



SURFACE VEHICLE RECOMMENDED PRACTICE

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Recommended Best Practice for Climatic Wind Tunnel Correlation

RATIONALE

The document was updated to include specific requirements for electrified vehicles (BEVs, PHEVs, HEVs). Additionally, it was updated to incorporate latest best practices as well as updated formatting for improved clarity.

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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 correlate results from different facilities, 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 OEMs 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
SAE J1263	Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques
R-430	Aerodynamics of Road Vehicles

Rout, R., "Unique Correlation Technique for Real-World Flow Simulation in the Wind Tunnel," SAE Technical Paper 980033, 1998, <https://doi.org/10.4271/980033>.

Yen, J., Martindale, W., Duell, E., and Arnette, S., "Determining Blockage Corrections in Climatic Wind Tunnels Using CFD," SAE Technical Paper 2003-01-0936, 2003, <https://doi.org/10.4271/2003-01-0936>.

Yen, J., Martindale, W., and Duell, E., "The Plenum Method Versus Blockage Corrected Nozzle Method for Determining Climatic Wind Tunnel Air Speed," SAE Technical Paper 2004-01-0668, 2004, <https://doi.org/10.4271/2004-01-0668>.

2.1.2 Other Publications

U.S. EPA SC03 driving schedule representing vehicle operation with air conditioning, as set forth in cc

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 critical 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 the standard location used in the chamber being evaluated (typical locations are at the nozzle outlet or in the stilling chamber) that is used by the test cell for conditioning and in maintaining dry bulb temperature. Control sensor(s)' location shall be recorded. 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 to +38 °C.

Five temperature locations should be used to monitor the uniformity of air temperature at nozzle outlet as well as air outlet temperature of idle bypass air.

Air temperature around the cabin should be measured at four locations: Two sensors are to be placed along the centerline of the vehicle, 1/2 way between the ground and the highest point of the vehicle (excluding bolt-on items), 1 m forward of the front of the vehicle and 1 m away from the back of the vehicle. Left and right side vehicle ambient should be measured at a point 500 mm away from left side and right side of the glass, positioned at the center of the passenger compartment between front and rear boundary.

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 km/h.

3.4 Tractive Effort (Dynamometer/Road Load)

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/m².

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 km/h.

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 km/h.

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 second 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. Figure 1 demonstrates the origin of these forces. By conducting an on road coastdown per SAE J2263, these forces can be identified at predetermined speeds, at which point a best fit second 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 (Equation 1) will be discussed. How the equation is obtained is covered in SAE J2263.

$$\text{Target A,B,C} = \text{Vehicle Losses on Track} = \text{Wind / Air Friction} + \text{Tire / Axle Friction}$$

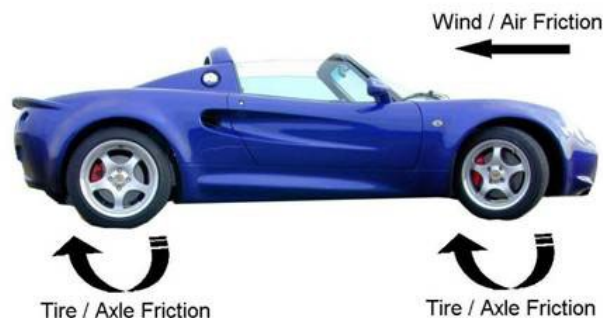


Figure 1 - Target road load forces experienced on a passenger vehicle

$$\text{Target Road Load Simulation Force (Vehicle)} = (A_v + B_v \cdot V + C_v \cdot V^2 + M_v \, dV/dt) \text{ Newtons} \quad (\text{Eq. 1})$$

where:

A_v = mostly constant friction (approximated by $C_{rr} \cdot W_v$) (units = N)

B_v = mostly variable friction (proportional to speed) (units = N/km/h)

C_v = mostly aero resistance (approximated by $1/2 \rho C_d A_F V^2$) (units = N/km/h²)

W_v = weight of vehicle (units = N)

M_v = mass of vehicle or weight/9.81 (units = kg)

V = vehicle speed (units = km/h)

t = time (units = seconds)

C_{rr} = coefficient of rolling resistance (units = none)

ρ = air density (units = kg/m³)

A_F = frontal area (units = m²)

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 vehicles 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 is 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. 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. Figure 2 shows typical losses that can be measured by the dynamometer load cell when running a coast down determination procedure.

Natural Losses of Vehicle and Dyno that can be measured by Dyno Loadcell

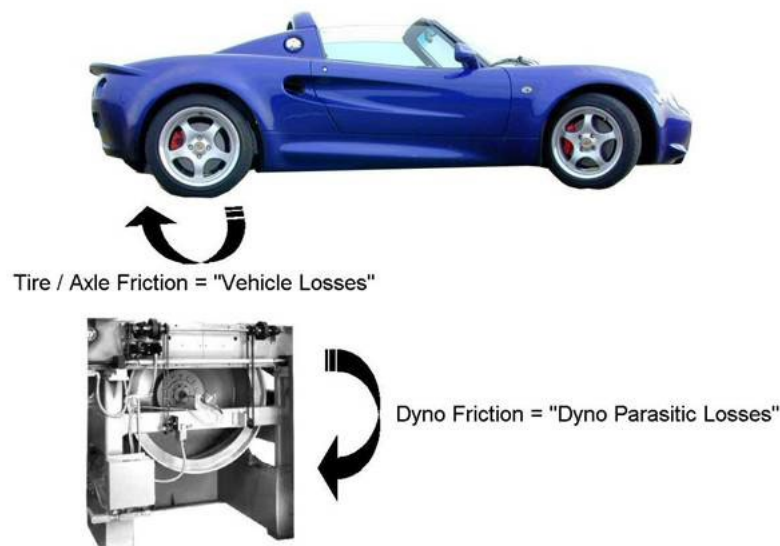


Figure 2 - Measurable forces in a climatic wind tunnel

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 procedure per applicable SAE document in 2.1.1. 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 second 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 versus 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.

$$\text{Trailer Road Load Simulation Force} = (A_T + B_TV + C_TV^2 + M_T dv/dt) \text{ Newtons} \quad (\text{Eq. 2})$$