HYBRID TECHNOLOGIES
ELECTRIC VEHICLE
CONVERSION

TEST PLAN

PREPARED BY eTV
March 2008
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1.0 Definitions

**A-Weighting Scale (dBA)**
Decibels with the sound pressure scale adjusted to conform to the frequency response of the human ear. A sound level meter that measures A-weighted decibels has an electrical circuit that allows the meter to have the same sound sensitivity at different frequencies as the average human ear. There are also B-weighted and C-weighted scales, but the A-weighted scale is the one most commonly used for measuring noise.

**Ambient Temperature**
It is the temperature of the air surrounding an object.

**Anti-Lock Braking System (ABS)**
An anti-lock braking system is a safety system that prevents a vehicle’s wheels from locking up during heavy braking. Essentially, the ABS regulates the braking pressure on the wheel, allowing it to continuously have traction on the driving surface.

**Barometric Pressure**
Barometric pressure is the pressure (force over area) exerted by a column of air above a fixed point, expressed in kilopascals (kPa).

**Battery-to-Wheel Energy Consumption (Electric Vehicles)**
The DC energy used in a battery to propel the vehicle forward, measured in kWh/100 km.

**Battery-to-Wheel Fuel Consumption (Electric Vehicles)**
The Battery-to-Wheel Energy Consumption divided by the energy density of gasoline in L/100 km.

**Burnout**
Burnout results from an incorrect method of warming up the tires of a vehicle, normally by pressing the accelerator pedal and applying the emergency brakes of a vehicle at the same time.

**Criteria Air Contaminants (CAC)**
A group of pollutants that includes sulphur oxides (SO₂), nitrogen oxides (NOₓ), particulate matter (PM), volatile organic compounds (VOC), carbon monoxide (CO) and ammonia (NH₃).

**Data Acquisition System (DAS)**
A device designed to measure and log parameters over a given time period, either continually or continuously.

**Drive Train**
The components of an automotive vehicle that connect the transmission with the driving axles, including the universal joint and drive shaft.

**Electric Governor**
It is a device that electronically regulates the amount of fuel injected by a fuel injection pump.

**Electrical Consumption**
It is the AC or DC electricity consumed by a vehicle, measured in kilowatt-hours per 100 kilometres (kWh/100 km).

**Energy Density**
The amount of energy stored in a fuel, measured in megajoules per litre (MJ/L).
Fuel Consumption (or Tank-to-Wheel Fuel Consumption)
The amount of fuel consumed per unit of distance. The accepted unit of fuel consumption in Canada is litres per one hundred kilometres (L/100 km).

Fuel-to-Wheel Fuel Consumption
The Tank-to-Wheel fuel consumption of the vehicle, corrected for production, refining and transmission efficiencies, calculated in L/100km.

Gs (or G-Force)
The G-Force is a measurement of acceleration in relation to free fall. For example, an acceleration of 1 G is equal to the acceleration due to standard gravity (9.81 metres per second squared – 9.81m/s²).

Greenhouse Gas (GHG) Emissions
Gases in the environment that absorb and emit radiation. Common GHG emissions include water vapour (H₂O), carbon dioxide (CO₂), methane (NH₄), nitrous oxide (NOₓ), ozone (O₃) and chlorofluorocarbons (CFC).

Lateral Acceleration
Lateral acceleration is the component of acceleration during cornering that forces a vehicle towards the inside of a turn. Essentially, the lateral acceleration is equal to the centrifugal acceleration (outward force) needed to maintain a steady turn.

National Institute of Standards and Technology (NIST)
A measurement standards laboratory with a mission to promote innovation and industrial competitiveness by advancing measurement science, standards and technology in ways that enhance economic security and improve quality of life.

Tank-To-Wheel Fuel Consumption (or Fuel Consumption)
It is the fuel consumed by the vehicle per unit of distance, measured in L/100 km.

Traction
Adhesive friction. Traction is the element of vehicle dynamics that gives speed and directional control to the driver.

Transient Response
Transient response is the vehicle's ability to recover from one corner and set up for the next corner (see Slalom Test).

Tread Depth
The distance measured in the major tread groove nearest to the centre line of the tire, from the base of the groove to the top of the tread.
2.0 Introduction

Electrification of transportation is an exciting and innovative area. Only three years ago, market projections for the commercialization of electric vehicles (EVs) were for a 10-to-15-year timeframe. While there are currently few CMVSS-certified electric vehicles on the road in Canada, their introduction is now imminent. Many manufacturers are exploring the possibility of introducing electric vehicles in Canada within the next two to three years. The eTV program has been active in encouraging the introduction of electric vehicles in Canada through partnerships with industry, manufacturers, utilities and government.

Despite imminent market plans for EVs, little systematic laboratory emissions and dynamic performance testing has been conducted on them in Canada, perhaps because very few EVs (either production or prototype models) have been available for evaluation. Hybrid Technologies Inc., located in Mooresville, North Carolina, had successfully converted a vehicle from gasoline to fully electric by replacing the internal combustion engine with an electric motor and adding lithium-ion batteries and their proprietary battery management system (BMS). In order to provide information to help address barriers facing EVs, the eTV program commissioned Hybrid Technologies to convert a vehicle, using its patented system. The converted vehicle will provide an opportunity for eTV to begin testing and evaluating BEVs at an early state of commercialization and to develop baseline performance levels for battery technologies early on in the program’s lifecycle. eTV will evaluate the viability of a fully electric mode of transportation, to assess its potential to help Canadians reduce their fuel consumption and greenhouse gas emissions.

Vehicles that are 100% electric are different from conventional gasoline or diesel vehicles in that their energy typically comes from being charged for a few hours from a standard 110 V or 220 V electrical outlet. The batteries provide the electric motor with the energy needed to propel the vehicle.

The 2006 Daimler-Chrysler PT Cruiser, the base vehicle in which the Hybrid Technologies Electric Conversion was installed, is a front-wheel drive, five-passenger vehicle. The PT Cruiser is in the special purpose or SUV class and is therefore considered a light-duty truck with regard to Canadian Company Average Fuel Consumption (CAFC) and U.S. Corporate Average Fuel Economy (CAFE) standards. The vehicle is also equipped with regenerative braking that captures, stores and reuses the kinetic energy as the vehicle slows or brakes. A single-speed reduction has been added as an overdrive to help drivers accelerate more quickly—mostly because it is not common to have a gearbox that can handle the higher torque characteristics of electric motors. Essentially, the vehicle’s wheels are being driven directly by the motor at all times. This results in favourable torque (acceleration) through all ranges of speeds.

The specifications for the battery pack and the vehicle, provided by Hybrid Technologies, are set out below.

<table>
<thead>
<tr>
<th>Battery Pack</th>
<th>Vehicle Fuel Efficiency and Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>250 kg</td>
</tr>
<tr>
<td>Type</td>
<td>Kokam lithium-ion</td>
</tr>
<tr>
<td>Voltage</td>
<td>315 V</td>
</tr>
<tr>
<td>Capacity</td>
<td>~28 kWh</td>
</tr>
<tr>
<td>Usable Capacity</td>
<td>~25 kWh</td>
</tr>
<tr>
<td>Cycle Life</td>
<td>1,500 full charges</td>
</tr>
<tr>
<td>Charging Time</td>
<td>6-8 hours (220 V / 15 A)</td>
</tr>
<tr>
<td>Fuel / Energy Type</td>
<td>Electricity</td>
</tr>
<tr>
<td>Electrical Efficiency*</td>
<td>13.2 kWh/100 km</td>
</tr>
<tr>
<td>Driving Range</td>
<td>190 km</td>
</tr>
<tr>
<td>All Electric Top Speed</td>
<td>125 km/h</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>Electric Only</td>
</tr>
<tr>
<td></td>
<td>OEM Vehicle ~211 g/km</td>
</tr>
<tr>
<td>Operational Temperature Range</td>
<td>-20°C – 45°C</td>
</tr>
</tbody>
</table>

*Combined efficiency claimed on a full battery stat- of-charge

Table 1: Specifications for the Hybrid Technologies EV

The batteries consist of 10 Kokam maintenance-free lithium-ion packs, each comprising eight 100Ah cells in series. The high energy density of the packs gives the vehicle a very favourable range. The packs can be recharged with regenerative braking. The vehicle is also equipped with an LCD touch screen that serves as a vehicle operations
monitor. At the touch of the screen, the driver can access information on the mileage remaining, power consumption, individual cell state-of-charge, battery temperature, drive time, distance travelled and average speed.

Various aspects of the performance of the vehicle will be evaluated, as well as the effects of cold climate conditions on performance.

3.0 Pre-Test Verification Procedure

The Hybrid Technologies Converted PT Cruiser arrived at Transport Canada’s Ottawa Headquarters in the summer 2007. Upon arrival, individuals within the Vehicle Programs thoroughly inspected the vehicle. While various deficiencies were noted, no operational deficiencies were reported. Thus the vehicle was licensed for use on Canadian roads.

4.0 Methodology

The Hybrid Technologies Converted PT Cruiser, herein referred to as the “test vehicle”, will undergo the following three phases of testing and evaluation:

- Phase 1: Laboratory Electrical Consumption and Emissions Testing
- Phase 2: Dynamic Performance Testing
- Phase 3: On-road Evaluations

4.1 Phase 1: Laboratory Electrical Consumption and Emissions Testing

The test vehicle will complete mileage accumulation prior to laboratory testing at Environment Canada. A minimum of 3,500 kilometres will need to be accumulated before any of the following testing cycles can be conducted on a dynamometer. Mileage accumulation will occur on a pre-determined test route similar to the one used by Transport Canada’s Fuel Consumption Program (FCP) drivers. For details, please refer to Emissions Research and Measurement Division (ERMD) Report #06-09: Mileage Accumulation Route.

Additionally, during the mileage accumulation phase, electrical consumption will be measured from the vehicle either by installed electric clamps measuring amperage, voltage, and time, or by recording the amount of electricity consumed by using a kW/h meter on the dedicated plug for charging the vehicle.

Tests for both emissions and energy consumption will be performed and analyzed by Environment Canada personnel from the Emissions Research and Measurement Division (ERMD) of the Environmental Science and Technology Centre located in Ottawa, Ontario. This facility is Canada’s national vehicle emissions and fuel consumption testing laboratory. Apart from testing fuel consumption and emissions against Canadian and U.S. standards, ERMD is also involved in joint research efforts with other government departments and private industry. Selected cycles will be followed as accurately as possible. The driver of the vehicle will attempt to achieve the maximum and minimum speeds during each driving cycle.

The vehicle will then be returned to Transport Canada, where weekly exercising will resume until favourable weather makes dynamic performance testing possible. Section 5.0 outlines the duty cycles over which the testing will be performed, as well as the pollutants and emissions that will be measured and analyzed.

4.2 Phase 2: Dynamic Performance Testing

Dynamic performance tests will be performed at the Transport Canada testing facility located in Blainville, Québec. The facility has been operated by PMG Technologies for more than 15 years. PMG performs testing for the Road
Safety group of Transport Canada as well as for individual manufacturers or groups that wish to avail themselves of the lab’s facilities. PMG will perform all controlled track tests for the test vehicle, as outlined in Section 6.0

![Figure 1: Test Centre Track, Location Blainville, Québec](image)

4.3 Phase 3: On-road Driver Evaluations

A third phase of evaluations will be performed by having drivers/evaluators drive the test vehicle for a distance of 30 to 100 kilometres and fill out a questionnaire/evaluation form. These results will then be compiled in order to help identify any issues or abnormalities that are consistent among respondents. It is anticipated that between 20 and 30 responses will be collected for this test vehicle.

The results of all three phases of testing will be compiled into a final report that will be circulated to project partners. Additionally, some data and results will be disseminated on the eTV website, to highlight various performance characteristics.

5.0 Laboratory Electrical Consumption and Emissions Testing

eTV’s objective in performing these tests is to evaluate the vehicle’s ability to reduce fuel consumption, greenhouse gas (GHG) emissions, criteria air contaminants (CAC) or other evaporative emissions, according to standardized testing cycles. These cycles will be taken from the U.S. Environmental Protection Agency’s *Code of Federal Regulations* (CFR).

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Testing Standard</th>
<th># Cycles</th>
<th>Temperature</th>
<th>Fuel</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Driving</td>
<td>US FTP-72 (LA4)</td>
<td>5</td>
<td>STP</td>
<td>Electricity</td>
<td>ERMD (Ottawa, ON)</td>
</tr>
<tr>
<td>Urban Driving</td>
<td>US FTP-72 (LA4)</td>
<td>4</td>
<td>-7°C</td>
<td>Electricity</td>
<td>ERMD (Ottawa, ON)</td>
</tr>
<tr>
<td>Highway Driving</td>
<td>US HWFET</td>
<td>8</td>
<td>STP</td>
<td>Electricity</td>
<td>ERMD (Ottawa, ON)</td>
</tr>
<tr>
<td>Aggressive Driving (x2)</td>
<td>US 06</td>
<td>4</td>
<td>STP</td>
<td>Electricity</td>
<td>ERMD (Ottawa, ON)</td>
</tr>
<tr>
<td>Electrical Load (x2)</td>
<td>US SC03</td>
<td>5</td>
<td>STP</td>
<td>Electricity</td>
<td>ERMD (Ottawa, ON)</td>
</tr>
</tbody>
</table>

*Table 2: Chassis Dynamometer Testing Cycles*

5.1 U.S. FTP-72 (UDDS) Cycle

This cycle will be performed at least twice to ensure reliability of results. FTP-72 is performed both at normal ambient conditions as well as in cold (-7°C) test conditions.
U.S. FTP-72 (Federal Test Procedure) is also known as the Urban Dynamometer Driving Schedule (UDDS) or the LA-4 cycle. The cycle is a simulation of an urban driving route that is approximately 12.1 km (7.4 miles) long and takes 1,369 seconds (approximately 23 minutes) to complete. The cycle consists of multiple stops and achieves a maximum speed of 91.3 km/h (56.7 mph). The average speed of the cycle is 31.5 km/h (19.6 mph).

The cycle is separated into two phases. The first phase begins with a cold start and lasts 505 seconds (a little over 8 minutes), with a distance of 5.8 km (3.6 miles) and an average speed of 41.2 km/h (25.6 mph). The second phase begins after an engine stop of 10 minutes. It lasts 864 seconds (about 14 minutes). All emissions are recorded in g/km and g/mile.

The U.S. FTP-72 will be repeated until the battery is fully depleted.

The weighting factors are 0.43 for the first phase and 0.57 for the second phase. The parameters for the driving cycle are listed below.

- Ambient temperature = 20°-30°C (68°-86°F)
- Cold temperature = –7°C (19.4°F)
- Time = 1,369 seconds (22 minutes, 49 seconds)
- Distance = 12.1 km (7.4 miles)
- Top Speed = 91.3 km/h (56.7 mph)
- Average Speed = 31.5 km/h (19.6 mph)
- Number of Stops = 18

5.2 US06 Supplemental Federal Test Procedure

The US06 Supplemental Federal Test Procedure (SFTP) is used in addition to the above-mentioned FTP-75. The US06 simulates aggressive acceleration, higher speed driving behaviour, including rapid speed fluctuations following start-up. The cycle takes 596 seconds (nearly 10 minutes) to complete, with a total distance of 12.8 km (8.0 miles).
travelled. The maximum speed of the cycle is 129.2 km/h (80.3 mph). The average speed of the cycle is 77.4 km/h (48.4 mph).

The US06 driving cycle will be repeated until the battery is fully depleted.

The parameters for the driving cycle are listed below.

- Ambient temperature = 20°-30°C (68°-86°F)
- Time = 596 seconds (9 minutes, 56 seconds)
- Distance = 12.8 km (8.0 miles)
- Top Speed = 129.2 km/h (80.3 mph)
- Average Speed = 77.4 km/h (48.4 mph)
- Number of Stops = 5

5.3 US SC03 Speed Correction Driving Schedule

The US SC03 Speed Correction Driving Schedule is used in addition to the above-mentioned FTP-75. It simulates urban driving and engine load with the air-conditioning unit turned on for the entire duration of the test (Note: A/C fan speed to be determined). The cycle takes 596 seconds (nearly 10 minutes) to complete, with a total distance of 5.8 km (3.6 miles) travelled. The maximum speed of the cycle is 88.2 km/h (54.8 mph), and the average speed is 34.8 km/h (21.6 mph).

The SC03 driving cycle will be repeated until the battery is fully depleted.
The parameters for the driving cycle are listed below.

- Ambient temperature = 20°C - 30°C (68°F - 86°F)
- Time = 596 seconds (9 minutes, 56 seconds)
- Distance = 5.8 km (3.6 miles)
- Top Speed = 88.2 km/h (54.8 mph)
- Average Speed = 34.8 km/h (21.6 mph)
- Number of Stops = 6

5.4 U.S. HWFET Cycle

The United States Highway Fuel Economy Test (U.S. HWFET) cycle was developed by the Environmental Protection Agency to determine the highway fuel economy for light-duty vehicles. The cycle is a simulation of higher speed highway driving. It takes 765 seconds (nearly 13 minutes) to complete, with a total distance of 16.5 km (10.3 miles) travelled. The maximum speed of the cycle is 96.5 km/h (59.9 mph) and a minimum speed of 45.7 km/h (28.4 mph) is reached at the 296-second (about 5-minute) mark of the cycle.

The US HWFET cycle will be repeated until the battery is fully depleted.
The parameters for the driving cycle are listed below.

- Ambient temperature = 20°-30°C (68°-86°F)
- Time = 765 seconds (12 minutes, 45 seconds)
- Distance = 16.5 km (10.3 miles)
- Top Speed = 96.5 km/h (59.9 mph)
- Average Speed = 77 km/h (48.3 mph)

5.5  Electrical Consumption Calculations

5.5.1  AC Power Consumption

The AC power consumption is the amount of AC electricity required to charge the vehicle per unit of distance, usually measured in watt-hours per mile (Wh/mi). The AC power consumption is higher than the DC power consumption, simply because there are power losses during the transmission of power from the battery and also when converting electrical energy to mechanical energy (in the electric motor).

Similar to fuel-powered vehicles (where energy is expressed as litres of fuel), it is important to note how much electricity is being consumed (and paid for) per unit of distance for each driving cycle. This will give consumers an understanding of the operational costs of driving the vehicle.

The AC energy will be measured with a Hioki 3193 Power HiTester measuring unit with Universal Clamp-On CT 9278 (200 A range), which records the amperage of AC energy during charging. Clamping instructions are detailed in section 5.5.4 below. This will be done in order to quantify the electricity (energy) use and determine the test vehicle battery’s state-of-charge and total capacity over the various duty cycles.
The AC power running through the line can be calculated using the simple formula:

\[ \text{Power (W)} = \int_{0}^{t} \text{Volts (V)} \times \text{Amperage (A)} \]

Equation 1

By integrating power over time, the energy consumed can be determined:

\[ \text{Energy (kWh)} = \int_{0}^{t} \text{Power (kW)} \times \text{time (hr)} \]

Equation 2

And finally, AC energy consumption of the vehicle can be calculated in kWh/100 km.

\[ \frac{\text{AC Energy Consumption (kWh/100km)}}{\text{Driving Cycle Distance (km)}} = \frac{\text{AC Energy (kWh)}}{\text{Driving Cycle Distance (km)}} \times 100 \]

Equation 3

5.5.2 DC Power Consumption

The DC power consumption is the amount of DC energy delivered from the battery to propel the vehicle forward. Power will be measured both in and out of the electrical control module (an indication of how much regenerative braking has occurred). The DC power consumption will be measured by the Hioki analyzer described above. Clamping instructions are outlined in section 5.5.4 below.

\[ \frac{\text{DC Energy Consumption (kWh/100km)}}{\text{Driving Cycle Distance (km)}} = \frac{\text{DC Energy (kWh)}}{\text{Driving Cycle Distance (km)}} \times 100 \]

Equation 4

5.5.3 Electrical Efficiency

The electrical efficiency of the vehicle can be determined by dividing the AC efficiency by the DC efficiency. This will indicate how much power is lost from other components of the vehicle, as well the effectiveness of regenerative braking in helping to re-charge the batteries.

\[ \text{Efficiency} = \frac{\text{AC Energy Consumption}}{\text{DC Energy Consumption}} \times 100 \]
5.5.4 Clamping Instructions

The Hioki analyzer will be attached to the vehicle in the manner shown in Figure 7 below.

![Clamping Instructions](image)

**Figure 6: Clamping Instructions**

5.6 Well-To-Wheel Analysis and Equivalent Fuel Consumption

To make electrical consumption (kWh/100 km) figures meaningful, it is necessary to convert to an equivalent fuel consumption figure (L/100km). Essentially, we are taking the battery-to-wheel electrical consumption and converting it into tank-to-wheel fuel consumption (as used on fuel consumption labels). To do this, we must consider the wheel-to-well analysis of electricity production and gasoline production, as shown in Figure 6.

![Wheel-to-Well Analysis](image)

**Figure 8: Wheel-to-Well Analysis to Determine Equivalent Fuel Consumption**

*Note:* “E” is the energy density of gasoline (MJ/L), “$e_{electricity}$” is a lumped efficiency value that includes both the average generation and average transmission efficiencies of electricity, and “$e_{gasoline}$” is a combined efficiency value that includes both the refining and distribution efficiencies of gasoline.
5.6.1 Battery-to-Wheel Fuel Consumption

Converting the energy consumption of electric vehicles into the equivalent battery-to-wheel fuel consumption (L/100 km) simply depends on the energy density of gasoline.

Equation 6

\[
\text{Fuel Consumption} \left( \frac{L}{100\text{km}} \right)_{\text{battery-to-wheel}} = \frac{\text{Energy Consumption} \left( \frac{kWh}{100\text{km}} \right) \times 3.6}{E_{\text{gasoline}} \left( \frac{MJ}{L} \right)}
\]

where:

\( E_{\text{gasoline}} \) = the energy density of gasoline ≈ 32.05 MJ/L

5.6.2 Tank-to-Wheel Fuel Consumption

Finally, the full cycle fuel economy for an electric vehicle must include the efficiencies for both electric power generation and transmission.

Equation 7

\[
\text{Fuel Consumption} \left( \frac{L}{100\text{km}} \right)_{\text{tank-to-wheel}} = \text{Fuel Consumption} \left( \frac{L}{100\text{km}} \right)_{\text{battery-to-wheel}} \times \left( \frac{\eta_{\text{electricity}}}{\eta_{\text{gasoline}}} \right)
\]

where:

\( \eta_{\text{electricity}} \) = lumped efficiency value for electricity ≈ 0.303 (Fuel consumption numbers for electric vehicles)

\( \eta_{\text{gasoline}} \) = lumped efficiency value for gasoline ≈ 0.830 (Fuel consumption numbers for electric vehicles)

6.0 Dynamic Performance Testing

6.1 Environmental Conditions

The temperature during the vehicle ambient soak period will be between 16°C and 32°C (60°F to 90°F). The ambient temperature during road testing will be between 5°C and 32°C (40°F to 90°F). The atmospheric pressure will be between 91 kPa and 104 kPa. The tests will be performed in the absence of rain and fog. The recorded wind speed at the testing location will not exceed 16 km/h (10 mph).

6.2 Tire Conditions

If not factory installed, the tires used will be changed to those recommended by the manufacturer or approved by eTV personnel as the best available equivalent. Tires will be conditioned and inflated as recommended by the vehicle manufacturer. PMG will condition and warm up the tires, as per their usual dynamic testing procedures. No special agents that increase traction will be added to the tires or track surface and “burnouts” to heat the tires for added grip will not be allowed.
6.3 Track Conditions

The track surface should be clear of debris, be level to within ± 1% (except during gradient tests) and have a hard, dry surface. Tests will be run in both directions when they are performed on a road test route. The direction of travel need not be reversed when operating on a closed track.

6.4 Acceleration Evaluation

The maximum acceleration of the test vehicle will be determined by starting the vehicle from a standing start.

- The vehicle will be evaluated by accelerating to the maximum attainable speed in a quarter mile (1,320 ft).
- The vehicle will be evaluated by accelerating to the maximum attainable speed in a kilometre (1,000 m).

Speed points will be recorded beginning at 0 km/h and in 10-km/h intervals thereafter, to the maximum speed attained. Time versus distance travelled will also be recorded using a DAS.

The maximum acceleration of the test vehicle will be determined by starting the vehicle from a rolling start.

- The vehicle will be evaluated by accelerating to a velocity of 8 km/h (5 mph). At the minimum required velocity, the throttle will be depressed “full open”. Acceleration will continue until a maximum velocity of 98 km/h (60 mph) is reached. Shifting will occur at what is determined to be an optimal shift point.

6.5 Maximum Speed in Gear

The maximum speed attainable in each gear will be tested and recorded. The driver will start from a standing start for first gear only. The vehicle will be accelerated, changing gears only when the vehicle’s engine speed has reached its maximum peak rpm – as indicated by the tachometer or by the DAS if calibrated correctly – with no increase in revolutions per minute for at least three seconds. The maximum speed and revolutions per minute for each gear will be recorded.

6.6 Top Speed

The overall top speed will be tested and recorded. The vehicle’s speed will be recorded from the DAS and not the vehicle’s speedometer. Because the vehicle’s top speed is affected by wind, this test will be run in both directions and averaged.

6.7 Handling

6.7.1 Lateral Skid Pad

The lateral skid pad test will be used to determine the maximum speed that the test vehicle can achieve in a cornering situation. Lateral acceleration is measured in Gs, where 1.0 G is equal to the net effect of this acceleration and the acceleration imparted by natural gravity. When the vehicle reaches its cornering limit, it will either under-steer or over-steer, losing traction on the curve. When the vehicle loses traction, the maximum lateral acceleration will be recorded.

The vehicle will follow a circle that is approximately 100 m (300 feet) in diameter. The circle will be constructed using pylons arranged to follow the pattern of the circle. The pylons will be placed at equal distances to allow the centre of gravity of the vehicle to travel the distance of the circle while maintaining the driving profile of a circle. The vehicle will run a lap in each direction as fast as the car will allow without falling off the driving line.
Figure 7: Skid pad layout
6.7.2 Emergency Lane Change Manoeuvre

The emergency lane change manoeuvre test will be based on ISO 3888-2:2002 Passenger Cars –Test Track for a severe lane change manoeuvre – Part 2: Obstacle Avoidance. The test will be conducted on a 160-foot long pylon course with two 12-foot wide lanes. The right-hand lane will be blocked at the 80-foot mark. The driver will begin the run in the right lane, swerve into the left, and then immediately cut back into the right. If any pylons are hit, the run will be disallowed. The average speed maintained throughout the course will be recorded.

![Figure 8: Emergency lane change](image)

<table>
<thead>
<tr>
<th>Section</th>
<th>Length</th>
<th>Lane Offset</th>
<th>Width</th>
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<tr>
<td>1</td>
<td>12 m</td>
<td>-</td>
<td>1.1 x vehicle width* + 0.25</td>
</tr>
<tr>
<td>2</td>
<td>13.5 m</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>11 m</td>
<td>1</td>
<td>Vehicle width* + 1</td>
</tr>
<tr>
<td>4</td>
<td>12.5 m**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>12 m</td>
<td>-</td>
<td>1.3 x vehicle width* + 0.25, but not less than 3 m</td>
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</tbody>
</table>

* Vehicle width means overall width of the vehicle without rear view mirrors.
** To ensure high lateral accelerations at the end of the track, section 4 is 1 m shorter than section 2.

*Table 3: Emergency lane change parameters*
6.7.3 Turning Circle

The test vehicle will perform a curb-to-curb turning circle to measure the total distance that the wheels travel. The diameter of the turning circle will be recorded in metres.

![Figure 9: Turning circle](image)

**Figure 9: Turning circle**
6.7.4 Slalom

A slalom course has become the baseline test for what is known as "transient response" or the vehicle's ability to recover from one corner and set up for the next corner. Ideally, because the vehicle is still leaning in the opposite direction to the turn it is entering, the transient response is evaluated.

Pylons will be arranged in a straight line and the test vehicle will manoeuvre between them (See Figure 10). The pylons will be placed 100 feet (~ 30 m) apart over a total distance of 600 feet (~ 180 m). Timing will begin when the test vehicle crosses the plane of the first pylon and end when the test vehicle crosses the plane of the final pylon. Entry and exit speeds to the slalom will have to be determined through successive trials.

Figure 10: Standard Slalom Course
6.8 Noise

The test vehicle will perform the CMVSS 1106 – Noise Emissions test at PMG Test in Blainville, Québec. Cabin noise will be measured in decibels (db) using the A-weighting scale (dBa). A sound level meter (example, Brüel & Kjær Type 2236) will be used to measure sound at different intervals of the vehicle’s running state. The sound will be measured at states of:

- idle
- acceleration – full throttle
- 110 km/h (~ 70 mph)
- 100 km/h (~ 62 mph)
- 80 km/h (~ 50 mph)
- 50 km/h (~ 30 mph)

The sound level meter or microphone will be positioned near the driver’s right ear. Measurements will be taken from the maximum reading obtained.

Figure 11: Brüel & Kjær Type 2236 sound level meter
6.9 Braking

The test vehicle will perform the CMVSS 135 - Light Vehicle Braking Systems test at PMG Technologies in Blainville, Québec.

A performance test will demonstrate deceleration in an abrupt stop at the following speeds:

- 50 km/h (30 mph) to 0 km/h (0 mph)
- 80 km/h (50 mph) to 0 km/h (0 mph)
- 100 km/h (60 mph) to 0 km/h (0 mph)
- 110 km/h (70 mph) to 0 km/h (0 mph)

The vehicle’s total braking distance in metres and time in seconds will be recorded. If the test vehicle is equipped with ABS brakes, the test driver will fully depress the brake pedal, allowing the computer to modulate the callipers. If the vehicle is not equipped with ABS brakes, the test driver will apply the brakes to the maximum point before the brakes lock. Should a lock occur, the result will be disregarded. If possible, a pressure-activated switch should be installed to record the start of the braking in relation to the vehicle’s speed.

6.10 Test Instrumentation

An instrument to measure vehicle speed as a function of elapsed time will be used in all of the procedures described in Section 6. The device must meet the following specifications:

- Equipment must be installed so that it does not hinder the driver or alter the operating characteristics of the vehicle.
- All instrumentation must be NIST traceable.

**Atmospheric Conditions (using a barometer)**

Accuracy ± 0.7 kPa or ± 0.2 inches of Hg

**Temperature**

Accuracy ± 1 °C (±2°F)

Resolution 1°C (2°F)

**Time**

Accuracy ± 0.1% of total coast down time interval

Resolution 0.1 seconds

**Tire Pressure (tire pressure gauge)**

Accuracy ± 3 kPa (± 0.5 psi)

**Speed**

Accuracy ± 0.4 km/h (± 0.25 mph)

Resolution ± 0.2 km/h (0.1 mph)

**Vehicle Weight**

Accuracy ± 5 kg (± 10 lb) per axle

**Wind**

Determination of average longitudinal and crosswind components to within an accuracy of ± 1.6 km/hr (± 1 mph)
6.11 Records

The following test parameters will be recorded for all of the procedures described in Section 6:

- Ambient temperature
- Barometric pressure
- Date and time of test
- Damage (if applicable)
- Deviations from any procedures
- Drive train ratios and those used during testing
- Duration of test, start and end
- Overall vehicle dimensions
- Tire pressure (to be recorded before and after each test)
- Test weight (including passengers, cargo and DAS equipment)
- Vehicle accumulated mileage at the start and end of testing
- Vehicle’s direction of travel
- Vehicle identification
- Vehicle’s speed (vs. time, as recorded by DAS)
- Wind direction (hourly average)
- Wind speed (hourly average)

7.0 Applicable Publications

The following publications provide the specifications as indicated. While different versions may exist, only the latest version available at the time of writing this document is cited below.

7.1 SAE Publications

Available from Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096-0001.
http://www.sae.org

SAE J 1263 Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques
SAE J 1470 Measurement of Noise Emitted by Accelerating Highway Vehicles
SAE J 1492 Measurements of Light Vehicle Stationary Exhaust System Sound Level Engine Sweep Method

7.2 Code of Federal Regulations

http://www.gpoaccess.gov/cfr/index.html

40CFR 86 – EPA; Control of Emissions from New and In-Use Highway Vehicles and Engines; Certification and Test Procedures
40CFR 600 – EPA; Fuel Economy of Motor Vehicles
7.3 Motor Vehicle Safety Standards

Available from the Department of Transport, Federal Government of Canada.
http://www.tc.gc.ca/roadsafety/mvstm_tsd/index_e.htm

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<tr>
<td>1106</td>
<td>Noise Emissions</td>
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7.4 International Organization for Standardization

Available at http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=31310

<table>
<thead>
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<tr>
<td>3888-2:2002</td>
<td>Passenger cars – Test track for a severe lane-change manoeuvre</td>
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7.5 American Society of Testing and Materials (ASTM)

Available from the American Society of Testing and Materials (ASTM) 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, USA. Obtained from the Transport Canada library.

ASTM D6751 Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels

7.6 Other Publications