks around US$250,000 to take an engine through the R49 certification process) and, for New Zealand, there being few facilities
that can offer testing to these standards (and even then, such facilities only offering the more easily achieved standards).

For this reason the following is offered as a guideline for those people or organizations wishing to provide evidence, other than by way of results from testing to appropriate internationally recognized test standards.

5. Minimum Requirement Guidelines

As has been mentioned, sound proof is required for performance claims. The following provides a guideline of what measures would be expected to be taken in order to provide sound proof, in absence of providing results obtained from testing to appropriate internationally recognized testing standards.

This guideline has been based upon accounting for the reasonable, potential, variables that could describe the performance of an engine. The principle provided here is to maintain potential variables at constant value where this is possible and to report on and consider the affect where this is not possible.

Engine Dynamometer Testing

The minimum potential variables requiring consideration for engine dynamometer testing include:

- Engine arrangement – to be kept constant apart from the inclusion of the device or additive. Any other changes are required to be noted and considered in light of the performance claims being made
- Ambient conditions – ideally the ambient conditions are to be maintained throughout the test sequence. Realizing ambient conditions can change during a test sequence, ambient values need to be noted and any changes considered in light of the performance claims being made. As a minimum engine test cell temperature and pressure, engine inlet air temperature, pressure and humidity need to be considered
- Fuel temperature – fuel temperature at delivery to the diesel pump to be maintained constant, within +/- 1°C for engine power-related claims, or otherwise noted and compensated for
- Fuel specification – fuel from the same batch to be used for the comparative test sequence
- Coolant temperature – inlet coolant temperature to be maintained and inlet and outlet coolant temperature to be monitored. Any variations to be considered and accounted for
- Where claims are of more fundamental combustion or engine operation nature then the various pressures and temperatures through the engine’s air charge and exhaust system and cylinder pressure traces would require reporting, or other evidence provided to support the claimed performance
- Fuel metering – precision of the fuel metering system to be identified and claimed performance change to be greater than twice the precision of the fuel metering system
• Engine power – precision of the engine power and torque measurement to be provided and claimed performance change to be greater than twice the precision of the power/torque meter
• Basic engine operation variables such as engine speed and power relative to the engine’s torque curve require identification for claims relating to increased power or torque
• The engine requires suitable pre-conditioning before testing and all instruments and the engine require at least one-hour of warm up (or greater in the case of the instruments where recommended by the instrument supplier)
• A test sequence requires multiple tests that include at least one return to base-engine (no device or additive) mode and any performance variations in base-engine mode results accounted for.

It is noted this set of potential variables may not be complete for a specific arrangement being considered and monitoring of other variables would be required where a change in these other variables could bring about a measurable change in the performance result being considered.

Engine operation and the testing environment should also be kept within those conditions normally expected for the engine’s operation in a vehicle. Any variation from this requires notification and consideration in terms of performance claims being made.

**Vehicle Dynamometer Testing**

The minimum potential variables requiring consideration for vehicle dynamometer testing include:

• Vehicle test arrangement – to be kept constant apart from the inclusion of the device or additive. Any other changes are required to be noted and considered in light of the performance claims being made
• Ambient conditions – ideally the ambient conditions are to be maintained throughout the test sequence. Ambient values need to be noted and any changes considered in light of the performance claims being made. As a minimum dynamometer room temperature and pressure and humidity need to be considered
• Fuel specification – fuel from the same batch to be used for the comparative test sequence
• Fuel metering – precision of the fuel metering system to be identified and claimed performance change to be greater than twice the precision of the fuel metering system
• Engine power – precision of the engine power and torque measurement to be provided and claimed performance change to be greater than twice the precision of the power/torque meter
• Basic vehicle operating variables such as roller speed, engine gear used and power relative to the engine’s torque curve require identification for claims relating to increased power or torque
- The vehicle requires suitable pre-conditioning before testing including at least five minutes of full load operation. All instruments require at least one-hour of warm up (or greater as specified by the instrument supplier).
- A test sequence requires multiple tests of use with and without the device or additive, cycling between the base vehicle mode and the device or additive mode at least twice and any variations between base-vehicle arrangement mode or device/additive mode results, respectively, being accounted for.

**On-Road Vehicle Performance Trials**

Vehicle trials are extremely complex due to the number of variables involved. Performance claims derived from vehicle trials normally require careful identification of the conditions and arrangement of the trial in order to provide meaningful results and in an effort to avoid complex analysis. Methodology to provide sound conclusions would be required to consider:

- Vehicle numbers in the trial, numbers being sufficient to provide statistically significant conclusions (the number of vehicles involved increasing significantly with each known variable identified)
- Trial vehicles to include blind control vehicles (allowing seasonal variations, road conditions and driver variations to be considered)
- Fuel quality, in particular changes in quality during the trial period
- Fuel use measurement (including dispenser calibration, refueling procedures and recording of fuel usage, fuel pilferage)
- Road conditions including proportion of congestion, free-flow operation
- Routes, ensuring test and control vehicles operate the same routes
- Weather
- Vehicle/engine loading (including the use of ancillary loads, where appropriate)
- Vehicle maintenance including standardization
- Driver selection and management (including circulating through the trial vehicles)
- Vehicle original condition and performance
- Data quality and screening methods
- Quality of data analysis
- Post trial vehicle performance