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Low Rolling Resistance Tires

TEST PLAN

Prepared by eTV
February 2009



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1.0 Definitions

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).

Base Inflation Pressure

The inflation pressure corresponding to the maximum load of the tire.

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.

Capped Inflation Pressure

The inflation pressure of the tire, which has been inflated at the ambient temperature of test area and sealed with a cap or valve.

Contact Patch

The section of the tire that is in contact with the road - all forces needed for acceleration, braking and cornering are transmitted through this section.

Coastdown

A procedure used to determine the time for a vehicle to coast (in neutral) from a specified speed to a target speed (e.g. from 105 km/h to 15 km/h), in order to simulate rolling resistance and aerodynamic drag for dynamometer testing.

Criteria Air Contaminants (CAC)

A group of pollutants that includes sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOC), carbon monoxide (CO) and ammonia (NH₃).

Crosstalk

An interaction between the applied load and spindle force sensors that causes potential errors in spindle force measurements, and therefore an error in the rolling resistance co-efficient.

Data Acquisition System (DAS)

A device designed to measure and log parameters over a given time period, either continually or continuously.

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).



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 (NO_x), ozone (O₃) and chlorofluorocarbons (CFC).

HWFET (Highway) Driving Cycle

The United States Highway Fuel Economy Test – a driving cycle, usually conducted on a dynamometer, which determines the highway fuel economy of light-duty vehicles.

Maximum Load

The maximum weight in pounds (lb) or kilograms (kg) (or load limit) given for a single tire, as indicated on the tire sidewall.

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.

Laboratory Test Wheel

The device used to test vehicle tires for rolling resistance coefficients and other physical properties.

Parasitic Losses

The losses associated with performing a mechanical task. For example, in relation to rotating a tire, it is the force required to rotate the inertia (mass) of the tire and wheel.

Rolling Resistance

A force that opposes the rotation of the tire, resulting from the deformation of the tire into the contact patch.

Rolling Resistance Co-efficient (RRC) - Dynamic

A comparative, dimensionless parameter that defines how much force is used to deform a tire in order for it to maintain contact with a surface at different speeds. The dynamic RRC can be measured at a standard reference condition (a function of the tire’s maximum load and base inflation pressure) or at a special condition (a function of the vehicle’s load and recommended tire inflation pressure).

Rolling Resistance Co-efficient (RRC) - Static

A comparative dimensionless parameter that defines how much force is used to deform a tire to maintain the contact patch of the tire on a surface at a constant speed. The static RRC can be measured at a standard reference condition (a function of the tires maximum load and base inflation pressure) or at a special condition (a function of the vehicles load and recommended tire inflation pressure).

Standard Mean Equivalent Rolling Force (SMERF)

It is the dynamic rolling resistance coefficient averaged over the UDDS and HWFET driving cycles.

Standard Reference Condition (SRC)

The regulated inflation pressure and speed, specified such that tires could be compared at a single condition. For passenger car “p” type tires, these conditions are: Tire Load - 70% of Tire and Rim Association 240 kPa, Inflation Pressure: 260 kPa (38 psi), and Speed: 80 km/h (50 mph).

Thermal Efficiency

This is the percentage of thermal energy in a fuel that is converted into mechanical energy.



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.

UDDS (City) Driving Cycle

The Urban Dynamometer Driving Cycle is the driving cycle, usually conducted on a dynamometer that determines the city fuel consumption of a light-duty vehicle.

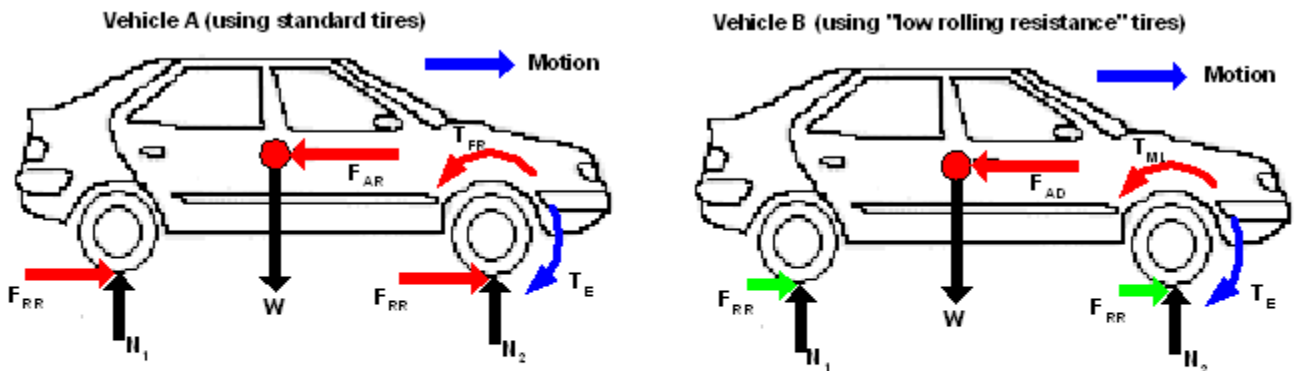
Uniform Tire Quality Grade (UTQG)

A rating system created by the U.S. National Highway Traffic Safety Association (NHTSA) that allows consumers to compare tires based on their treadwear, traction and temperature.

2.0 Introduction

New and innovative technologies can help improve fuel efficiency and reduce greenhouse gas (GHG) emissions for light-duty vehicles. Alternative fuels, electric batteries, hydrogen electric fuel cells, hybrid technologies, and improved power trains, emissions controls and aerodynamics all have the capacity to reduce vehicle emissions on Canadian roads. However, the use of low rolling resistance (LRR) tires as replacement tires may also help to reduce fuel consumption in vehicles.

It takes energy to get a vehicle down the road. Part of that energy is used to overcome air resistance (drag), friction resistance (e.g. internal friction such as in the transmission) and rolling resistance. Once a vehicle has been manufactured, a driver can do little to reduce the air or friction resistance. But a driver may be able to do something to minimize rolling resistance. A vehicle’s fuel consumption is the direct result of its total resistance. The diagram below shows the resistance forces opposing the motion of two vehicles. Vehicle A (using standard tires) has a rolling resistance force opposing the torque of the engine. Vehicle B (using LRR tires) also experiences a rolling resistance force. However, with all other resistance forces remaining constant, Vehicle B, with LRR tires, should have lower fuel consumption.



- W = weight of vehicle (force)
- H₁ = reaction (force)
- F_{RR} = rolling resistance (force)
- F_{AD} = aerodynamic drag (force)
- T_E = engine (torque)
- T_{ML} = mechanical losses (torque)

Figure 1: Rolling Resistance and Other Resistance Forces Affecting a Vehicle



What Is Low Rolling Resistance and Why Is It Important?

Tires are an important component of a vehicle. Aside from giving the traction required for braking and steering of the vehicle, they also support the load and provide a cushion between the vehicle and the driving surface.

As the wheels turn to move the vehicle forward, the tires change their shape in order to make and maintain contact with the road. The section where the tire touches the road is called the contact patch. All of the forces needed for acceleration, braking and cornering are transmitted through this contact patch. It is the ability of the tires to adapt their shape (deform) that ensures proper grip and comfort (smooth versus bumpy ride). The rubber compounds in a tire give off energy in the form of heat when they are deforming—if you have ever touched a tire after it has been running for some time, you will realize just how much heat is generated and how much energy is wasted. The amount of energy required by the tire to deform is called rolling resistance. Tires that have a low rolling resistance require less energy to deform into the contact patch.

All tires have a rolling resistance coefficient—a number that defines how much resistance a tire encounters as it deforms into the contact patch—both at a steady state when the vehicle speed is kept constant, and in a dynamic state when the vehicle’s speed is changing (such as when accelerating or slowing down). Generally, a tire with a higher rolling resistance coefficient will cause a vehicle to burn more fuel to keep moving. And by consuming more fuel, the tailpipe emissions (GHGs and other pollutants) also increase.

LRR tires help to reduce fuel consumption by minimizing the energy wasted as heat as the vehicle rolls down the road. According to Michelin (Michelin website, 2010), if all vehicles worldwide were equipped with LRR tires, it would result in a CO₂ emissions reduction of 80 million tonnes. By selecting tires with LRR and by maintaining the tires through the course of their life, vehicle fuel efficiency could be improved by as much as 4.5%. As well, a study from the California Energy Commission¹ found that the use of LRR tires on light-duty fleets is cost effective: over 300 million U.S. gallons (10 million barrels) of fuel could be saved per year. At a cost of US\$2.90/gallon, that’s a potential savings of more than US\$870 million! According to Statistics Canada, Canadians consumed 41 billion litres of gasoline in 2009 (Statistics Canada website, 2009). If using LRR tires can help to improve fuel efficiency by 4.5%, that could translate into a saving of 1.8 billion litres per year. At a cost of \$1/litre, that’s a potential savings of \$1.8 billion!

The eTV program is undertaking a study on LRR tires to:

- quantify the time a vehicle is able to coastdown for a predetermined reduction in rolling resistance;
- assess whether rolling resistance has an impact on dry braking distances;
- evaluate the extent to which rolling resistance can affect fuel consumption;
- determine whether rolling resistance coefficients can be used to compare the environmental benefits of tires.

The study will allow Canadians to learn more about the benefits of low rolling resistance tires and their contribution to reducing fuel consumption and emissions.

3.0 Tire Selection and Pre-Test Verification Procedure

The brands and sizes of tires on the market vary greatly with respect to the classes and types of vehicles on the road. Since eTV’s mandate pertains to light-duty vehicles, the low rolling resistance study will evaluate only those tires that are used on passenger cars and light-duty trucks. The 25 tires selected for testing cover a variety of parameters, including different vehicle sizes (compact, mid-size, full size), tire widths, tire profiles, rim sizes, manufacturers, all-

¹ *California State Fuel-efficient Tire Report: Volume II*. California Energy Commission. January 2003.



season and winter tires. Given that this is a pilot study, it was decided to limit the tire choice to those that can be fitted on 15-inch and 16-inch rims. These sizes are very common in Canada, representing a large percentage of light-duty tire sales.

The 25 tires selected for testing will be purchased from a Canadian retailer. Upon arrival, each tire will be visually inspected for any anomalies in the tire tread. All relevant information required for shipment to the United States will be documented, including manufacturer, model, size, load rating, speed rating, UTQG rating, weight, date of manufacture, and country of origin.

After having completed the visual inspection, the tires will be shipped to Smithers Scientific Services in Ravenna, Ohio, where the laboratory testing for rolling resistance coefficients will be conducted. The tire models selected for testing are summarized in Appendix A.

4.0 Methodology

All tires tested as part of this pilot study, herein referred to as the “test tires”, will undergo the following three phases of testing and evaluation:

- Phase 1: Laboratory rolling resistance coefficient testing
- Phase 2: Dynamic performance testing
- Phase 3: Evaluation of real-world fleet fuel consumption

4.1 Phase 1: Laboratory Rolling Resistance Coefficient Testing

eTV will test each tire model in a laboratory for both steady-state and dynamic rolling resistance coefficients. Laboratory testing ensures that all tires are tested under similar conditions, so that the tires’ rolling resistance coefficients, or “resistance to rolling”, can be compared. Testing tires for rolling resistance coefficients is non-destructive. The tire is not be damaged or deformed during testing, and the integrity of the tire carcass and tread pattern does not compromise vehicle safety should the tires be used on the road again.

The rolling resistance coefficients will be determined for each tire model through testing by Smithers Scientific Services, which is ISO 17025 accredited as well as GM TIP-certified and Ford-correlated to perform rolling resistance testing. Smithers Scientific also works with most of the major tire suppliers, and performs testing on behalf of the United States Department of Transportation’s NHTSA and the California Energy Commission.

As shown in Figure 2 below, rolling resistance coefficient testing will be performed on a laboratory test wheel, as per procedures outlined in the Society of Automotive Engineers’ Surface Vehicle Recommended Practices (see Section 8.1 for complete reference). Section 5.0 of this document outlines the tests as well as the conditions under which the testing will be performed.



Figure 2: Laboratory Testing Apparatus (Courtesy MTS Systems Corporation)

4.2 Phase 2: Dynamic Performance Testing

Dynamic testing will be performed on the test tires with different rolling resistance coefficients, to analyze how rolling resistance affects parameters such as braking distance and coastdown times. The purpose of this testing is twofold: to determine if rolling resistance has an effect on the braking distance of a vehicle and to quantify how much “rolling-time” a vehicle can need with a known reduction in rolling resistance.

Dynamic performance testing 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 on the tires, as outlined in Section 6.0.

eTV engineers will also conduct coastdown testing on roads in the National Capital Region. In a coastdown test, the vehicle is driven to a specified speed and stabilized then allowed to coast to a target speed. The road being used will be clear of debris, be level to within $\pm 1\%$ (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. All coastdown data will be corrected for temperature and barometric pressure.



Figure 3: Motor Vehicle Test Centre (Blainville, QC)



4.3 Phase 3: Evaluation of Real-World Fleet Fuel Consumption

Real-world fleet fuel consumption is required to evaluate the extent to which rolling resistance can affect fuel consumption. Normally a vehicle would be tested on a dynamometer over an Environmental Protection Agency (EPA) driving cycle. The challenge with simply switching tires on a vehicle and testing on an EPA dynamometer driving cycle is that the driving cycles are generally too short to be able to accurately isolate any potential fuel savings through the use of LRR tires. Any improvement in fuel consumption through the use of LRR tires would likely fall within the degree of error of the instrumentation used for the test.

The only remaining way to quantify any potential fuel savings is to monitor fuel consumption of different tire models over a significant amount of mileage. Since the rolling resistance coefficients for each tire is known from laboratory testing, the result of on-road, real-world testing should indicate the percentage difference in fuel consumption for a known reduction in rolling resistance coefficient.

As part of eTV’s partnership with the Canada Science and Technology Museums Corporation (CSTMC), security personnel will use an eTV fleet vehicle equipped with LRR tires to conduct security patrols at the museums in the National Capital Region, accumulating more than 5,000 kilometres per month on pre-established routes over a one-year period. eTV recognizes that data from a large fleet of vehicles is more desirable than the data from a single vehicle. However, this one vehicle should provide useful information about whether the use of LRR tires could have a positive or negative effect on fuel consumption in a high mileage vehicle, particularly in light of the fact that there will be a number of different drivers. From a statistically significant point of view, however, this small, anecdotal, real-world trial cannot be given nearly as much consideration as the controlled testing performed over Phases 1 and 2.

5.0 Laboratory Rolling Resistance Coefficient Testing

The laboratory testing and analysis set out in Table 1 below will be performed on the test tires.

Test Parameter	Test Standard	Location
Steady-State Rolling Resistance Coefficient	SAE J1269	Smithers Scientific Services (Ravenna, Ohio)
Dynamic Rolling Resistance Coefficient	SAE J2452a	Smithers Scientific Services (Ravenna, Ohio)
Standard Mean Equivalent Rolling Force	SAE J2452b	Smithers Scientific Services (Ravenna, Ohio)

Table 1: Laboratory Test Listing

5.1 Steady-State Rolling Resistance Co-efficient

The following procedure will provide a standardized method for collecting data, to be used for various purposes such as making tire comparisons, determining load and pressure effects and correlating test results with fuel consumption tests. The steady-state rolling resistance coefficients will be tested and calculated in accordance with SAE J1269.

Testing will involve three different methods for calculating the rolling resistance:

- the force method – measuring the reaction force at the spindle and converting it to rolling resistance;
- the torque method – measuring the torque input to the test machine and converting it to rolling resistance;
- the power method – measuring the power input to the test machine and the speed of the test wheel and converting them to rolling resistance.

5.1.1 Equipment and Instrumentation

The equipment most commonly used for this procedure is the laboratory test wheel (Diameter: 1.708 m) and ancillary



measuring instrumentation. The width of the test surface must exceed the tread width of the tire being tested. The test surface must have a medium-coarse (80 grit) texture.

5.1.2 Test Tires and Rims

The tires to be tested are listed in Appendix A. The test rims must have an approved contour and width for the size of the tire tested, as specified by the Tire and Rim Association or similar organization. Smithers Scientific Services will provide the test rims.

5.1.3 Alignment and Control Accuracy

All test conditions must be maintained at their specified levels to ensure accuracy. The following alignment and control accuracies are specified, such that their combined effect on rolling resistance does not surpass a standard deviation of 0.5 N (0.1 lbf). Except for special considerations discussed in the following, test parameters must be maintained within the following limits:

Tire Load Fore-Aft Offset:	+/- 0.2 mm (0.01 in)
Tire Load Angular Offset:	+/- 0.3 degree
Tire Slip Angle:	+/- 0.1 degree
Tire Inclination Angle:	+/- 0.2 degree
Tire Load:	+/- 20 N (5 lbf)
Inflation Pressure:	+/- 1.5 kPa (0.2 psi)
Test Wheel Speed:	+/- 1.5 km/h (1.0 mph)
Ambient Temperature:	+/- 4°C (7°F)

5.1.4 Instrumentation Accuracy

The instrumentation used for reading and recording of data must be sufficiently accurate and precise to provide rolling resistance measurements with a standard deviation of no greater than 0.5 N (0.1 lbf) for passenger car and light-duty truck tires. To achieve this level of accuracy, measurements common to the three methods must be maintained with the following accuracies for the tires being tested:

Tire Load:	+/- 10 N (2 lbf)
Inflation Pressure:	+/- 1kPa (0.1 psi)
Temperature:	+/- 0.2°C (0.5°F)
Speed:	+/- 1km/h (0.6 mph)

In addition to this, the use of the force method, torque method and power method requires the following accuracies for the tires being tested:

Spindle Force:	+/- 0.5 N (0.1 lbf)
Loaded Radius:	+/- 1 mm (0.04 in)
Torque Input:	+/- 0.3 Nm
Power:	+/- 10 W
Test Wheel Speed:	+/- 0.2 km/h (0.1 mph)

5.1.5 Test Parameters

The recommended test consists of several test points at which the equilibrium rolling resistance and equilibrium



inflation pressure are determined. A single point, the Standard Reference Condition (SRC) for passenger car tires, will also be established, to be used later for the coastdown method of determining rolling resistance.

Test Point No.	Tire Load (% of Max Load)	Tire Inflation Pressure (Base Pressure +/- Increment)
1	90	-50 kPa (-7.3 psi) Capped
2	90	+70 kPa (+10.2 psi) Regulated
3	50	-30 kPa (-4.4 psi) Regulated
4	50	+70 kPa (+10.2 psi) Regulated
SRC	70	+ 20 kPa (+2.9 psi) Regulated

Table 2: Test Points and Standard Reference Condition

The test will be conducted at a surface speed of 80 km/h (50 mph) or at a test wheel rotational speed of 26.02 rad/s (248.49 rpm).

5.1.6 Test Procedure

Break-In

To break in the tires, they will be operated at test point 1 for a period of one hour. A minimum cool-down period of two hours will follow the break-in period, to allow the tire to return to test-room temperature.

Thermal Conditioning

The test tire will be placed in the thermal environment of the test location for two hours to achieve thermal equilibrium before testing.

Warm-Up

The tire will be run long enough on the test surface, under each set of conditions, to achieve a steady-state value of rolling resistance. The warm-up time will be 30 minutes for the first test point and 10 minutes for the remaining test points.

Data Measurement and Recording

The achievement of steady-state conditions will be verified by monitoring the rolling resistance. Parameters to be recorded include tire identification, test machine identification, test conditions and test variables. These data will be recorded on a sheet designed specifically for that purpose (See Appendix B for a sample Steady-State Rolling Resistance Recording Sheet).

Measurement of Parasitic Losses – Skim Reading and Machine Offset Reading

Load on the tire will be reduced to a value sufficient to maintain tire rotation at test speed without slippage. A skim load of 100 N (20 lbf) is recommended.

The tire and wheel assembly will be removed from the test surface. At test speed, input torque and input electrical power will be read. It should be noted that parasitic losses of the rotating tire and wheel assembly will not be measured and must be determined separately. This will be accomplished by recording the spindle force in the forward and reverse direction.



5.1.7 Data Analysis

Parasitic losses will be subtracted from the gross readings to yield the net spindle force, net torque and net electrical power. For the force, torque and power methods, the skim reading will be subtracted from the reading for each test point. For the torque and power method, the machine offset reading and the tire spindle bearing loss will be subtracted from the reading for each test point.

Equation 1 – Force Method

$$F_X = \frac{(F_{X-FWD} - F_{X-REV})}{2} \quad (1) *$$

$$F_R = F_X \left(1 + \frac{R_L}{R}\right) \quad (2)$$

F_X = magnitude of net tire spindle force, N (lbf)
 F_{X-FWD} = machine measurement – forward direction
 F_{X-REV} = machine measurement – reverse direction
 F_R = rolling resistance, N (lbf)
 R_L = loaded radius, m
 R = test wheel radius, m
 * crosstalk compensation

Equation 2 – Torque Method

$$T = T_{machine} - T_{skim} \quad (3) *$$

$$F_R = \frac{T}{R} \quad (4)$$

T = net input torque, N*m
 $T_{MACHINE}$ = machine torque measurement
 T_{SKIM} = machine skim torque measurement
 F_R = rolling resistance, N (lbf)
 R = test wheel radius, m (in)
 * skim torque compensation

Equation 3 – Power Method

$$F_R = c * \frac{P}{v} \quad (5)$$

F_R = rolling resistance, N (lbf)
 $c = 3.60$
 P = net power input, W
 v = test surface speed, km/h

Equation 4 – Data Adjustment to Ambient Reference Temperature

Individual values of rolling resistance will be adjusted to the reference temperature of 24°C by using the following relation:

$$F_{RR} = F_R [1 + k(T_A - T_R)] \quad (6)$$

F_R = rolling resistance at ambient reference temperature, N (lbf)
 F_{RR} = rolling resistance measured at a test point, N (lbf)
 T_A = average ambient temperature measured at a test point, °C
 T_R = ambient reference temperature
 k = temperature adjustment factor = 0.0060 (°C)



Equation 5 – Rolling Resistance Coefficient

The rolling resistance coefficient will then be calculated by dividing the rolling resistance by the load on the tire, as follows:

$$C = \frac{F_{RR}}{F_Z} \quad (7)$$

C = rolling resistance coefficient, dimensionless
F_{RR} = rolling resistance, N
F_Z = tire load, N

5.2 Steady-State Rolling Resistance Co-efficient (Special Condition)

The procedures outlined in Section 5.1 will be repeated under the special conditions specified in the table in Appendix A.

5.3 Dynamic Rolling Resistance Co-efficient

The following procedure will provide a standard for collecting and analyzing rolling resistance data with varying vertical load, inflation pressure and velocity. The test will be used for a variety of purposes, such as making tire comparisons, determining load and pressure effects, and correlating test results with fuel consumption test results. The rolling resistance coefficients will be tested and calculated in accordance with SAE J2452. The main methods to be used in this procedure are the force method and torque method, as described in Section 5.1.7 of this document.

5.3.1 Important Considerations

Test equipment, test tires and rims, alignment and control accuracy must be consistent with Sections 5.1.3 and 5.1.4 of this document. In addition, the use of the force method and torque method in this procedure requires the following accuracies for the tires being tested:

- Spindle Force: +/- 0.1 N (0.02 lbf)
- Loaded Radius: +/- 1 mm (0.04 in)
- Torque Input: +/- 0.1 Nm (0.9 in-lb)

5.3.2 Test Conditions

The method consists of a stepwise coastdown from 115 km/h to 15 km/h, as described in Section 5.3.3 of this document. The test will be performed under a special condition and the Standard Reference Condition.

5.3.3 Test Procedure

Stepwise Coastdown

When the tire has reached rolling resistance equilibrium at 80 km/h for the load/inflation, the stepwise coastdown will begin by accelerating the test tire to 115 km/h. When speed, load and pressure are stabilized, data will be collected. NOTE: No more than 60 seconds will be spent in accelerating to 115 km/h and gathering the first data point. The test tire will then be decelerated to the next lowest target speed, stabilized, and the data collected. These steps will be repeated until the final speed of 15 km/h has been attained. The entire coastdown will be repeated in the reverse direction to correct for crosstalk. A graphical example of speed versus time for a stepwise coastdown is provided in Figure 4 below.

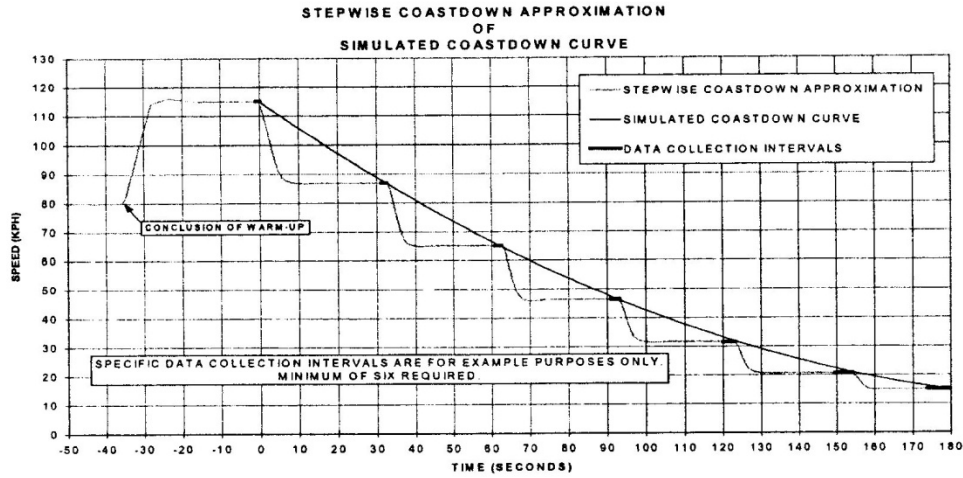


Figure 4: Stepwise Coastdown Approximation Curve

Measurement of Parasitic Losses

Both a skim reading and a machine-offset reading will be taken at each test speed. An example of a parasitic loss correction is set out in Figure 5 below.

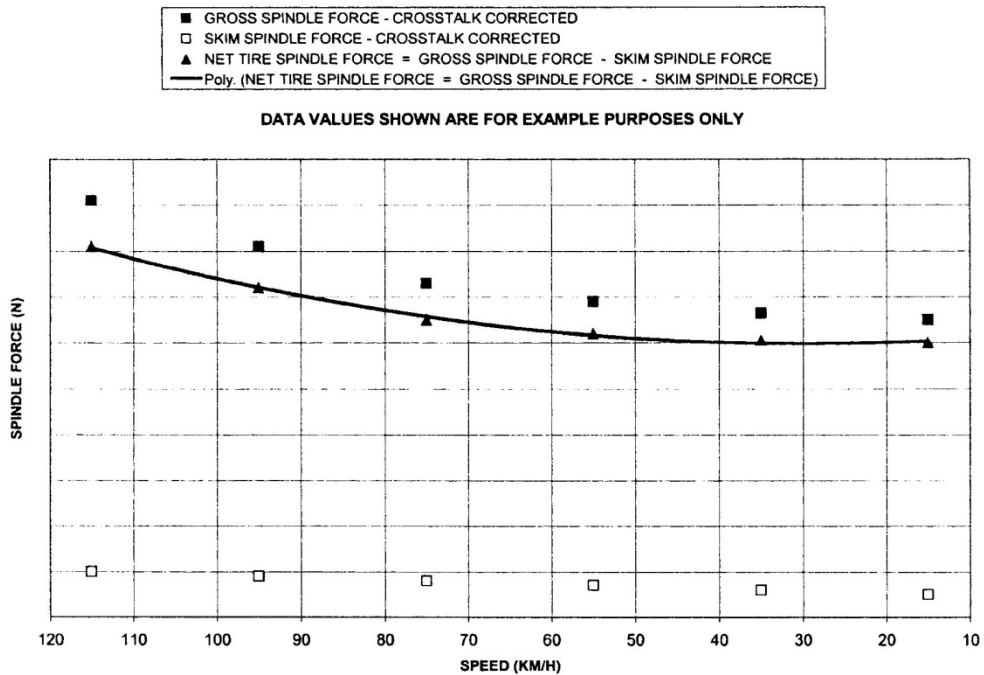


Figure 5: Parasitic Loss Correction Example

5.3.4 Measurement and Recording

All data measured using the stepwise coastdowns will be recorded on the data sheet developed specifically for that purpose (See Appendix C for a sample Stepwise Coastdown Data Measurement and Recording Sheet).



5.3.5 Data Analysis

The formulas set out in Section 5.1.7 of this document will be used to calculate the corresponding rolling resistance for each load-pressure-speed combination. After the rolling resistance values have been obtained, the data reduction method will be performed.

A model will be developed, using measured data that relates rolling resistance to load, inflation pressure and speed for a given tire. The model will be represented by an equation such as the one set out in Equation 6 below.

Equation 6

$$RR = P^\alpha L^\beta (\alpha + bV + cV^2) \quad (8)$$

RR = rolling resistance (N)
P = Inflation Pressure (kPa)
L = applied load (N)
V = Speed (km/h)
 α, β = exponents
a,b,c = constants

NOTE: The exponents will be calculated by minimizing the sum of the squares of residuals between the temperature-corrected rolling resistance measurements (F_R) and the rolling resistance calculated using Equation 6 (RR).

The following flowchart summarizes the data reduction process for the force and torque methods of measurement.

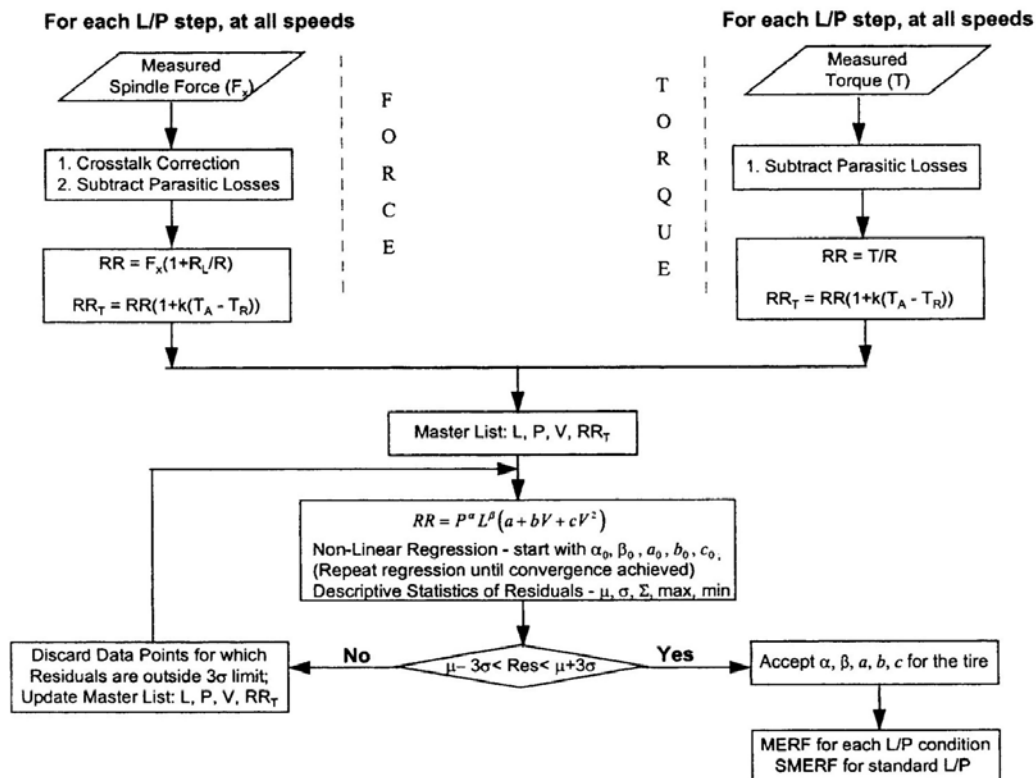


Figure 6: Data Analysis Flowchart (SAE J2452, Page 13)



5.4 Dynamic Rolling Resistance Co-efficient (Special Condition)

For each batch of tires, the procedure outlined in Section 5.3 will be repeated under the special conditions specified in the table in Appendix A.

5.5 Mean Equivalent Rolling Force (MERF)

If the dynamic rolling resistance coefficient is known at a specified load and pressure (whether it is the Standard Reference Condition or a Special Condition), only speed is a function of time. The Mean Equivalent Rolling Force (MERF) can be calculated for that condition by integrating the function of speed of a particular driving cycle over time, using the following equation:

Equation 7

$$MERF = \frac{F^{\alpha} L^{\beta} \int_{t_0}^{t_f} (a + bV + cV^2) dt}{\int_{t_0}^{t_f} dt} \quad (9)$$

NOTE: P and L are the pressure and loads at the SRC or at a Special Condition specified in the table in Annex A.

5.5.1 UDDS Driving Cycle

The 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 following figure shows the speed versus time graph of the UDDS driving cycle.

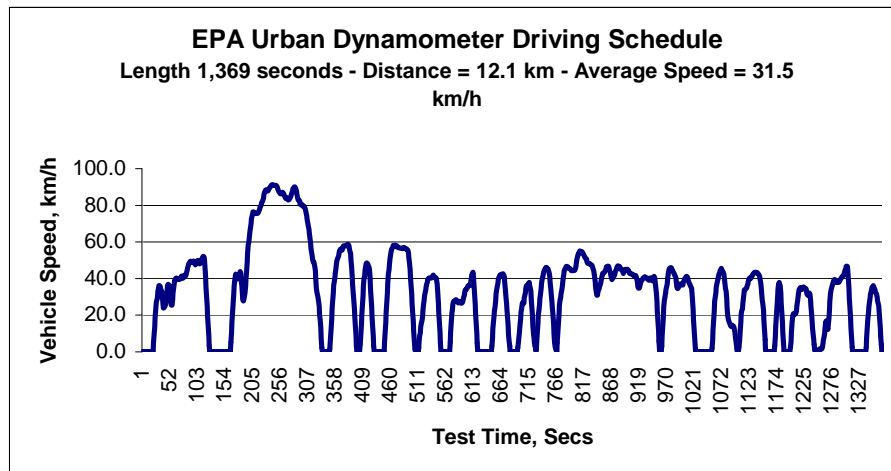


Figure 7: UDDS Driving Cycle



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)
- Length = 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 (19.7 mph)
- Number of Stops = 18

5.5.2 U.S. HWFET Driving 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 following figure shows the speed versus time graph of the HWFET driving cycle.

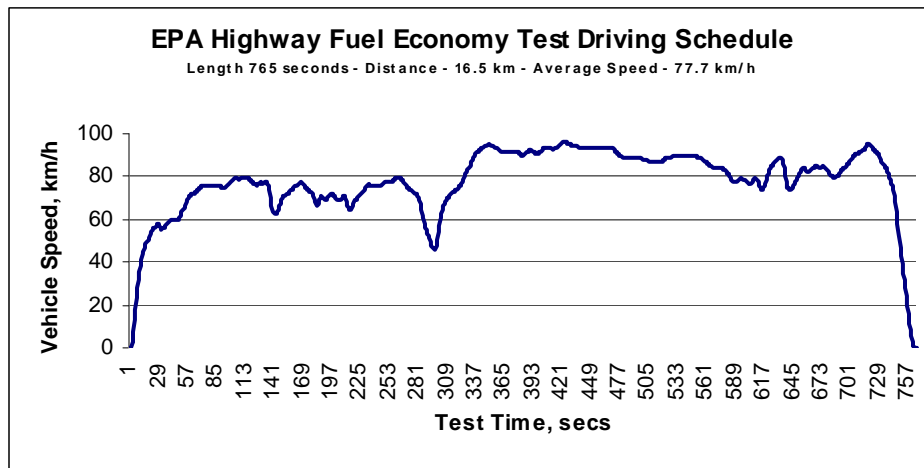


Figure 8: HWFET Driving Cycle

The parameters for the driving cycle are listed below.

- Ambient temperature = 20°-30°C (68°-86°F)
- Length = 765 seconds (12 minutes, 45 seconds)
- Distance = 16.5 km (10.3 miles)
- Top Speed = 96.5 km/h (59.9 mph)
- Average Speed = 77.7 km/h (48.3 mph)

5.6 Standard Mean Equivalent Rolling Force (SMERF)

The SMERF can be calculated as the weighted average of the MERF (at SRC) over the urban and highway driving cycles, using the following equation:



Equation 8

$$SMERF = 0.55 (SMERF_U) + 0.45 (SMERF_H)$$

6.0 Dynamic Performance Testing

The evaluations set out in Table 3 below will be performed on the test tires.

Test Parameter	Testing Standard	Runs	Location
Coastdowns	SAE J1263	12	National Capital Region
Dry Braking	Internal	2	PMG Technologies (Blainville, QC)

Table 3: Dynamic Performance Testing Schedule

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). 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 15 km/h (9 mph).

6.2 Tire Conditions

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. Special agents that increase traction will not be added to the tires or track surface and “burnouts” to heat the tires for added grip will also not be allowed.

6.3 Track Conditions

The driving surface will 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 Coastdowns

Several variables affect the fuel consumption of motor vehicles. These include environmental conditions (wind, pressure, temperature, humidity, precipitation), road conditions (surface condition, grade, temperature), tire conditions (pressure, load), and how aggressively the driver operates the vehicle. By simply switching tires while keeping all other variables nearly constant, coastdowns on a single vehicle will quantify how much extra time a vehicle takes to decelerate. Theoretically, the longer the coastdown time, the lower the rolling resistance of the tire model tested. Due to time constraints, only Batch #1 (P195/60R15) and Batch #2 (P215/60R16) will be tested for coastdown times (See table in Appendix A).

6.4.1 Equipment and Instrumentation

The equipment to be used during the coastdown procedure is the DL1 Data Logger produced by Race Technologies (shown in Figure 9 below). The DL1 is a state-of-the-art “black box” data logger that is capable of storing several vehicle parameters, including speed, time, lateral and longitudinal acceleration and GPS coordinates—data that can be



downloaded for later analysis on a computer. The DL1 is powered by the 12 V accessory vehicle plug, and has a magnetic antenna that must be placed on the roof of the vehicle to receive GPS reception.



Figure 9: DL1 Data Logger

6.4.2 Methodology

The DL1 will be securely fastened to the centre of the dash of the vehicle, preferably in a level position. Once the DL1 is powered and has a GPS signal, the vehicle will be accelerated to 110 km/h and then shifted into neutral. Data recording will begin when the red “Start/Stop Logging” button on the face of the instrument is pressed. The vehicle will then be allowed to coast from 105 km/h to 15 km/h. Once the vehicle has reached 15 km/h, data recording will be stopped.

The vehicle will be deemed to have successfully completed the run if it was kept on a straight path without touching the brake. The procedure outlined above will be repeated 11 times for a total of 12 runs. Six runs will be executed in each direction to ensure more accurate results.

6.4.3 Data Analysis and Results

The results from the coastdown will be recorded on a flash card and transferred to a computer for analysis. The data files will be converted and saved in a comma separated value (CSV) format that can be opened with Microsoft Excel.

The coastdown speed-time data will be adjusted so that the vehicle’s speed at the beginning of the test is 105 km/h (time = 0 seconds). The coastdown time (seconds) for each vehicle will be recorded at 95 km/h, 85 km/h, 75 km/h, 65 km/h, 55 km/h, 45 km/h, 35 km/h, 25 km/h and 15 km/h. The time that the vehicle took to coast during each 10-km/h interval between 105 km/h and 15 km/h will be noted. Of importance, however, is the total time taken for the vehicle to coast from 105 km/h to 15 km/h. This analysis will be repeated and the results will be averaged for all 12 coastdown runs for a single tire model.

6.5 Dry Braking

Vehicles in Canada are required to conform to CMVSS TSD 135, which determines whether the vehicle “Passes” or “Fails” by stopping in a pre-defined stopping distance. The purpose of testing different tires for their braking distance in this project is to determine whether or not rolling resistance has an effect on dry braking distance.

6.5.1 Methodology

As set out in Figure 10 below, the vehicle will be accelerated on a dry track from the test point at line AA towards line BB, to a speed of 100 km/h. The vehicle’s speed should remain constant at 100 km/h between lines BB and CC. At the moment the vehicle reaches line CC, the driver will apply the brakes hard enough to engage the anti-lock braking system on all four wheels. The test will be repeated at least once on a dry track to ensure accuracy.

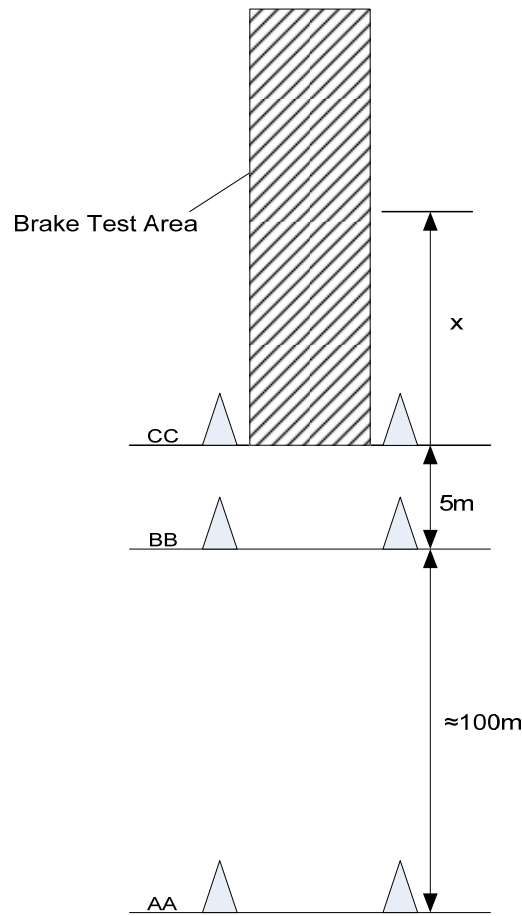


Figure 10: Brake Test Course Set Up

6.5.2 Data Measurement

The distance needed to stop will be recorded for both trials. Other parameters to be recorded include:

- date/time, vehicle year, make, model, weight (including the driver) and location of centre of gravity;
- tire manufacturer, model, speed, load and inflation pressure;
- conditions of test track;
- environmental conditions.

6.5.3 Data Analysis and Results

The stopping distance vs. rolling resistance coefficients will be graphed for each tire tested. The results will show whether there is a correlation between dry braking distance and rolling resistance.

6.6 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. This device, as well as all other instrumentation used, must meet the following specifications:

- Be installed so that it does not hinder the driver or alter the operating characteristics of the vehicle;
- 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 $\pm 0.1\%$ 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/h (± 1 mph)

6.7 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 Evaluation of Real-World Fleet Fuel Consumption

As part of eTV's partnership with the Canada Science and Technology Museums Corporation (CSTMC), security personnel will use TC#06-031, a 2006 Ford Escape Hybrid from the eTV fleet, to conduct security patrols at the Science and Technology, Agriculture, War and Aviation museums in the National Capital Region. The CSTMC security personnel accumulate more than 5,000 kilometres per month, which should be enough mileage to be able to quantify the amount of fuel used and to determine if there is a savings.

The OEM installed or stock tires on the Ford Escape Hybrid (all-season and winter) will be tested at Smithers Scientific Services for rolling resistance coefficients. Fuel consumption will be monitored on a daily basis by recording the litres of fuel and mileage in "oil and gas logs" at fill-ups. The fuel consumption will be monitored with the stock tires for one season, and then switched with tires with a lower SMERF for the next season. The fuel consumption with both sets of tires will then be compared.

8.0 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.

8.1 SAE Publications

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

- SAE J1263: Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques
- SAE J1269: Rolling Resistance Measurement Procedure for Passenger Car, Light Truck, and Highway Truck and Bus Tires
- SAE J2452: Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance

8.2 Code of Federal Regulations

Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402
<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

8.3 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

- CMVSS TSD 135 Light Vehicle Brake Systems



Appendix A: Tire Models Selected For Testing

Batch #1 – P195/60R15 TC #08-009 – 2008 Pontiac G5 Special Conditions - Average Tire Load: 700 lb, Recommended Pressure: 30 psi		
Tire # 1	87H	360 A A
Tire # 2	87S	740 A B
Tire # 3	92R XL	N/A (Winter)
Tire # 4	92H XL	N/A (Winter)
Tire # 5	87T	-
Batch #2 – P215/60R16 TC #08-019 – 2008 Toyota Camry Special Conditions – Average Tire Load: 800 lb, Recommended Pressure: 32 psi		
Tire # 6	94H	580 A A
Tire # 7	84T	360 A A
Tire # 8	94T	800 A B
Tire # 9	94S	-
Tire # 10	540	540 A B
Batch #3 – P195/65R15 TC #08-036 – 2008 Honda Civic Special Conditions – Average Tire Load: 702 lb, Recommended Pressure: 31 psi		
Tire # 11	92H	400 A B
Tire # 12	87S	400 AA A
Tire # 13	89S	620 A B
Tire # 14	89S	620 A B
Tire # 15	89T	700 A B
Batch #4 – P195/55R16 TC #10-003 BMW 118d Special Conditions – Average Tire Load: 738 lb, Recommended Pressure: 31 psi		
Tire # 16	86V	400 A A
Tire # 17	87V	N/A (Winter)
Tire # 18	87V	180 A A
Tire # 19	87V	560 A A
Tire # 20	87V	460 A A
Batch #5 – P235/70R16 TC #06-031 – 2006 Ford Escape Hybrid Special Conditions – Average Tire Load: 887 lb, Recommended Pressure: 35 psi		
Tire # 21	106S	N/A (Winter)
Tire # 22	91H	680 A B
Tire # 23	106T	520 A B
Tire # 24	104T	440 A A
Tire # 25	104T	640 A B



Appendix B: Steady-State Rolling Resistance Recording Sheet

Tire Identification		Test Machine Identification	
Tire Number		Test Wheel Diameter	
Tire Size, Max Load, Speed Rating		Test Wheel General Condition	
Tire Load Range*		Tire Mounting Configuration	
Tire Maximum Inflation Pressure		Method of Parasitic Loss	
Serial Number			

Tire History	
Break-In Information	
Use of Tire Beforehand	
Other Pertinent Information	

Test Conditions	
Date / Time	
Rim Width and Contour	
Rotational Direction **	

Data Recording (Gross Readings)								
Test Point	1		2		3		4	
Warm-Up Time Period (min:sec)								
Speed (km/hr)								
Load (N)								
Inflation Pressure (kPa)								
Spindle Force (N)								
Input Torque (Nm)								
Input Electrical Power (W)								
Loaded Radius (m)								
Ambient Temperature (°C)								

Measurement of Parasitic Losses			
Skim Reading (N)			
Machine Offset Torque (Nm)			
Machine Offset Power (W)			

- * If applicable
- ** Determined for the tire side with serial number

Appendix C: Stepwise Coastdown Data Measurement and Recording Sheet



Tire Identification		Test Machine Identification	
Tire Number		Test Wheel Diameter	
Tire Size, Max Load, Speed Rating		Test Wheel General Condition	
Tire Load Range*		Tire Mounting Configuration	
Tire Maximum Inflation Pressure		Method of Parasitic Loss	
Serial Number		Other Pertinent Information	

Test Conditions	
Date / Time	
Rim Width, Contour and Material	
Rotational Direction **	
Tire Load/Inflation Pressure	
Target Load/Inflation Conditions	
Time Period for Warm up	

Data Recording (Gross Readings)											
Test Point	1	2	3	4	5	6	7	8	9	10	11
Speed (km/hr)	115	105	95	85	75	65	55	45	35	25	15
Load (N)											
Inflation Pressure (kPa)											
Spindle Force (N) ***											
Input Torque (Nm)											
Loaded Radius (m)											
Ambient Temperature (°C)											

Measurement of Parasitic Losses			
Skim Reading (N)			
Machine Offset Torque (Nm)			
Machine Offset Power (W)			

- * If applicable
- ** Determined for the tire side with serial number
- *** Forward/Reverse Direction