SURFACE VEHICLE RECOMMENDED PRACTICE

J2777™ JAN2016

Issued 2007-01
Revised 2016-01

Superseding J2777 JAN2007

Recommended Best Practice for Climatic Wind Tunnel Correlation

RATIONALE

This document has been declared "Stabilized" by the SAE Interior Climate Control Steering Committee and will no longer be subjected to periodic reviews for currency. Certain references are being deleted as they are not publicly available. It has been determined by the committee that there is no longer any customer pull for further maintenance, review or revision to the standard.

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1. SCOPE

With many corporations and suppliers conducting development and validation tests at different Climatic Wind Tunnel sites, there is an increasing need for a recommended best practice that defines a process by which climatic wind tunnels can be correlated. This document addresses the test methods and metrics used to obtain similar results, independent of location, for Heating Ventilation and Air Conditioning (HVAC) and Powertrain Cooling (PTC) development. This document should be used as a guideline to make sure key aspects of tunnel testing are covered when comparing various climatic wind tunnel facilities.

The depth of the correlation program is ultimately influenced by program objectives. Therefore a correlation program, for the intent and purposes of this document, can range from just a few tests to a full analysis that involves multiple vehicle tests identifying limitations and statistical boundaries. Using recommendations in this document will eliminate most of the items that effect facility mismatch in a correlation program.

1.1 Background

With manufacturers and OEM's conducting development and validation tests at different Climatic Wind Tunnel sites, there is an increasing need to establish correlation between test facilities. Several climatic wind tunnel organizations and affiliations assembled to discuss a plan to determine what was necessary to complete a successful correlation program. It became obvious that first and foremost all groups involved must understand the variations in climatic wind tunnel design. As a result, attention was diverted to a series of meetings dedicated to special topics, presented by experts in the climatic wind tunnel industry. The information collected throughout these discussions is the foundation used in publishing this document.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2263 Road Load Measurements Using Onboard Anemometry and Coastdown Techniques

SAE J2264 Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques

U.S. EPA SC03 driving schedule representing vehicle operation with air conditioning, as set forth in Appendix I of 40 CFR Part 86

Rout, R. K., "Unique Correlation Technique for Real-World Flow Simulation in the Wind Tunnel," SAE 980033

Yen, J. C. et al., "Determining Blockage Corrections in Climatic Wind Tunnels Using CFD," SAE 2003-01-0936

Yen, J. C. et al., "The Plenum Method versus Blockage Corrected Nozzle Method for Determining Climatic Wind Tunnel Airspeed," SAE 2004-01-0668

Hucho, W.-H., Aerodynamics of Road Vehicles, 4th Ed., 1998, SAE

3. FACILITY CAPABILITIES

With environmental and vehicle load simulation being the primary function of climatic wind tunnels, it is imperative that all facility parameters are captured in the effort of reproducing "real world" conditions that exist within the test environment. The accuracy of the instruments used in the measurement of these parameters is detrimental to the outcome of the test. Although calibration methods and processes are not included in scope of this document, demonstration of compliance of calibration should be included in the final correlation report. It's recommended that the instrumentation used throughout the correlation effort is calibrated and traceable to the National Institute of Standards and Technology.

3.1 Air Temperature

Air temperature is also referred to as dry bulb temperature. It is the temperature the test vehicle will experience while in the test section and is set for specific condition. Its point of measurement should be before the test vehicle and after the heat exchanger that is used by the test cell for conditioning and in maintaining dry bulb temperature. A preferred location would be in the exit air stream prior to leaving the exit nozzle. A precision probe or RTD, (Resistive Thermal Device) should be used for measuring this parameter. The range of operation for the purpose of this practice is -15 °C to +38 °C.

3.2 Humidity

Humidity can be measured by obtaining wet bulb temperature, using a chilled mirror, or other forms of humidity analyzers. This measurement should be in close proximity of the location in which dry bulb temperature is measured and follows the same criteria for location. The range of operation for the purpose of this practice is 40 to 90 % RH.

3.3 Vehicle Speed

Generally dynamometer roll speed is measured and reflects the actual vehicle wheel speed. The speed measured by the vehicle is not necessarily the same as the target speed measured at the roll dynamometer. Therefore speed set point, for the purpose of this correlation effort, is dynamometer roll speed (both target and measured). The range of accuracy for the purpose of this practice is 0 to 110 kph.

3.4 Tractive Effort

This also requires a chassis dynamometer and is the measurement of the net force applied to the vehicle power train after vehicle and dynamometer losses are accounted for. The tractive effort target force as it relates to speed is the measurement that should be used throughout the correlation program and carried from facility to facility. In doing so, variation in dynamometer roll size, load cell orientation, etc remain specific to a given facility and not the vehicle under test. The range of accuracy for the purpose of this practice will be determined by the capability of the vehicle under test.

3.5 Solar Simulation

Solar (Sun) simulation is required for HVAC / PTC development and validation. There are a number of different solar simulation arrays currently in use, the most common being IR and near full spectrum. The variation in solar simulators must be well documented and understood at each facility used. The effects of a few solar simulators currently in use are illustrated in Section 6 of this document. The maximum range of accuracy for the purpose of this practice should be a uniform distribution of 1000 W/m^2.

3.6 Wind Speed and Blockage Correction

Typically the wind speed measurement is upstream of the vehicle under test. Facility instrumentation is used to infer the wind speed based on previous calibration tests. It is important that wind speed (as corrected for blockage) matches the dynamometer roll speed in a steady state mode and follows as close as possible to transient conditions. The range of accuracy for the purpose of this practice should be at least 0 to 110 kph.

Aerodynamic interferences due to discrepancies in boundary conditions in a wind tunnel simulation compared to the open road are collectively referred to as “blockage”. Blockage depends not only on the wind tunnel boundary conditions, but also the size and shape of the vehicle under test and the method used to measure the facility’s wind speed. Corrections for blockage are therefore desirable for the best possible wind speed simulation. This is discussed in more detail in Section 5.

3.7 Nozzle Size

Exit nozzle size used at each facility involved in the correlation effort needs to be documented and referenced as necessary when comparing results. Facilities that have extendable nozzles should use the nozzle to vehicle front end distance typically used for HVAC and PTC tests. Facilities that can vary their exit nozzle size (nozzle inserts or flaps) should use the maximum nozzle size possible to meet the wind speed requirement of 0 to 110 kph.

4. DYNAMOMETER LOAD SIMULATIONS

Regardless of individual climatic wind tunnel capabilities, dynamometer load simulation needs to result in good correlation between facilities. While most groups have their own process for duplicating real world force loads, the method necessary to correlate wind tunnel facilities can be simplified into a 2nd order polynomial equation that includes vehicle, trailer, and grade simulation forces. Identifying the vehicle and trailer load equation and making sure the loads are applied at the vehicle powertrain will result in exceptional load correlation between facilities. Otherwise it’s one of the biggest causes of correlation mismatch.

4.1 Vehicle Target Road Load Simulation Force

The target road load simulation force is the force that must be overcome by the vehicle powertrain to maintain steady speed on a flat road. The illustration below demonstrates the origin of these forces. By conducting an on road coastdown per SAE J2263 – Road Load Measurements Using Onboard Anemometry and Coastdown Techniques, these forces can be identified at predetermined speeds. At which point a best fit 2nd order polynomial equation can be derived. Since the purpose of this paper is to provide recommendations that result in optimum correlation, only the Target Road Load Simulation Force equation will be discussed. How the equation is obtained is covered in SAE J2263.

Figure 1 - Target road load forces experienced on a passneger vehicle

Target Road Load Simulation Force (Vehicle) = $(A_V + B_V{*}V + C_V{*}V^2 + M_V\, dV/dt)$ Newtons (Eq. 1)

where:

A_V	= Mostly Constant Friction (approximated by $Crr{*}W_V$)	Units = N
B_V	= Mostly Variable Friction (proportional to speed)	Units = N/kph
C_V	= Mostly Aero Resistance (approximated by $1/2\rho C d A_F V^2$)	Units = N/kph^2
W_V	= Weight of Vehicle	Units = N
M_V	= Mass of Vehicle or Weight / 9.81	Units = kg
V	= Vehicle Speed	Units = kph
t	= Time	Units = Seconds
Crr	= Coefficient of Rolling Resistance	Units = None
ρ	= Air Density	Units = kg/m^3
A_F	= Frontal Area	Units = Meters^2

4.2 Matching the Target Road Load Force on a Chassis Dynamometer

While the Target Road Load Simulation Force equation is common to all facilities involved in the correlation effort, the method of applying the target force becomes specific to the facility conducting the correlation test. The reason for this is that climatic wind tunnels will have slight differences in chassis dynamometer configurations. Tire to dynamometer roll interface and load cell locations are just a few examples. In addition the vehicle itself exhibits retarding forces when installed in the climatic wind tunnel test section. A good example of this would be the vehicle tie down restraint forces exhibited in all three axes. These types of vehicle and dynamometer (loss) forces are not included in the Target Road Load Force Equation obtained on road, making it necessary for adjustment when installed on a chassis dynamometer.

4.2.1 Vehicle Coast down Determination - Preferred Method

The preferred method for assuring target road load forces are seen by the vehicle powertrain is performing a vehicle coast down on a chassis dynamometer. The coast down should be conducted in accordance with SAE J2264 “Chassis Dynamometer Simulation of Road Load Using Coast down Techniques”. SAE J2264 provides a method for dynamometer load coefficient adjustment that eliminates variations in chassis dynamometer, and interface configurations. In other words, the load measured by the chassis dynamometer load cell is specific for a given facility and installation, but the target load applied at the vehicle powertrain remains the same. This is especially important for running low load tests, such as those required for HVAC. The illustration below shows typical losses that can be measured by the dynamometer load cell when running a coast down determination procedure.

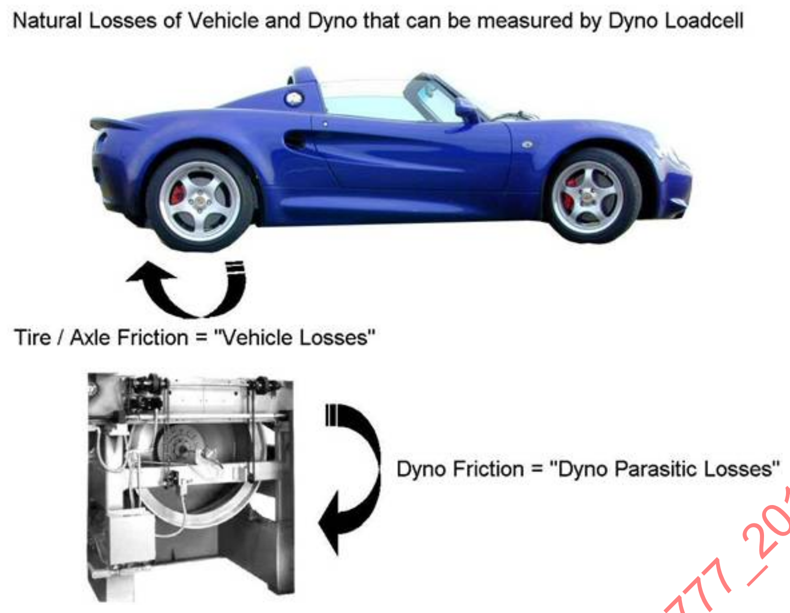


Figure 2 - Measurable forces in a climatic wind tunnel

It's important to note that the proving ground coast down (SAE J2263) and the chassis dynamometer coast down (SAE J2264) are separate tests. They are used in conjunction to assure target loads are applied at the vehicle powertrain, regardless of the facility conducting the test.

4.2.2 Vehicle Coast down Determination - Alternative Methods

Climatic wind tunnel facilities can closely approximate the SAE J2264 standard by developing alternative methods, making optimum use of a chassis dynamometer that doesn't have the coastdown capability. An adjustment to the A, B and C coefficients, or a clever execution of a built in dynamometer calibration program to name a just a few examples. If an alternative method is used in lieu of a coast down determination, it must be well documented and understood by all facilities involved.

4.2.3 Vehicle Coast down Quick Check

Once the coast down determination procedure is executed, the road load simulation can be verified by performing a quick check coast down. (See 2.1.2 - TP 712C, Quick Check Coast downs). The time it takes for a vehicle to coast down on the chassis dynamometer should be consistent with the manufacturers target coast down time.

4.3 Trailer Road Load Simulation

Trailer road load forces experienced in the real world can be simulated in a laboratory environment similar to a vehicle. The difference being empirical data should be used to derive the trailer road load equation (also a 2nd order polynomial equation). Measured trailer drawbar (load cell) forces are obtained from a particular vehicle and trailer combination at predetermined speeds. The A, B, and C coefficients are derived from the load vs. speed curve for a vehicle/trailer combination that's best suited for the vehicle under test. While manufacturers typically simulate a trailer that yields the largest load in a given weight class, a lighter load can be used for the correlation program. This may eliminate the necessity of terminating tests prematurely or replacing failed components, each of which add to variability in the correlation program.

$$\text{Trailer Road Load Simulation Force} = (A_T + B_T V + C_T V^2 + M_T\, dv/dt) \text{ Newtons} \qquad \text{(Eq. 2)}$$

4.4 Grade Load Simulation Force

By adding grade [G] to the equations defined in 4.1 and 4.3, we can simulate grade loads in a climatic wind tunnel using the following equation:

$$\text{Vehicle Grade Load Simulation Force} = (A_V + B_V{*}V + C_V{*}V^2 + W_VG + M_V\,dv/dt)\ \text{Newtons} \quad \text{(Eq. 3)}$$

$$\text{Trailer Grade Load Simulation Force} = (A_T + B_T{*}V + C_T{*}V^2 + W_TG + M_T\,dv/dt)\ \text{Newtons} \quad \text{(Eq. 4)}$$

where:

G = Sin [Arc Tan [% grade]] and % grade is in decimal format

4.5 Vehicle, Trailer and Grade Load Simulation Force

By simply adding like coefficients in 4.1, 4.3 and 4.4 the complete road load simulation equation used for correlation becomes:

$$\text{Vehicle, Trailer and Grade Load Simulation Force} = \text{Vehicle Target Force} + \text{Trailer RLS Force} + \text{Grade Force} = [(A_V + A_T) + (B_V + B_T)V + (C_V + C_T)V^2 + (W_V + W_T)G + (M_V + M_T)dv/dt]\ \text{Newtons} \quad \text{(Eq. 5)}$$

4.6 Simulated Mass

4.6.1 Simulated Vehicle Mass Used for HVAC

Simulated vehicle mass used for HVAC testing can vary depending on the program objectives. The suggested vehicle mass for HVAC correlation testing is:

Vehicle Curb Mass + 1/2 tank fuel + 2 passengers (for correlation purposes, 150 kg will be used to simulate fuel and passengers for HVAC tests).

4.6.2 Simulated Vehicle Mass Used for PTC/Thermal

Simulated vehicle (only) mass used for PTC/Thermal tests can vary depending on the program objectives. The suggested vehicle (only) mass for PTC Thermal testing is GVM [Gross Vehicle Mass], defined as follows:

Vehicle Curb Mass + full tank fuel + maximum passengers and cargo, kilograms.

4.7 Simulated Mass Used for Trailer

Simulated trailer mass used for PTC/Thermal can also vary depending on the program objectives. The suggested trailer mass for PTC/Thermal testing is a function of the vehicle/trailer combination for the given trailer class, shape, dimensions and mass. Facilities using different methods for simulating trailer road load forces will experience considerable loading mismatch. This is explained in more detail in 4.7.1 below.

4.7.1 Trailer Classifications (Different Loads for Same Mass)

Manufacturers use different approaches to identify the way trailers are simulated on a chassis dynamometer. Simply put, various trailer sizes and shapes can yield different loads for the same mass. The illustration below demonstrates the load effects of different trailer sizes using same trailer mass. All trailers were towed using the same vehicle, yet the trailer load forces are considerably different. It's up to the correlation lead to determine which trailer type is to be used throughout the entire program, get it into the load equation described in 4.3, and use it consistently throughout the program.

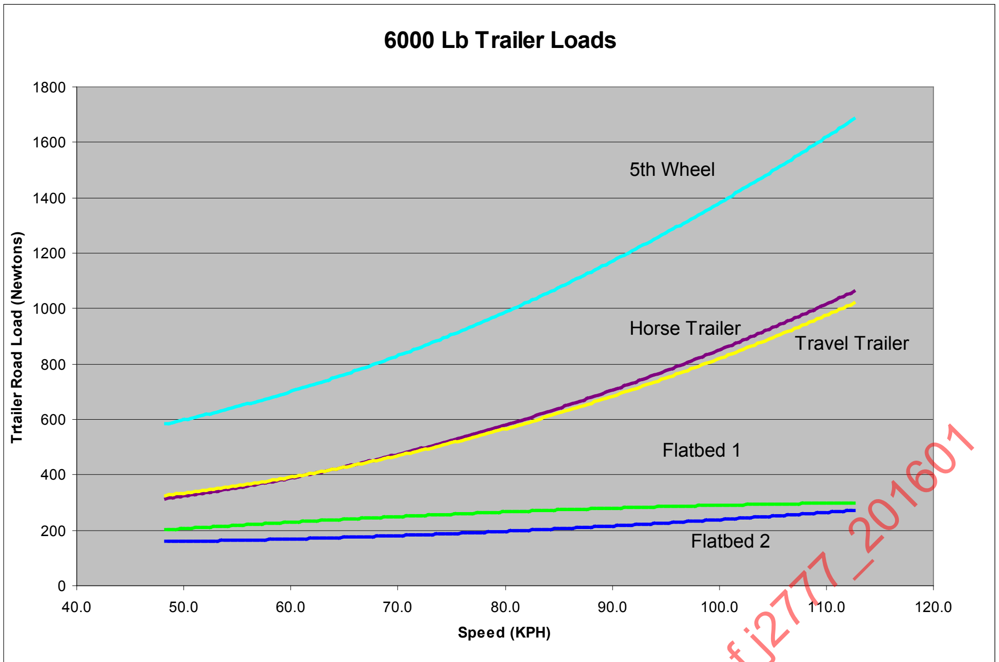


Figure 3 - Variability in trailer road load forces with the same trailer weight

5. WIND SPEED SETTING AND TUNNEL BLOCKAGE CORRECTIONS

Although calibration methods and processes are not included in the scope of this document, wind speed measurement and compensation for test section blockage must be discussed to assure the proper volumetric airflow is measured through vehicle front end. Certain considerations will be covered in this section to assure the (corrected) wind speed results in proper front end airflow. Otherwise uncorrected wind speed or front end air flow will result in one of the hardest influences to identify as a contributor to facility mismatch.

5.1 Wind Speed Considerations

Wind speed setting consists of two steps: one is the calibration of the facility instrumentation in an empty wind tunnel and the other being empirical corrections for aerodynamic interferences (blockage) seen by the vehicle in the tunnel but not on the open road. These interferences are influenced by tunnel dimensions, vehicle size and shape, and the location of the instrumentation used to measure and set wind speed.

5.2 Wind Speed Calibration Considerations

Wind speed calibration is just an extension of instrument calibrations, but the entire wind tunnel is the instrument in this case. The objective of the wind speed calibration is to develop a calibration curve or lookup table that relates a velocity standard to the instrument(s) used by the facility to measure the wind speed. The velocity standard is typically a pitot-static probe. It should be mounted somewhere in the empty test section (e.g., front dynamometer rolls) and should always be placed in the same position in subsequent wind speed calibrations. Similar to other conventional laboratory instruments, running the tunnel through several (5-10) main fan speed rpm settings provides a data set from which a calibration relationship can be developed between the velocity standard and the wind tunnel's built-in instrumentation. With this relationship available to the tunnel's control software, it is then possible to remove the velocity standard, install the vehicle, and set the tunnel's wind speed during an actual test.

A number of methods may be used to measure the facility's wind speed.

Preferred measurement techniques include:

Pressure difference across contraction (nozzle method)

Pressure difference between settling chamber and plenum (plenum method)

Alternative measurement techniques include:

Vane anemometer in nozzle or (preferably) settling chamber: may be influenced by the presence of the vehicle, but may be more accurate than pressure instrumentation for wind speeds below 20 km/h

Hot-wire anemometer: requires corrections for temperature, density, and relative humidity and can be influenced by to the presence of the vehicle, but may be more accurate than pressure instrumentation wind speeds below 20 km/h

Pressure differential across fan: least susceptible to vehicle presence, but a different wind speed calibration is required if “idle bypass” vents are ever used without closing off flow through the nozzle

Main fan rpm: not preferred as there is a different mass flow from the tunnel’s fan based on size of vehicle (the fan would need a different system curve for each vehicle)

5.3 Wind Tunnel Blockage Considerations

The first illustration below demonstrates that on the open road, the velocity field several meters upstream of the front bumper “knows” the vehicle is there. In other words, the vehicle creates pressure that slows down the wind speed forward of the vehicle, as required by the Bernoulli principle. As shown in the plot, the wind speed measured by the boom anemometer is lower than the wheel speed.

The boom anemometer in the photo is located roughly where the wind tunnel nozzle would be in a climatic wind tunnel. Therefore, without even considering aerodynamic interferences (“blockage”) due to differences between the road and the wind tunnel, it can be seen that simply setting the wind tunnel instrumentation to provide an air speed at the nozzle exit which is equal to the wheel speed will result in too much airflow at the front end of the vehicle relative to what it would see on the open road.

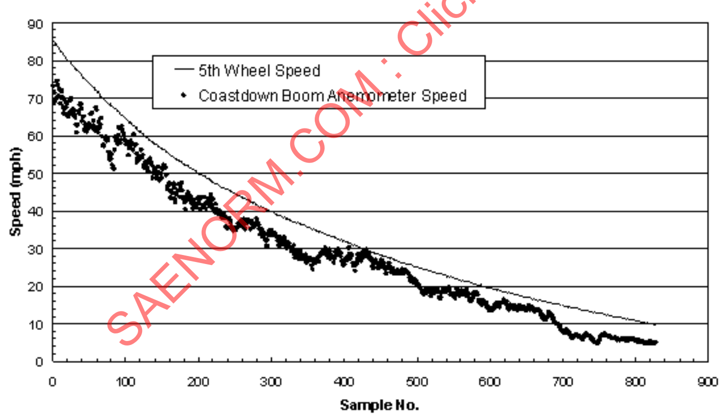


Figure 4 - On road wind velocity measurement using boom annemometer

On the open road, the vehicle may be considered to be submerged in a jet of air of infinite size. In a wind tunnel simulation, this is not the case, as suggested in the sketch below. Aerodynamic interferences occur at the boundaries of the wind tunnel compared to the open road. For example, the wind tunnel’s nozzle area is only slightly larger—and sometimes even smaller—than the frontal area of the vehicle under test. Interferences also occur at the edges of the air jet as it passes over the vehicle, due to the presence of walls (in closed-jet wind tunnels) or quiescent air (in open jet wind tunnels).

The vehicle’s size relative to the nozzle, the quiescent air surrounding the jet, the resulting shear layer, the developing boundary layer on the tunnel floor, and the distance between the front bumper and the nozzle exit plane are all factors that do not exist in an interference-free (open-road) environment.

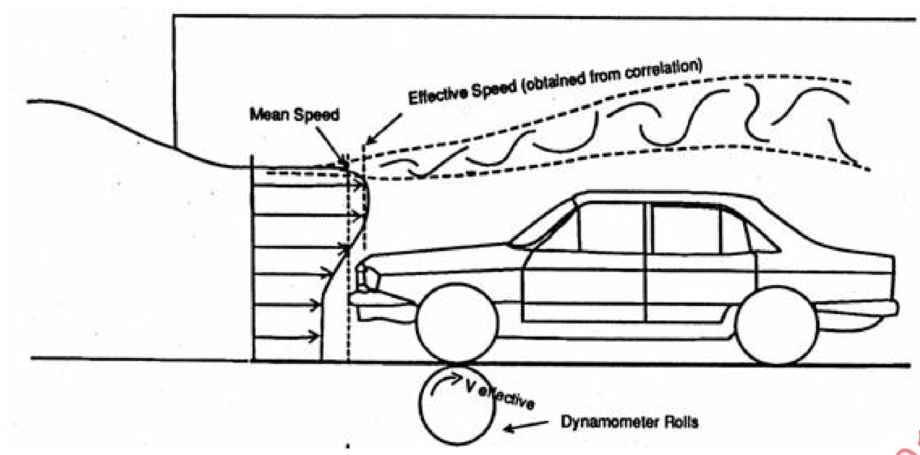


Figure 5 - Wind tunnel velocity profile

In a climatic wind tunnel, the result of these interferences is a distortion in the velocity field in front of and around the vehicle. Some parts of the vehicle experience a reduction in speed compared to the open road, and other parts may experience an increase. For most climatic wind tunnel tests, the front end air flow should match the open road.

For large aerodynamic wind tunnels, theoretical corrections for blockage can usually be applied because the presence of a vehicle in the wind tunnel jet results in a mathematically “small” distortion of the jet. This is not the case in climatic wind tunnels, so that empirical corrections based on track or road testing are necessary to account for different vehicle sizes and shapes. Typically, a reasonable correction can be developed for individual generic classes of vehicles (e.g., sedan, SUV, small pickup, large pickup). In some cases, a single correction is possible if the appropriate dimensionless parameters are identified and included in the correlation analysis. Modern computational methods may also be appropriate. Examples are provided in the references section of this document.

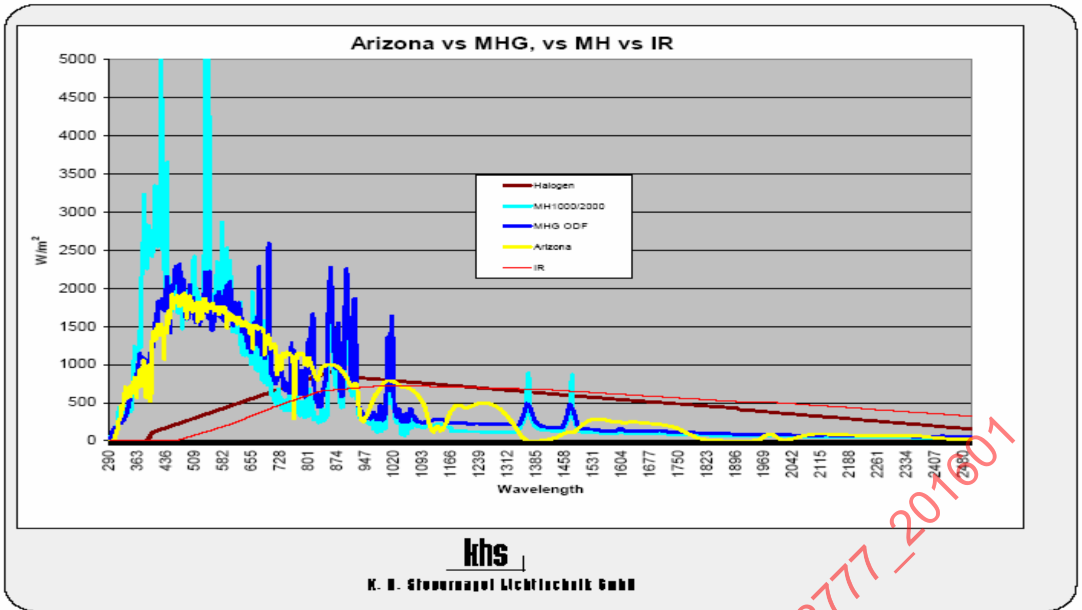
Without blockage corrections, the error in wind speed setting may be as high as 10% to 15%, particularly if the vehicle is large and the front bumper is less than about 1 m downstream of the nozzle exit plane. However, the error is typically closer to 5%, but it is also in the non-conservative direction (i.e., wind tunnel speed is *higher* than what would be seen on the road). Blockage corrections can reduce this to 2% or less.

6. SOLAR SIMULATION

Solar intensity, uniformity, spectrum, vehicle glass angle, vehicle interior/exterior color and distance to the vehicle under test are a few of the influences solar simulation can have an effect on the vehicle temperatures. These influences, if not well measured and documented, can lead to correlation mismatch, particularly for HVAC performance tests.

6.1 Solar Spectrum

The recommended solar spectrum should be as specified below (from the 2006 version of SC03 emissions testing as outlined in 40 CFR part 86). The solar array should exhibit a distribution as close as possible to the Global Radiation Spectrum. Since non-compliance to this spectrum may be acceptable for the correlation effort, solar simulation lamp type and spectrum will need to be documented and included in the final report. The illustration below shows the spectral distribution of different types of radiation sources, with Metal-Halide Global (MHG) closely simulating the Global Radiation Spectrum.



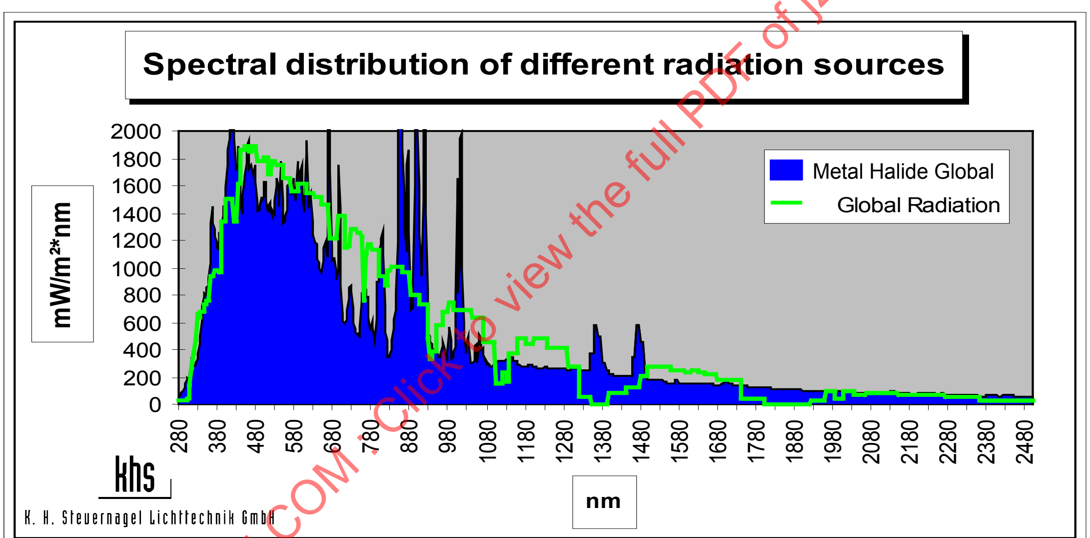


Figure 6 - Global and simulated solar radiation spectrum

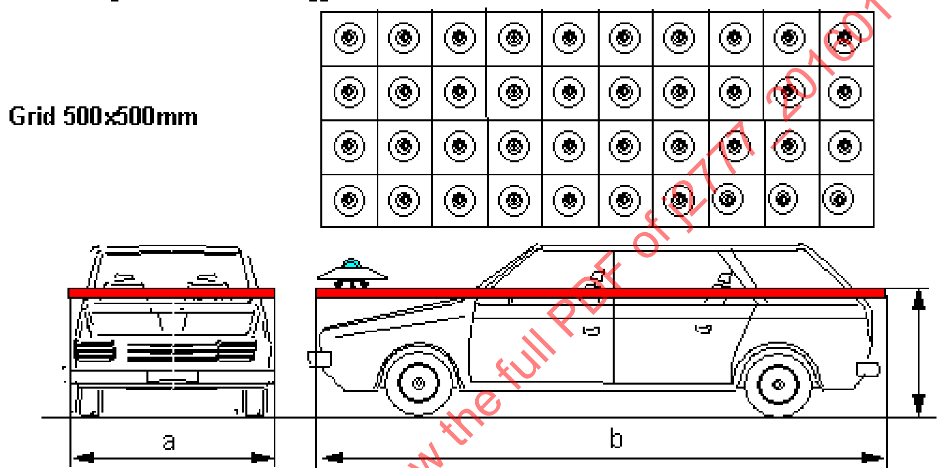
6.2 Solar Intensity and Distribution

Solar intensity and distribution requirements can vary depending on the program objectives. The solar density required for the correlation effort should be 1000 watts/meter^2. It is recommended that the solar load distribution as measured at the extremes, fore/aft and left/right of the vehicle under test, not exceed 15% (10% preferred) of the nominal setting at a height of one meter from the test section floor. Recommendations for measuring distribution and uniformity are shown in the illustration below.

Spectral Power Distribution:	**Wavelength range**	**Percent of total spectrum**
	< 320nm	**0%**
	320-400nm	**0......7%**
	400-780nm	**45.....55%**
	> 780nm	**35.....53%**
Uniformity of Irradiance: point (1000W/m²)	**+/- 15% (10% recommended) irradiance set**	

Needs to be verified by measuring each point of a 500mm grid over the entire footprint of the test vehicle at the elevation of 1000mm above

Uniformity of Radiant Energy



Radiation Angle of Incidence: Must be 90 degrees from the test cell floor.

Figure 7 - Recommended solar simulation distribution

6.3 Solar Lamp Height

Solar lamps lamp distance from the roof of the vehicle centerline, 30 cm rear of the windshield to the lamp array bulbs or lens should be measured and included in the final report.

6.4 Side Banks

If solar side banks are used, the location and angle of incidence with respect to the roof of the vehicle centerline 30 cm rear of the windshield should be documented and included in the final report.

6.5 Measurement

Solar load should be monitored continuously during testing. It is recommended that (2) solar pyranometers be situated one at the base of the windshield and the other at the rear back glass as shown in the illustration below. The solar pyranometer readings should be included in the data recorded for each test.

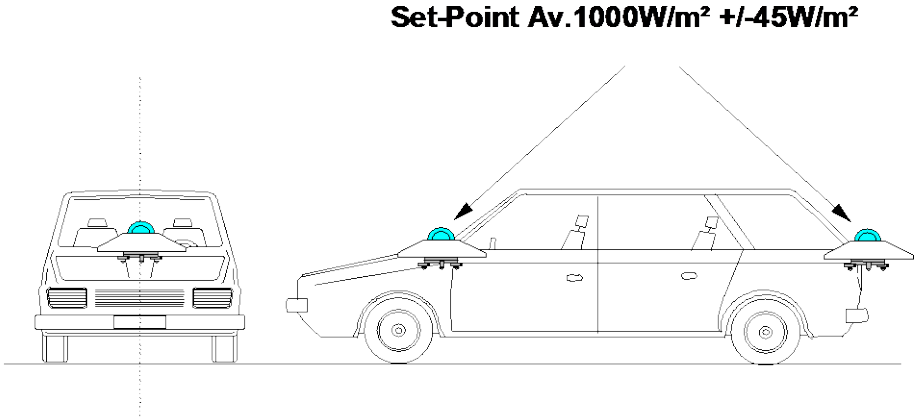


Figure 8 - Simulated solar measurement

6.6 Considerations

While solar lamp type and placement are critical parameters for the correlation effort, other influences must be considered. For example, the solar load on a vehicle interior may be affected by glass angles and types as illustrated below. The angle of glass is fixed as part of the correlation vehicle design; however glass type may be optional and as a minimum should be documented and included in the final report.

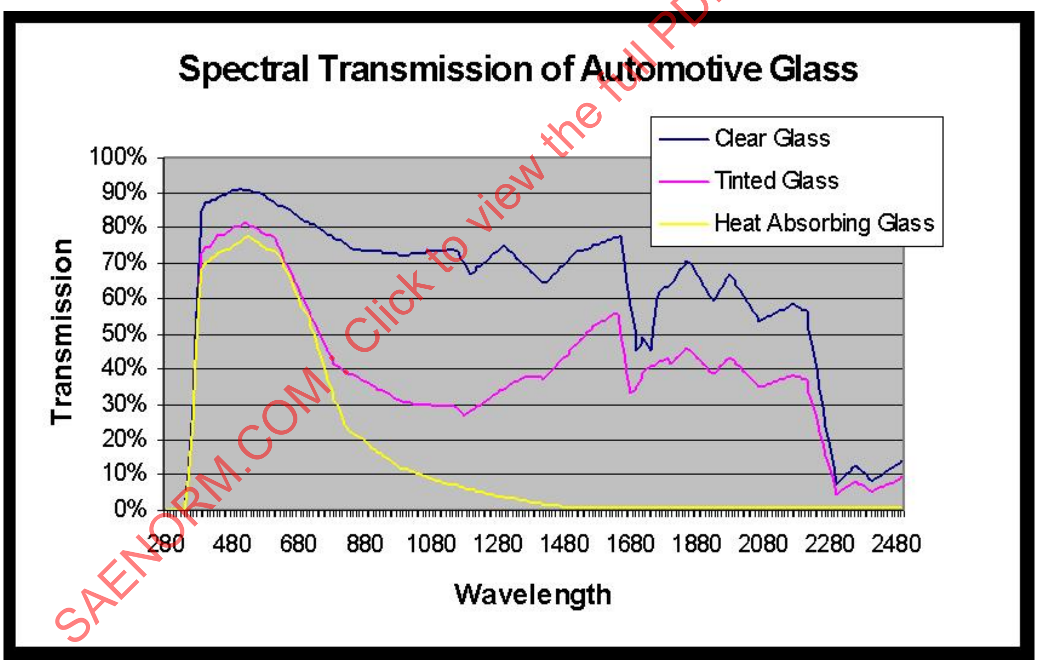


Figure 9 - Solar transmission as a function of glass type

Exterior and interior vehicle colors and finishes can also affect the outcome of the correlation test as illustrated below. The exterior and interior colors of the vehicle under tests should also be documented and included in the final report.

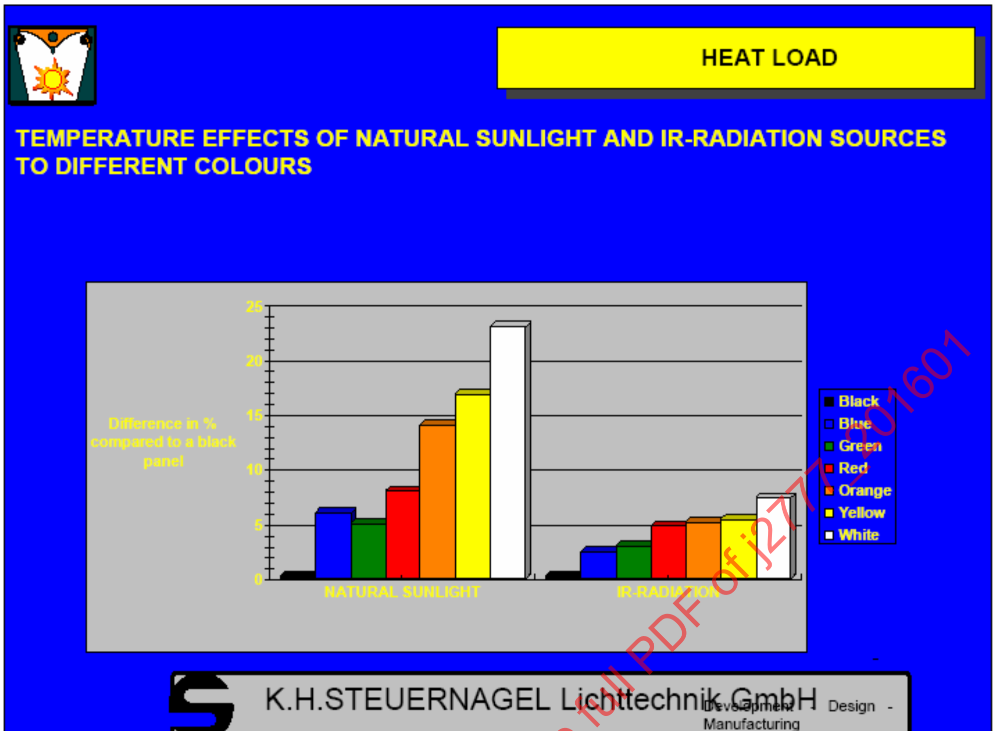


Figure 10 - Temperature effects of solar sources to different colors

7. IDLES AND SOAKS

Typically this phase of the test is designed to simulate a condition when a vehicle is parked in front of a wall or stopped on the road (traffic light or traffic jam) with or without a vehicle in front. This is normally the most severe condition that an HVAC system is exposed to in a hot environment, since this condition realizes little to no air available to cool the condenser. Simulation of this condition is very critical in predicting the performance of the vehicle HVAC system. Most idle breezes, drafts, and directions of air flow are difficult to measure in both engine on idles or engine of soaks.

A flow visibility video should be considered at each of the facilities involved in the correlation effort, as this condition is very difficult to measure and quantify with instrumentation alone. It is recommended that the airflow in front of the vehicle (front bumper center grill) and up to the two sides near B- pillar at be measured for each facility invlolved.

7.1 Idle and Soak Configurations

Some facilities completely turn off the airflow in the nozzle to simulate the real world idle condition. Since the engine is typically hot, the vehicle tends to add heat to the test chamber increasing the surrounding ambient. In order to maintain the test section temperature, a low volume of air is re-circulated in the tunnel circuit through the test chamber in order to carry added the heat away from test section. An idle door is used in front of the nozzle opening to block the air from the front of the vehicle. The re-circulating air is bypassed (redirected) by means of a set of idle doors located in the nozzle straight section before the nozzle opening. This design allows the test section temperature to be controlled within a certain tolerance level depending on the facility capability.

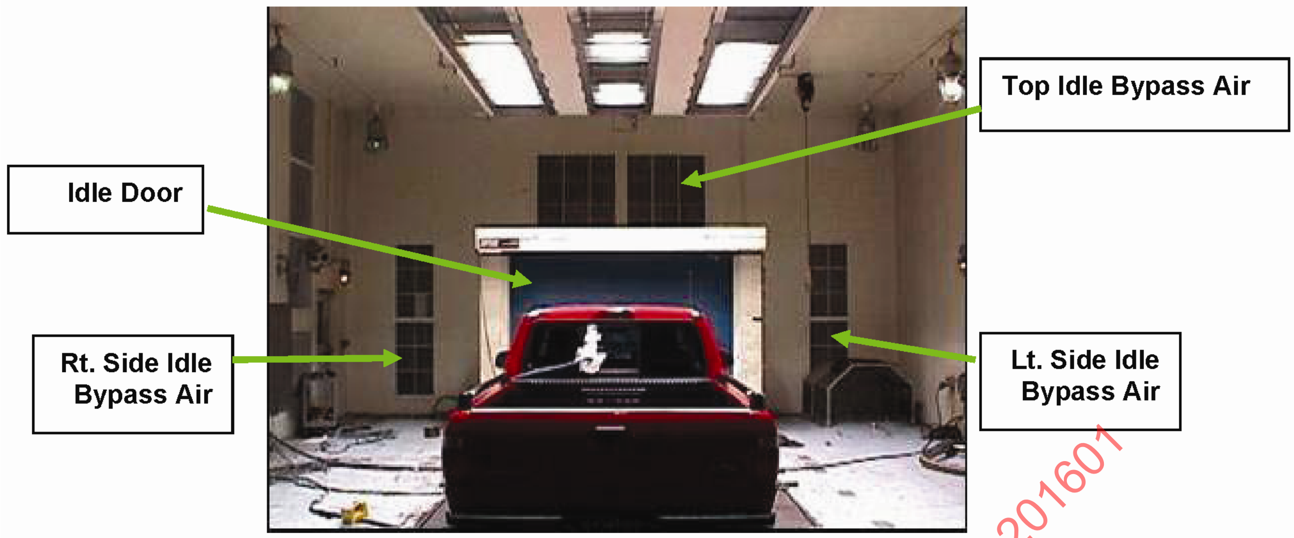


Figure 11 - Vehicle in wind tunnel showing bypass air configuration

The automotive testing community uses different combinations or variations of idle bypass air design. Some facilities use bypass doors, which allow the air to flow on both sides of the test chamber but away (immediate vicinity) from the sides of the vehicle. Others use by pass doors that direct air over the top of the exit nozzle. Or a combination of the two can be used.

If a facility does not have an idle bypass capability, an idle board or wall can be placed in front of the vehicle. This allows low volume airflow to continue into the climatic wind tunnel test section to maintain temperature and humidity control. This configuration may also have significant impact on the test results. If used, the idle board configuration, dimensions, and distance to front bumper should be measured and recorded.

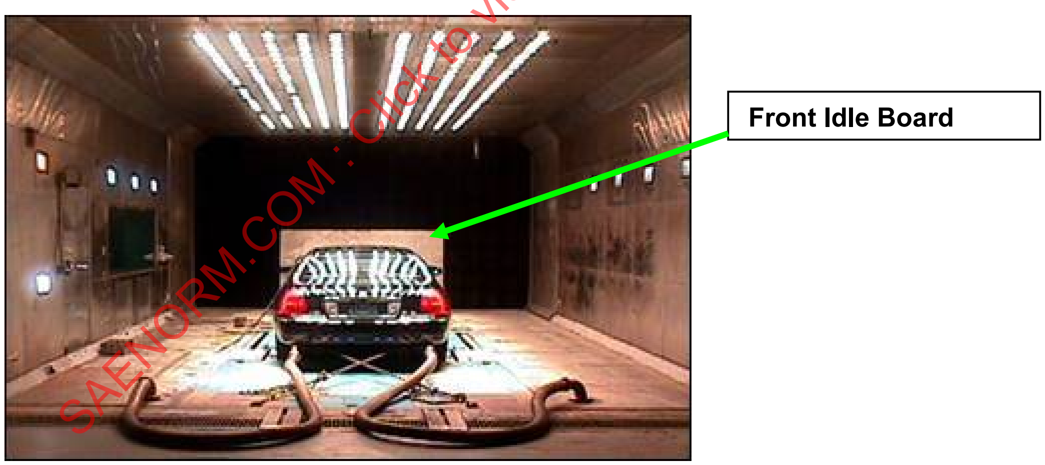


Figure 12 - Vehicle in wind tunnel with air bypassair using idle board

7.2 Test Section Temperature During Idle

The test section temperature during an engine on or engine off idle is very critical for the idle performance and must be controlled and measured. It is recommended that the test section ambient air temperature during the idle portion of the test be maintained within ±1 °C of the target test temperature, measeure at near the wind tunnel exit nozzle, before the bypass or idle board.

7.3 Vehicle Soak

7.3.1 High Temperature Soak (Before Test)

Before the solar soak begins, the vehicle should be blown down (preconditioned) using 50 km/h wind speed with the doors and windows open and the vehicle air mode set in outside air (where possible). The vehicle should be conditioned for a minimum of 1 hour and as long as it takes to get the vehicle interior mass temperature to be within 1 °C of the target test temperature.

7.3.2 High Temperature Solar Soak

Vehicle should be soaked to a specified average interior breath level temperature in conjunction with a vehicle mass interior mass temperature (i.e. seat rail of knee bolster) Engine off, windows and doors closed idle door down or idle board in place.

During this soak period the average solar load should be 1000 watts/m² as described in Section 6.

7.3.3 High Temperature Soak Time

The soak time should be a minimum of 1 hour. Any additional soak time should include the time it takes for interior breath level temperatures and vehicle interior mass temperature to reach a target temperature within the limits set by the correlation lead. The combinations of these three variables (soak time, interior breath and mass temperatures) will give the correlation lead an idea of how consistent the solar simulation and soak condition are across the facilities involved.

7.3.4 Low Temperature Soak (Before Test)

For low temperature soaks, the vehicle soak should be conducted with windows and doors open and at a wind speed of 50 kph. No artificial means of lowering temperature, particularly engine oil temperature, should be used.

7.3.5 Low Temperature Soak Time

The vehicle soak will continue until all vital fluids and interior mass temperatures are at the ambient test temperature within ±1 °C. To expedite testing, the vehicle can be presoaked in a soak room and moved into the test section prior conducting a test.

8. WIND TUNNEL COMPARISON TEST SCHEDULES

The purpose of constructing the following test procedures is to allow a comparison of test data between different tunnels. The tests were constructed to include various events that are commonly employed when testing vehicles in Climatic Wind Tunnels. More than one iteration of the tests should be conducted to assure repeatability within a given facility. The correlation lead should determine how many times each test needs to be conducted.

The following recommendations should be considered prior to conducting the correlation test procedures:

A common vehicle (same vehicle) is shared between various tunnels, in an effort to remove vehicle and instrumentation differences that affect the outcome of the comparison effort. The A/C charge level and vital fluids must also be checked prior to running each test.

A pretest checklist should be developed and utilized. Thought starters for a pretest checklist can be found in Appendix A.

A coastdown determination (or equivalent) is completed. See Section 4.

An onboard Data Acquisition System (DAS) is utilized such that all parameters are measured at the unit, including parameters provided by the facility. All parameters should be measured and recorded using the onboard DAS at a sampling rate of 1 sample per second.

The gear required for each of the Road Load simulation Tests should be the highest gear. The gear for the WOT test depends on the vehicle being test and should be identified by the correlation lead.

8.1 Heater Test

8.1.1 Ambient Conditions

Temperature: -15 °C
Relative Humidity: Document
Solar Intensity: Solar Off

8.1.2 Data Recording Rate: 1 sec

8.1.3 Vehicle Mass: Curb Mass + 150 kg

8.1.4 Procedure

1. Allow vehicle to obtain ambient temperature as described in Section 7.
2. Start recording data before starting vehicle to capture cold soaked condition.
3. Start vehicle.
4. Set Front (and Rear) HVAC controls to:
   Full hot
   Highest blower speed
   Floor outlets
   Air supply in outside air mode
5. Accelerate vehicle (3 kph/s) to 50 kph.
6. Maintain 50 kph for 10 minutes.
7. Accelerate vehicle (3 kph/s) to 80 kph.
8. Maintain 80 kph for 15 minutes.
9. Bring vehicle to a stop (5 kph/s).
10. Deploy idle door or board and idle in neutral for 10 minutes.
11. Stop Data Recording
12. Test Complete.

8.2 AC Test

8.2.1 Ambient Conditions

Temperature: 38 °C
Relative Humidity: 40%

8.2.2 Data Recording Rate: 1 sec

8.2.3 Vehicle Mass: Curb Mass + 150 kg

8.2.4 Procedure

1. Open vehicle doors and windows and allow vehicle to obtain ambient temperature (solar off).
2. Start recording data to capture vehicle starting condition.
3. Close vehicle doors and windows.
4. Apply solar intensity of 1000 W/m² for 1 hour (while recording data)
5. Start vehicle
6. Set Front (and Rear) HVAC controls to:
   Full cold
   Outside air mode
   Highest blower speed
   Position A/C duct outlets and louvers
7. Accelerate vehicle (3 kph/s) to 50 kph.
8. Maintain 50 kph for 10 minutes.
9. Accelerate vehicle (3 kph/s) to 80 kph.

10. Maintain 80 kph for 15 minutes.
11. Bring vehicle to a stop (5 kph/s).
12. Deploy idle door or board and idle in neutral for 20 minutes.
13. Stop Data Recording
14. Test Complete.

8.3 Powertrain Cooling Test #1

8.3.1 Ambient Conditions

Temperature: 38 °C
Relative Humidity: 40%
Solar Intensity: 1000 W/m²

8.3.2 Data Recording Rate: 1 sec

8.3.3 Vehicle Mass: Gross Vehicle Mass Rating (GVMR)

8.3.4 Procedure

1. Start recording data to capture vehicle starting condition.
2. Start vehicle
3. Set Front (and Rear) HVAC controls to:
   Full cold
   Outside air mode
   Highest blower speed
   Position A/C duct outlets and louvers
4. Accelerate vehicle to 110 kph (5kph/s).
5. Maintain 110 kph Road Load for 30 minutes.
6. Obtain 110 kph Wide Open Throttle (WOT) condition.
7. Maintain 110 kph WOT for 20 minutes.
8. Bring vehicle to a stop (5 kph/s).
9. Deploy idle door or board and idle drive for 20 minutes and neutral for 10 minutes.
10. Stop Data Recording
11. Test Complete

8.4 Powertrain Cooling Test #2

8.4.1 Ambient Conditions

Temperature: 38 °C
Relative Humidity: 40%
Solar Intensity: 1000 W/m²

8.4.2 Data Recording Rate: 1 sec

8.4.3 Vehicle Mass: Gross Combined Mass Rating (vehicle and trailer)

8.4.4 Procedure

1. Start recording data to capture vehicle starting condition.
2. Start vehicle
3. Set Front (and Rear) HVAC controls to:
   Full cold
   Outside air mode
   Highest blower speed
   Position A/C duct outlets and louvers
4. Accelerate vehicle to 90 kph (5 kph/s).