Introduction of LVV Standard 90-10(00)
(Exhaust Gas Emissions)

The purpose of this LVV Information Sheet is to introduce to LVV Certifiers the new LVV Standard 190-10(00) (Exhaust Gas Emissions), and in particular explain the background behind the development of the standard, so as to enable the LVV Certifiers to gain a good understanding of the principles involved in the LVV exhaust gas emission testing regime, due to be implemented in June 1 2008.

To follow is a chronological account of how the process has evolved. The LVV Information Sheet is intended to summarise the thought processes and work undertaken during the development of this standard, which provides an insight into what the objectives of the process are, how it works, and what is involved in applying the process.

Introduction

In 2003, Land Transport New Zealand advised LVVTA of their intention to introduce air quality emission standards into the New Zealand vehicle fleet some time into the future, and requested that LVVTA develop an 'alternative' low volume vehicle standard, to be applied to those scratch-built and modified production low volume vehicles that may not be able to comply with main-stream emissions regimes aimed at the modern mass-produced vehicle fleet. LVVTA is not opposed to playing a part in improving air quality emissions within New Zealand's motor vehicle fleet, and agreed to take responsibility for dealing with low volume vehicles.

Work has progressed on this project since then, and as a result of the research undertaken and the work carried out on and off during the past 5 years, LVVTA now has the Low Volume Vehicle Standard 90-10(00) (Exhaust Gas Emissions) completed, and is ready for training of the LVV Certifiers, and implementation.

1 Objectives

1.1 LVVTA's development of an air quality emissions testing regime has aimed to capture the basic intent and spirit of improving air quality emissions in motor vehicle engines, but in such a way as to provide a testing regime that is achievable, practical, and cost-effective for one-off and small-volume builders and modifiers. The LVV regime recognises that, for various reasons, not all one-off and small-volume builders can incorporate the latest engine and induction system technology into their vehicles.

1.2 The low volume vehicle standard has been developed using analysis of recognised international standards, and by balancing the spirit and intent of those standards with cost-effective solutions to the real-world one-man environment that the LVV certifiers will be faced with.

1.3 The outcome is not a laboratory-type testing process (because of the costs associated with such testing regimes that mass-manufacturers can meet but clearly would be unachievable for one-off or small volume builders and modifiers), but is a process that gives a reasonable and reliable indication of a vehicle's exhaust emissions. Further, the process will do a very thorough job of identifying, and correcting or rejecting, excessive emitters, in a quantifiable, consistent, repeatable, legally defensible, and above all achievable and cost-effective way, giving everyone involved a reasonable degree of assurance that acceptable air quality emission levels are achieved before any low volume vehicle can be certified for entry into the vehicle fleet.

1.4 We are mindful that the requirements behind the application of any such testing regime should be balanced against the very small proportion of the vehicle fleet that low volume vehicles make up.

1.5 We believe that the key to the success of the other low volume vehicle standards already implemented, is by putting processes in place that are workable for the hobby car enthusiasts. By putting in place something that is workable, and is seen to be reasonable, we will earn the continued co-operation and support of the hobby car membership. Unreasonably harsh requirements, or an unreasonably expensive process, will have the effect of forcing people into working outside of the legal requirements that are in force.

1.6 Note that 2-stroke engines have not been included within the scope of this exercise, or the associated low volume vehicle standard. The incidence of 2-stroke engines amongst low volume vehicles is so low as to be virtually non-existent, whilst the problems associated with testing 2-stroke engines are significant, including potential damage to the equipment used during the test process.

Generally, 2-stroke engines are not subject to exhaust gas inspections via exhaust gas analysis in regulatory environments around the world. If the incidence of 2-stroke engines within the LVV environment in New Zealand ever changed significantly, LVVTA would review the situation at that time.

2 About hobbyist low volume vehicles

The nature of a low volume vehicle

2.1 By their very nature, hobbyist low volume vehicles are vehicles that are generally fastidiously maintained, both aesthetically and mechanically, and are usually performance-oriented to some degree, so it's a reasonable assumption that these vehicles are unlikely to be gross emitters to begin with.

2.2 Because of the show quality and performance nature of such vehicles, hobbyist low volume vehicles are generally not used for everyday transportation, therefore on a per-vehicle basis, contribute comparatively little to the emissions problem that our country faces.

2.3 Unlike many vehicles in the fleet used for commercial purposes or daily transportation, hobbyists' low volume vehicles are generally much-treasured possessions that get - so to speak - stored during the week, tuned on Saturday morning, polished on Saturday afternoon, and driven on Sunday – if the weather is fine.

Even then, they are not driven in high-density urban corridors; - in fact drivers of such vehicles avoid traffic congestion like the plague because their vehicles are grossly unsuited to this type of operation. Instead, they tend to enjoy the open rural roads en-route to the beach, a picnic, or a car club event.

Low volume vehicle numbers

2.4 Only 60,000 or so low volume vehicles have been certified in NZ since the first Low Volume Vehicle Code was developed in 1992. Less than .02% of that number are scratch-built low volume vehicles. This means that scratch-built low volume vehicles (sports cars, hot rods, kit cars etc) make up something in the order of .0007% of the total number of vehicles entering the national vehicle fleet annually.

2.5 Given the small number of low volume vehicles in the fleet, and the shorter distances that they travel per year than main-stream vehicles, the air quality emissions testing process for them should not be unreasonably difficult to achieve, nor costly.

Disproportionately problematic

2.6 Although small in number, low volume vehicles are disproportionately problematic due to the age of some of the engines used, the difficulty in applying an idle-based test because of the high amount of valve-overlap that many LVV engines have, the difficulty in fitting catalytic converters into old and small vehicles.

For this reason, it is very important that a testing regime is developed and introduced that meets the unique and varied needs of this small but problematic group of motor vehicles.

2.7 In order to ensure that an appropriate process is developed and introduced, the LVVTA is keen to take the initiative and self-regulate on air quality emissions, as we have done for every other facet of NZ’s legislative requirements over the past 15 years, to ensure that the outcome is cost-effective and achievable.

3 Initial research, 2003 and 2004

Loaded test, not idle-based

3.1 Many engines in low volume vehicles are performance-oriented, and feature (amongst other modifications) camshafts that incorporate a lot of valve-overlap at idle speeds. High valve over-lap often causes a lean situation, which in turn produces poor air quality emissions during the time that an engine is operating at idle speed.

3.2 There can be many reasons for valve-overlap causing a lean idle situation, including combustion chamber shape, and carburettor size and design. The high duration of the valve-overlap, an important element in improved performance characteristics at higher engine speeds, is none-the-less likely to allow exhaust gases to remain or re-enter the combustion chamber and thus lean out the incoming fuel mixture at low speeds and natural idle speeds.

Another cause of excessively lean emissions at idle is a lack of a strong enough vacuum signal to the carburettor to draw enough fuel for the engine to idle slowly and still draw in the correct amount of fuel.

Some engine combustion chamber designs are more prone to this situation than others, such as the semi-hemispherical shape of the Ford 'Cleveland' series, the full hemispherical design of some Chrysler engines (old and new), and many modern twin overhead camshaft 4-cylinder engines.

3.3 There is however no direct correlation between air quality emissions at idle, and at a higher RPM loaded test - a vehicle can emit good air quality at idle and poor air quality in a high-RPM loaded situation (what might be commonly applied during normal on-road driving), and conversely a vehicle that emits poor air quality at idle can emit good air quality in a high-RPM loaded test.

3.4 The test process that is aimed at vehicles which see very little idle-speed operation (ie. are not daily drivers in high-density urban corridors) should therefore not condemn an engine with high valve over-lap (and therefore poor emissions at idle), because it is quite possible that the engine will produce satisfactory emissions in its natural (higher-RPM running) environment.

3.5 Clearly, an idle-based test could be inappropriately prohibitive for a great number of performance-oriented low volume vehicles, and a more meaningful test process will be one that tests the exhaust emissions of a low volume vehicle as it is being physically operated on a road at normal cruise speeds, and on a road under load (acceleration).

Gas analysis equipment and processes

3.6 Having established that a loaded test was the direction that LVVTA needed to go in order to achieve the most meaningful reflection of actual on-road emissions, the initial thoughts for LVV air quality emissions testing involved either a two-gas or a four-gas analyser. However, the cost of the testing equipment is prohibitive for LVV – the cheapest four-gas analyser available is close to $6000. Further, for an LVV certifier to be able to carry out a proper higher-RPM loaded test using a conventional two-gas or four-gas analyser (which is a much more meaningful test), a rolling road is necessary, which obviously is even more cost prohibitive.

3.7 LVVTA had to be mindful during the development of the LVV Exhaust Gas Emissions Standard, that this is a system not for high-volume vehicle manufacturers or 3000 Warrant of Fitness issuers, but for less than 60 low volume vehicle certifiers spread throughout New Zealand to apply to one-off specials and a small number of modified production vehicles, on the basis of as little as one vehicle every two or three months in some cases. Some LVV Certifiers operate in isolated areas where no rolling road dynomometers exist. Therefore, while providing a robust sampling process which will reflect actual on-road conditions:

(a) gas analysing equipment has to be affordable for the LVV certifiers; and

(b) site requirements and procedural requirements for air quality emissions must be accessible enough and simple enough that a LVV certifier can access a site within a reasonable proximity, and can manage the process unaided without highly-specialised and expensive equipment; and

(c) the testing process for air quality emissions must be quick enough and simple enough so that the process is sustainable cost-wise for the vehicle owners.

The LVV emissions testing solution

3.8 An interesting correlation is that, generally speaking, when a motor vehicle is properly tuned for optimum performance, then the air quality emissions will also be optimised. We have established that in cruise-speed and lightly-loaded situations, if the oxygen emission content (O_2) is good – in other words the air/fuel ratio is optimised (close to 'stochiometric'), then it follows that the engine is burning its fuel as efficiently as possible, and in turn, harmful pollutants being emitted are minimised.

3.9 Engine tuning for this outcome is something that motor race engineers have been doing for many years in order to maximise a vehicle's on-track performance. By assessing the ratio of air and fuel that an engine is burning, and tuning the engine on-track under loaded conditions accordingly using an on-board O_2 sensor and display gauge, an optimum balance of air and fuel burning will be achieved, which in turn will result in optimised performance.

3.10 Research has shown that the main harmful pollutants are minimised if an engine's O2 emissions can be assessed, which an air/fuel ratio test process conducted in real-life on-road conditions, will achieve. In the most basic terms:

(a) Carbon Monoxide emissions are minimised if the engine is not running too rich; and

(b) Oxides of Nitrogen emissions are minimised if the engine is not running too lean; and

(c) Hydrocarbon emissions are minimised if the engine is running cleanly with no misfiring.

3.11 In modern catalytic converter-equipped production vehicles, the O2 sensor has the primary function of providing real-time feedback of exhaust emission conditions for the control of engine fuelling management. This sensor type has proven to be robust and reliable in providing this key information over many years of general application.

It is worth noting here that O2 testing is included in many other long-established test and inspection programmes around the world as a key indicator for Carbon Monoxide, Oxides of Nitrogen, and Hydrocarbon emissions.

3.12 The low volume vehicle standard has been based, therefore, on a simple and cost-effective solution, revolving around an air/fuel ratio test, carried out under actual loaded conditions at normal road speeds, via a dedicated O2 sensor. This assessment will do a very good job of establishing normal road-speed and loaded (under acceleration) air quality emissions.

3.13 The initial thoughts during the early phase of establishing LVVTA's air quality emissions testing process were that, in order to enable this test process to be carried out, every person constructing a scratch-built LVV, or carrying out an engine conversion (and therefore becoming subjected to this LVV standard), would be required by the technical regulations to incorporate within a specified part of the vehicle's exhaust system, a welded-in threaded socket capable of receiving a specific type of O2 sensor.

3.14 It was thought that this would enable the LVV certifier, at the time of LVV certification to connect a portable Lambda probe (O2 sensor) into the socket, run the wiring back into the vehicle to a gauge and power supply, and conduct an air/fuel ratio check whilst carrying out the vehicle's road-test (which is already required as part of the LVV certification inspection process).

3.15 This process would involve some cost to the vehicle owners to have the sockets welded in, and some additional time for the LVV Certifier, in that before carrying out the test, he would have to raise the vehicle on a hoist to connect the Lambda probe into the socket.

3.16 Details aside, this basic process would achieve the most real-world test (normal cruise-speed and loaded acceleration) and most closely reflect the sound and proven methods applied for exhaust gas sampling by vehicle manufacturers all around the world, without the cost of an expensive rolling road and four-gas analyser, and at the same time would overcome the problems associated with idle-testing high valve-overlap vehicles.

Catalytic converters in relation to low volume vehicles

3.17 Another subject that LVVTA wanted to understand was catalytic converters, as they would apply to a one-off or small-volume vehicle. LVVTA has met with people in California who are experts in both air quality emissions testing, and the diagnosis and repair of vehicles that fail the air quality emissions testing regime.

3.18 One of these people is a New Zealander who is a member of our Association, and who has been living and working in California for the past 21 years, and who has specialised in diagnostic work associated with air quality emission control systems for the past 12 years.

3.19 From our member's substantial experience in this industry; we know that:

(a) catalytic converters are now an effective way of reducing harmful air quality emissions from within New Zealand's low volume vehicles, now that our vehicle fleet is running on unleaded fuel, especially for electronically fuel-injected engines; and

(b) modern catalytic converters are much more efficient than those of 20 years ago; and

(c) despite this, the original catalytic converters fitted to a 20 year old vehicle with 200,000 kms on it, can, if the engine has been kept in a good state of tune throughout its life, still be in sufficiently good condition for the vehicle to still be capable of passing the stringent Californian 5-gas emissions testing, far exceeding the useful life originally predicted by vehicle manufacturers at the time; and

(d) the after-market industry is manufacturing performance and general purpose catalytic converters that work effectively, and the vehicles to which they are fitted are also capable of passing California's stringent 5-gas emissions testing.

Combination of gas analysis and catalytic converters

3.20 The fitment, or presence of, catalytic converters on their own without other measures being in place however, is of little consequence. If an engine runs too rich, the catalytic converters will be damaged to the point of being ineffective in burning off the harmful pollutants that they are designed to reduce. However, in this context, 'too rich' is indistinguishable without some form of gas analysis.

3.21 Successful air quality emission reduction will only be achieved, primarily through the use of a gas analyser and tuning, and secondarily, through the fitment of catalytic converters, where it is appropriate to fit them.

3.22 Having established that catalytic converters can form part of the solution, consideration has however had to be given to vehicles such as:

(a) motor-sport vehicles; and

(b) vehicles using very old engine technology; and

(c) very old-style and small vehicles with a floor-pan and chassis design that does not provide sufficient room to physically fit the required size and number of catalytic converters.

4 Ongoing development, 2005 and 2006

LVVTA-MoT meetings during 2005

4.1 Having established the basic principles of the LVV air quality emissions testing process during 2004, a discussion document outlining the above information (entitled Air Quality Testing for Low Volume Vehicles dated August 2005) was produced by LVVTA and presented to emissions experts Neil Allister and Lesley Emmett of the Ministry of Transport late in September of 2005. The discussion document outlined LVVTA's thought processes and plans at that point in time, for the way in which LVVTA proposed to base the low volume vehicle standard for air quality emissions. LVVTA was looking for views and guidance from the Ministry of Transport before proceeding further.

4.2 A number of meetings between LVVTA and the Ministry of Transport took place during 2005, which reviewed and considered the LVVTA August 2005 discussion document. Neil Allister and Lesley Emmett of the Ministry of Transport agreed in principle that the basic plan was sound, and offered some expert advice and opinions. On that basis, LVVTA continued into the development of the LVV air quality emissions testing process and standard, with the view to establishing the system in greater detail.

Equipment selection

4.3 After considerable research into the type of equipment that would be used, LVVTA decided upon a Lambdalink digital processor that controls an analogue gauge-face, and a narrow-band (heated) sensor, as the most suitable type of O2 measurement system available for this application (see section 6 for update on equipment information).

Electrical connections

4.4 Powering the system is very simple. Initially, for the Lambdalink gauge, two leads went to the vehicle battery, however the finished kit that the LVV Certifiers will use will incorporate an auxiliary 12-volt power source like a small gel-cell battery, which will sit with the gauge inside the vehicle. To power the sensor, four leads from the LambdaLink gauge are fed to the oxygen sensor.

The gauge

4.5 The 'LambdaLink' is a digital micro-controller based device, which indicates an engine's air-fuel ratio on an analogue gauge. It is compatible with a wide range of Lambda probes (oxygen sensors) ranging from narrow-band EGO sensors through to wide-band UEGO sensors. The gauge is not fixed, but is portable, and mounted (for the trials on a piece of timber) in such a way that it is self-supportive and remains in clear view of the tester during the test process. The gauge is shown in the photograph below.

LambdaLink gauge on temporary mount inside vehicle

Oxygen sensor

4.6 LVVTA's sensor of choice was the Bosch Semi-wide Band with heater. The heated sensor is required to heat the sensor above 300 degrees C, which is a requirement for correct operation, and also because there was a possibility that the sensor could be mounted in a tail-pipe installation kit which is situated at the end of the exhaust tail-pipe where the exhaust gases are much cooler. At the time of selection, LVVTA's thought's were still principally with attaching the sensor into a welded-in socket in the front pipe. A brief description of how an O2 sensor works is provided at the back (Appendix 1) of this LVV Information Sheet. Below is a photograph of an O2 sensor mounted into a threaded socket which has been welded into the front exhaust pipe.

Oxygen sensor installed into welded socket in front pipe

Initial testing

4.7 Initial testing went very well. In February of 2006 Kendall Bradley of LVVTA welded a socket for an additional oxygen sensor into the primary exhaust pipe in his 1992 (electronic fuel-injection-equipped) Toyota Scepter. This was positioned in close proximity to the factory oxygen sensor, which is fitted before the catalytic converter. Kendall then installed and ran the 'LambdaLink' system on his car.

4.8 Kendall operated the system in the car on a daily basis including to and from work for some time. The vehicle travelled approximately 70 km per day, on open road, motorway, and around town driving, proving to be very reliable.

4.9 On the open road, the gauge constantly displayed a reading of 14.6:1 at 100km on light throttle (cruise), this value indicating a close to optimum air/fuel ratio for the vehicle, known as 'stochiometric'. On passing or climbing a hill when the vehicle was under load the gauge displayed a reading of between 12.8:1 and 13.2:1 depending on the load and rate of acceleration required. These values indicated excellent fuelling control on the subject vehicle.

4.10 When decelerating, the gauge would not provide a reading because the fuel system would go so lean (when the exhaust gases contain so much oxygen which has not been used during the combustion process because fuelling is reduced to a very low level) that it was beyond the scope of the gauge's recording capability. This was caused by the Toyota's fuel injection system which cuts off fuel delivery when decelerating. The gauge reacted very quickly and clearly to varying throttle positions and engine loads.

4.11 A threaded socket was also welded into the 1500 cc 1994 Ford Laser of Doug St George, to see how the system performed on a carburetted vehicle as opposed to an EFI car. The results were very good on this car also; whilst (as expected) the air/fuel ratio figures weren't as close to the stochiometric ideal as the EFI Toyota, the test equipment responded well and the process worked without fault.

Further LVVTA-MoT meetings in 2006

4.12 A further meeting later in 2006 was held between LVVTA and Lesley Emmett and Neil Allister of the Ministry of Transport, for LVVTA to report back the details of the equipment selected, our findings from using the equipment, and to explain the further processes developed at that point.

4.13 Again, Lesley and Neil were agreeable and supportive in general terms, but both Lesley and Neil raised a number of questions and potential issues of a detail nature that they wanted LVVTA to investigate further.

4.14 During the process of addressing these questions, LVVTA has conducted a number of tests of vehicle exhaust emissions to gather real-world information in order to fine-tune our technical standard in such a way as to accurately test exhaust emissions in a manner that is closely-representative of how such vehicles are typically operated, that is both practically achievable and cost-effective.

4.15 Through Neil and Lesley's input, the original process specified by the standard has been improved in some areas, and interestingly, has in fact been simplified in some respects.

Accuracy testing of the Lambdalink system

4.16 Neil and Lesley suggested that we make comparisons between the results from the 'on-board' system such as that which we were proposing, and a fixed gas analyser and a rolling road dynamometer, in order to ensure that an on-board system was going to deliver reasonably accurate results.

4.17 In order to address this request, LVVTA staff-members Kendall Bradley, Doug St George, and Tony Johnson conducted some accuracy trials of the on-board LambdaLink digital gauge and Bosch oxygen sensor system fitted into the welded sockets in the front exhaust pipes in Kendall's and Doug's cars, against the fixed gas analyser and a rolling road dynamometer at Gary Capper Performance at 10 Crosbie Road in Pukekohe.

Gary Capper Performance has had considerable experience in performance dynomometer work on both road and race vehicles, and is considered an expert in his field.

4.18 Gary's dynamometer is a 'Dynamic Test Systems' brand machine, and his 4-gas analyser had recently been calibrated. Gary's analyser takes a reading from the tail-pipe. Below are the results recorded from these tests:

Vehicle: 1992 Toyota Scepter (Multi-point Fuel Injected 2200 cc IL4 engine)		
SPEED/LOAD	**LINK ON-BOARD GAUGE**	**DYNAMIC DYNOMOMETER**
100 kph cruise	14.4:1 - 14.5:1 (flickers)	14.7:1
80 kph slightly increased load	12.9:1 - 13.1:1 (flickers)	13.1:1
80 kph full throttle-power	12.7:1	12.8:1
90 kph cruise	14.6:1 - 14.8:1 (flickers)	14.9:1
100 kph cruise (2nd run)	14.7:1 - 14.9:1 (flickers)	14.9:1
Vehicle: 1994 Ford Laser (1500cc carburetted IL4 engine)		
SPEED/LOAD	**LINK ON-BOARD GAUGE**	**DYNAMIC DYNOMOMETER**
100 kph cruise	14.4:1 -14.5:1 (flickers)	14.6:1
95 kph cruise	14.5:1	14.9:1
80 kph full throttle-power	12.2:1	12.2:1
80 kph slightly increased load	12.6:1	12.6:1
100 kph cruise (2nd run)	14.5:1	14.7:1

Table 4.1 On-board gauge vs 4-gas analyser and dynamometer comparisons table

4.19 Throughout almost all of the comparisons, the biggest difference was .2 of a unit, which is considered negligible within the industry, and delivering results which are within the expected design performance characteristics of the much more complex and expensive 4-gas type analysers specified for in-service inspections in other parts of the world. Only in one instance (Ford Laser at 95 kph at cruise) was the difference greater, which was still less than one-half of a unit.

4.20 As shown in the table, the gauge's needle flickers almost constantly on the electronically fuel-injected engine when the oxygen sensor is installed into the front pipe, whereas Gary Capper's tail-pipe located sensor provided a steady reading. This is known as 'closed loop' operation. The result is a constant flip-flop back and forth from rich to lean (about twice a second), which allows the catalytic converter to operate at peak efficiency while keeping the average overall fuel mixture in proper balance to minimise emissions. Monitoring the output voltage while the system is running 'closed loop' will show a fluctuating signal voltage.

The fluctuations are actually showing the variations in mixture passing the sensor. When the engine is cold, or in power mode, the vehicle's engine management system controls fuelling by switching to a factory pre-set mixture setting, and a steady oxygen output signal can be seen.

4.21 As a result of this test process, LVVTA is satisfied that the LambdaLink gauge and Bosch sensor will provide results that closely reflect those that may be anticipated by applying a fixed 4-gas analyser and a rolling road dynamometer.

Comparisons between front pipe and tail-pipe

4.22 The next evolution of the test process came when MoT's Lesley Emmett suggested that it might be worth making comparative tests between the O2 sensor being inserted into the front pipe against testing from the tail-pipe. If negligible differences were to be found, taking tail-pipe readings as against requiring an adaptive socket to be welded into the front pipe in each vehicle tested would make the process quicker and easier for the LVV Certifier (reduce preparation time), and subsequent costs to the vehicle owner.

4.23 Interestingly, two of our LVV Certifiers who have had a lot of experience in race car tuning offered their view during our discussions on this subject at LVV Certifier training sessions in 2004, that the emissions recorded at the tail-pipe should be no different than those recorded at the front pipe. They were absolutely right.

The results of the comparisons are shown in the table below:

Vehicle: 92 Toyota Scepter (2200 cc IL4 engine)		
SPEED/LOAD	**SENSOR IN TAILPIPE**	**SENSOR IN FRONT PIPE**
Speed: Idle	15.2:1	14.6-14.8:1 flickers
Speed: 50 kph cruise	14.7:1	14.6-14.8:1 flickers
Speed: 70 kph cruise	14.7:1	14.6-14.8:1 flickers
Speed: 80 kph cruise	14.8:1	14.6-14.8:1 flickers
Speed: 100 kph cruise	14.8:1	14.6-14.8:1 flickers
Speed: 80 kph load	12.8:1	12.8:1

Table 4.2 Comparison between front pipe and tailpipe result table

4.24 It was clearly established that, apart from the idle test, no difference was found between the O2 levels emitted at the front pipe and the O2 levels emitted at the tail-pipe. We are not concerned at the difference recorded at idle, because idle–speed testing is of substantially less importance than simulated actual vehicle operation testing.

4.25 We also learnt during our testing that, at the tail-pipe, the fluctuations or flickering that an electronically fuel-injected engine gives when tested at the front pipe, disappear as the mixture averages itself out as it passes through the exhaust system. This actually creates an advantage in that it enables the tester to see the reading on the gauge much more easily when the reading is constant.

4.26 An additional benefit of tail-pipe testing is that the LVV Certifier does not need to get the vehicle onto a hoist so as to be able to install the oxygen sensor into the exhaust socket prior to conducting his testing, which saves time, and therefore reduces testing costs to the vehicle owner.

Tail-pipe installation kit

4.27 A 'Link' brand exhaust tail-pipe installation kit was purchased and trialled, and found to be most satisfactory on all tailpipe styles. This consists of a small length of 30 mm OD tubing with a sensor mounting-boss and a mounting-clamp welded to it, which is installed into the exhaust tail-pipe. The adapter is positioned inside the tail-pipe to ensure that only exhaust gases are passing through the sensor.

4.28 The sensor already in use is appropriate for this application because it is compatible with the Link tail-pipe installation kit, and it is a self-heating sensor which is necessary when testing so far back down the exhaust system.

4.29 The photograph below shows the new tail-pipe installation kit with sensor fitting, and the sensor temporarily screwed into place.

Tail-pipe adaptor kit mounted into exhaust tail-pipe

4.30 A wiring harness was made up to power the sensor, which feeds from the power supply and gauge mounted temporarily inside the vehicle, back to the sensor. These leads can be taped to the vehicle windows between the tail-pipe and where they feed through the side window, to prevent them from 'flapping' and causing paint damage during the test.

4.31 The whole process of preparing the vehicle for the test, when using the tail-pipe based sensor, takes less than five minutes.

Ambient air back-wash testing

4.32 Lesley Emmett wanted us to look into, and establish, the effects of ambient air back-wash up the tail-pipe during testing. We compared the readings that we obtained when the LambdaLink system was fitted to the Toyota Scepter and driven on the road, against the readings obtained on the rolling road dynomometer. These readings were identical.

4.33 It would seem, therefore, that air-flow around the tail-pipe whilst the vehicle is in motion has no effect on the oxygen emissions reading at the tail-pipe.

Depth of oxygen sensor insertion into tail-pipe

4.34 Lesley also asked us to look into and establish what effect might be had by varying the depth by which the oxygen sensor is inserted into the tail-pipe, from the tail-pipe outlet. We experimented with the length of pipe protruding out the rear of the tail-pipe (behind where the sensor was positioned) on a rolling road. No changes to the readings whatsoever could be identified.

4.35 We also experimented, upon Lesley's request, with the length of pipe protruding out the rear of the tail-pipe (behind where the sensor was positioned) on the road, on the Toyota Scepter, at various road speeds. We altered the position of the oxygen sensor in relation to the exit point of the exhaust by approximately 400 mm, and compared the readings.

Again, the readings recorded were identical except for the idle reading, as shown in the following table.

Vehicle: 1992 Toyota Scepter		
SPEED/LOAD	**STANDARD INSTALLATION KIT**	**400 mm EXTENSION**
Idle	15.2:1	15.4:1
50 kph cruise	14.7:1	14.7:1
70 kph cruise	14.7:1	14.7:1
80 kph cruise	14.8:1	14.8:1
100 kph cruise	14.8:1	14.8:1

Table 4.3 Emission testing results comparing standard installation kit and extension

4.36 LVVTA concludes from the various outcomes of the tail-pipe testing, that there is no benefit gained by imposing the added cost and inconvenience of having vehicle owners weld in an oxygen sensor socket into their front pipes. We are confident that the testing can all be conducted in a convenient and most satisfactory manner, with accurate and repeatable results, from the tail-pipe.

5 Further sampling, 2007:

Further modified and scratch-built vehicle testing

5.1 Having fairly well established the process by the end of 2006, some time was spent during the first half of 2007 testing a wide cross-section of modified and scratch-built vehicles to:

(a) give the equipment some 'mileage'; and

(b) refine the testing process; and

(c) assist in the development of the procedural requirements of the low volume vehicle standard; and

(d) understand what sort of air quality emissions various engine types produce in order to establish where the system's pass/fail parameters should be set.

5.2 To follow is a table that details the vehicle types tested, and the results found.

Vehicle	***Engine***	***Carb/FI***	***Std?***	***Exhaust***	***Idle***	***Cruise 100 kph***	***Load 60-100 kph***
1960 Ford Starliner	352 cu in V8 OHV	1 x 4 bbl	Std	Twin		12.8:1	11.7:1
1928 Ford Model-A Pickup	200 cu in 4cyl, S/V	1 x carb	Mod	Single		12.9:1	11.6:1
1992 Toyota Scepter	2.2 L OHC	EFI	Std	Single		14.7:1	13.0:1
1989 Toyota Corolla	1.3 L OHC	1 x carb	Std	Std		14.8:1	13.0:1
1966 Ford Fairlane	302 cu in V8 OHV	1 x carb	Mod	Twin		12.8:1	11.5:1
2004 Holden Ute	5.7 L V8 OHV	EFI	Mod	Two into one		14.8:1	12.6:1
1988 Ford Fairmont	6 L V8 OHV	1 x carb	Mod	Two into one		14.0:1	12.8:1
1991 Ford Fairmont	302 cu in V8 OHV	EFI	Std	Std		14.8:1	12.7:1
1989 Mitsubishi L200 ute	2.6 L OHC	1 x carb	Std	Std		14.0:1	13.0:1

Table 5.1 Preliminary emission testing results table, early 2007

5.3 It is perfectly reasonable for the figures to show low oxygen (rich) in the loaded mode, because additional fuel has to be delivered in order to move a vehicle's mass up to cruise, or up a hill.

5.4 From the results recorded to that point, it seemed that vehicles with fuel-injected systems monitored by electronic control units give very stable exhaust emissions at road speeds of 80 to 100 kph. Results at cruise (light throttle) are generally between 14.0:1 and 15.0:1. The perfect air and fuel mixture for power and economy (stochiometric) is 14.7:1, which is right within the operating range of all modern well-tuned vehicles that we tested.

5.5 Carburettor mixture settings will always be a compromise between economy and power, however our feeling was at the time that in most of the cases in the table above (with the possible exception of the 1928 Model-A Ford engine), tuning could bring about much-improved emission levels.

5.6 We set out next to target more vehicles using older engines, and in particular those using one or more carburettors as opposed to electronic fuel-injection. These vehicles are shown in the tables below.

Vehicle	*Engine*	*Carb/FI*	*Std?*	*Exhaust*	*Idle*	*Cruise 100 kph*	*Load 60-100 kph*
SB 1932 Ford Coupe	302 W OHV V8	1 x carb	Std	Twin	Wild fluctuation	14.7:1	12.5:1
SB 1929 Ford Rdstr	327 Chev OHV V8	Super-charged	Mod	Twin	17.0:1	17.0:1	17.0:1
1929 Model-A Tudor Black	350 Chev	1 x 4 bbl	Std	Twin	17.0:1	Wild fluctuation	17.0:1
1957 Chev Red 4-door	283 Chev OHV V8	1 x 2 bbl	Std	Twin	14.2:1	13.5:1	13.0:1
1930 Model-A Ford Tudor	289 Ford OHV V8	1 x 4 bbl	Std	Twin	17.0:1	14.0:1	Wild fluctuation
SB 1940 Willys Coupe	512 Ford OHV V8	Tunnel-ram 2 x 4 bbl	Mod	Twin	17.0:1	14.0:1	Wild fluctuation
1959 Ford Retractable	390 Ford OHV V8	1 x 4 bbl	Std	Twin	15.0:1	15.5:1	12.0:1
1953 Cadillac Coupe	331 OHV	1 x carb	Std	Twin	17.0:1	16.0:1	12.5:1
1957 Buick Coupe	350 Chev late model	TPI	Std	Twin	17.0:1	17.0:1	17.0:1
SB 1923 T	355 Chev OHV V8	Tunnel-ram 2 x 4 bbl	Mod	Twin side pipes	17.0:1	13.5	Wild fluctuation
1956 Cadillac Silver	365 Caddy OHV V8	1 x 4 bbl	Std	Twin	15.0:1	13.0	12.5:1
1940 Ford Pick-up	350 Chev OHV V8	Super-charged	Mod	Twin	17.0:1	14.5:1	13.5:1
1947 Ford Coupe	350 Chev OHV V8	1 x 4 bbl	Std	Twin	17.0:1	13.5:1	14.0:1
SB 1927 T-Roadster	307 Chev OHV V8	3 x 2 bbl	Mod	Twin side pipes	17.0:1	17.0:1	14.5:1
1960 Dodge Pioneer	313 Dodge OHV V8	1 x 2 bbl old engine	Std	Twin	12.5:1	14.0:1	12.5:1
SB 1932 Ford Coupe	355 Chev OHV V8	Super-charged	Mod	Twin	14.7:1	12.8:1	13.0:1
1969 Dodge Superbee	383 Dodge OHV V8	1 x 4 bbl	Mod	Twin	17.0:1	12.8:1	12.0:1
Model-A Ford Pick-up	Ford sidevalve	1 x carb	Std	Twin system	12.0:1	12.5:1	12.0:1
1934 Ford Pick-up	Chrysler 291 Hemi	4 x carb	Std	Zoomies	17.0:1	17.0:1	17.0:1

Table 5.2 Emission testing results table, various vehicles July & August 2007

5.7 Most noticeable is the very poor emissions shown at idle-speeds, which support our initial concerns that, because of the valve-overlap issue, idle-based testing is inappropriate for this type of vehicle. Also noticeable is that many of the vehicles that exhibit poor idle emissions 'clean up' well at cruise speeds.

5.8 It would appear that idle emissions depend on many variables including engine temperature, type of fuel delivery, state of tune of the engine, and effects from modifications. However, with the real-life simulation testing at normal operating speeds, variations and poor outcomes at idle speed is of no real significance, given the intended purpose and mileage travelled of low volume vehicles.

5.9 We believe that the 'wild fluctuations' observed during a small number of the tests are most likely to be as a result of problems with the vehicles' power valves (located in the main metering body in the carburettor) being affected by manifold vacuum. The manifold vacuum acting on the diaphragm at idle or normal load conditions is strong enough to hold the diaphragm closed and overcome the tension of the power valve spring. When high power demands place a greater load on the engine, and manifold vacuum drops below a pre-determined point, the power valve spring overcomes the reduced vacuum, opening the power valve.

5.10 When the power valve is damaged, it may stay completely open and allow fuel to discharge into the carburettor venturis all the time, creating a rich mixture, or if only slightly damaged (very small hole in the diaphragm or worn or broken spring) the engine vacuum may hold it partially closed most of the time, and the power valve spring may overcome this vacuum some of the time - this would cause the fluctuations in the tail-pipe readings, because the engine is fluctuating between rich and lean mixtures.

Setting pass/fail parameters for the LVV standard

5.11 From this testing process, we developed a set of pass/fail parameters in the low volume vehicle standard that we believe to be sensible and reasonable, in terms of meeting the basic spirit and intent of what the Land Transport Emissions Rule is setting out to achieve, whilst taking into consideration the number and the nature of the vehicles for which the low volume vehicle standard has been developed.

5.12 Almost half of the modified and scratch-built vehicles tested failed against our established parameters either on cruise-mode, acceleration-mode, or in some cases, both.

5.13 The final challenge for us was to focus on a few test-case carburetted vehicles with particularly old engines (such as the 1928 Model-A Ford engine recorded in the 'preliminary test early 2007' table), and see if they could be readily tuned back to a condition that could pass within our pass/fail parameters.

5.14 For this exercise, we chose mildly modified vehicles from the late 1920s and early 1930s, which 'failed' earlier testing. We re-tested them, established that they still 'failed', and then set about tuning them via adjustments to their carburettors' idle circuits and fuel metering systems.

The result of this exercise is shown in the table below.

Vehicle	***Engine***	***Carb/FI***	***Std?***	***Exhaust***	***Idle***	***Cruise 100 kph***	***Load 60-100 kph***
1932 Ford Tudor	OE Ford sidevalve	2 x carb	Std	Single system	17.0:1	12.5:1	11.5:1
▪ wound out jets .75 turn to improve idle emissions:					14.7:1	14.5:1	12.5:1
▪ changed jets from 38s down to 35s to improve cruise and load:							
1930 Ford A Roadster	Ford sidevalve	2 x carb (1 working)	Std	Twin system	13.0:1	17.0:1	17.0:1
▪ changed jets from 48s up to 51s to improve cruise and load:					13.0:1	17.0:1	14.0:1
▪ changed jets from 51s up to 57s to improve cruise and load:					12.0:1	14.0:1	12.5:1

Table 5.3 Tuning for emission compliance results table, September 2007

5.15 As can be seen from Table 5.3 above, the improvements came about quite easily, and were very dramatic. The 1932 Ford in particular, went from massively lean at idle and too rich under load to almost perfect through simple fuel system tuning.

5.16 As a result of the outcomes to the vehicles recorded in the above table, along with others that we have played with but never recorded, we are confident that all of the vehicles in Tables 5.1 and 5.2 that recorded a 'fail' against our parameters are capable of achieving a 'pass', given some attention to tuning. This statement does not include the 1957 Buick Coupe with the tuned-port injected engine, which clearly has a major set-up problem, and is likely to have had one of its crucial sensors disconnected or omitted during the engine installation.

6 Late change in equipment

6.1 A final twist occurred during meetings late in 2007 and early 2008, when the Ministry of Transport were going through the final approval process of the LVV Standard for Exhaust Gas Emissions. The MOT representatives involved were pleased with the standard, and the processes behind it, but expressed a strong desire to see us being able to test diesel vehicles if we could find the equipment to do it. At the time of our original equipment research in 2004, there was nothing that we were aware of that had the ability to successfully measure the 0_2 output of diesel engines.

6.2 Further research into similar equipment during early 2008 showed up the 'Innovate' brand's 'LM1' unit as being able to test diesel engines (using a 'wide-band' oxygen sensor), and with other features that the Lambdalink system didn't have, the LM1 appeared to be an excellent piece of equipment in more ways than just dealing with the diesel issue. The LM1 is much more modern, with greater capabilities than previous equipment, yet is still easy to use.

6.3 A new LM2 unit is scheduled for production sometime in 2008, but because no firm date by which time the LM2 would become available was available from Innovate, and with our time constraints with the implementation of the testing regime, the decision was made to go with the LM1. A picture of the Innovate LM1 unit is shown below.

Innovate LM1 gas analyser

7 Conclusions

7.1 In general terms, LVVTA is now at a point where we have confidence that the processes and technical requirements contained in the low volume vehicle standard for air quality emission systems will work very well. We are satisfied that:

(a) the Innovate LM1 gas analyser, wide-band oxygen sensor, and tail-pipe installation kit will provide an accurate method for measuring vehicle exhaust emissions on low volume vehicles, for all parts of New Zealand no matter how geographically isolated; and

(b) the outcome of the application of this process will, in every case, result in a motor vehicle that emits a satisfactory level of air quality, taking into consideration the number and nature of low volume vehicles; and

(c) after training (scheduled for April/May 2008), and aided by the use of Low Volume Vehicle Standard 190-10(00) (Exhaust Gas Emissions) together with an associated LVV Form-set, the process can be applied in a consistent and repeatable manner by the existing network of LVV Certifiers; and

(d) the cost to owners of modified and scratch-built low volume vehicles for the application of the process will be reasonable (estimated to be well under $100).

Finally:

Considerable time will be devoted to this subject at the next LVV Certifier training sessions in April/May 2008, and the details of the testing process, and content of the LVV Standard itself, will be discussed further then.

If you have any queries or require any further clarification relating to this Information Sheet, please feel free to contact the technical team in the Wellington LVVTA office on (04) 238-4343.

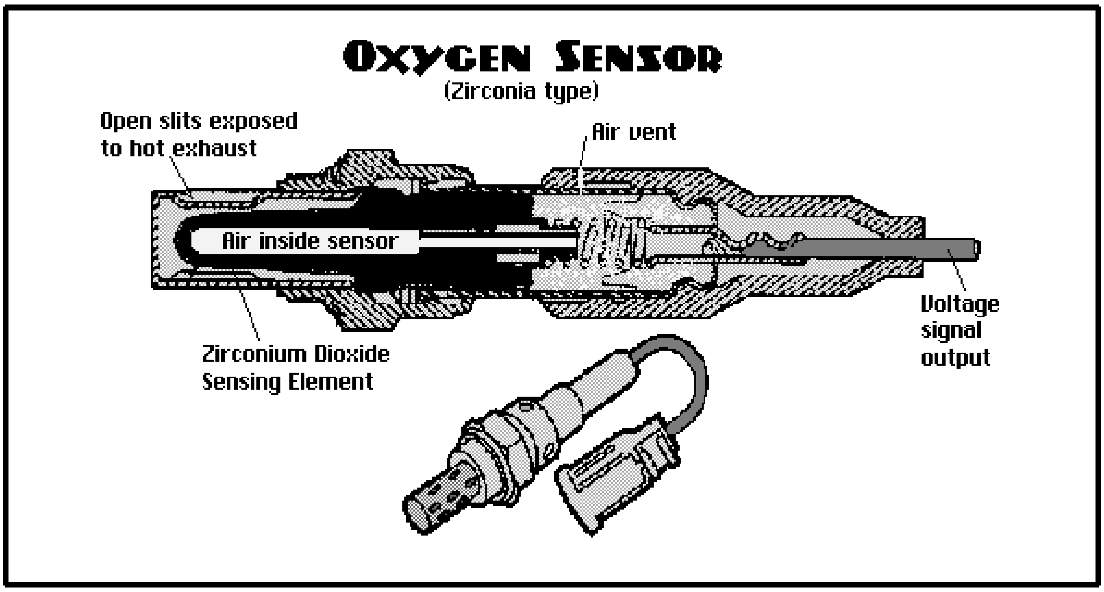
Appendix 1 - Explanation of how a Lambda probe or O_2 sensor works

The O_2 sensor monitors how much unburned oxygen is in the exhaust as the exhaust exits the engine. Monitoring oxygen levels in the exhaust is a way of establishing the fuel mixture. The O_2 sensor tells the computer if the fuel mixture is burning rich (less oxygen) or lean (more oxygen).

The O_2 sensor works like a miniature generator and produces its own voltage when it gets hot. Inside the vented cover on the end of the sensor that faces the exhaust gases is a zirconium ceramic bulb. The bulb is coated on the outside with a porous layer of platinum. Inside the bulb are two strips of platinum that serve as electrodes or contacts. The outside of the bulb is exposed to the hot gases in the exhaust while the inside of the bulb is vented internally through the sensor body to the outside atmosphere. The difference in oxygen levels between the exhaust gasses and the outside air within the sensor causes voltage to flow through the ceramic bulb. The greater the difference in oxygen levels, the higher that the voltage reading will be.

An oxygen sensor will typically generate up to about 0.9 volts when the fuel mixture is rich and there is little unburned oxygen in the exhaust. When the mixture is lean, the sensor's output voltage will drop down to about 0.1 volts. When the air/fuel mixture is balanced or at the equilibrium point of about 14.7 to 1 – known as 'stochiometric' (perfect) - the sensor will read around .45 volts.

Manufacturers install their O_2 sensors at the exhaust manifold, ahead of the catalytic converter. Some modern cars have as many as 4 sensors. A cut-away diagram of an O_2 sensor is shown below.



Cut-away diagram of an oxygen sensor