Motorcycle Industry Council

MIC Recommended Practice
Top Speed Test Procedure for Electric Motorcycles

Approved by the MIC Electric Vehicle Subcommittee, March 28, 2012
Minor Technical Corrections and Revisions, September 10, 2012

[The SAE is pursuing the development of this recommended practice as an SAE standard.]

The top speed test procedure is set forth below, followed by a detailed discussion of the rationale for the procedure beginning on page 6.

Top Speed Test Procedure

1. *Vehicle Applicability and Preparation*

1.1 Applicability. This procedure is applicable to a motorcycle as defined by SAE J213 that is propelled exclusively by electric motors energized by storage batteries with no on-board source of battery charging other than solar panels or a regenerative braking system.

1.2 Battery preconditioning. Prior to testing, batteries shall be charge-discharge cycled according to the recommendations of the vehicle manufacturer if such cycling is required to achieve maximum energy storage capacity. If the maximum power output of the vehicle's motor controller changes by more than 10% due to degradation of the vehicle's battery following 40 charge-discharge cycles, then the battery shall be subjected to at least 40 charge-discharge cycles prior to testing.[1]

1.3 Equipment. The vehicle shall be equipped as it is normally delivered to the ultimate purchaser and shall have any optional equipment installed that is delivered with more than 50% of the vehicles. However, in the case of vehicles with removable luggage (e.g., panniers), the luggage may be removed prior to testing as long as the fact that the luggage has been removed is specified (e.g., "maximum speed was measured with saddlebags and top case removed") along with any publication of the maximum speed. Vehicles with adjustable windscreens may be tested with the windscreen in the lowest position. Tires used shall be the same size and specification as those installed on the vehicle at the time of sale. Tires shall be inflated to the manufacturer's recommended inflation pressure and shall not be worn to less than 50% of the original tread depth. Any speed-limiting device installed on the vehicle shall not be deactivated.

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[1] "Charge-discharge cycle" shall have the same meaning as specified in SAE J2982. Alternatively, "charge-discharge cycle" shall mean the process involving the vehicle battery being fully recharged following discharge to the point that a warning message is displayed advising the operator to recharge the battery as soon as possible.

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1.4 Exterior Surface. The exterior surface of the vehicle shall be clean and free of any modifications that would affect aerodynamic drag (e.g., removal of mirrors or addition of tape over seams in bodywork).

1.5 Vehicle Preconditioning. The vehicle shall be stored at an ambient temperature not less than 68°F (20°C) for at least 6 hours prior to testing. During this time, the vehicle's battery shall be charged to a full state-of-charge.

1.6 Accessories. Any accessories not necessary for routine high-speed operation (e.g., a radio or intercom system) may be switched off.

2. Driver/Rider

2.1 The driver/rider shall weigh at least 80 kg when fully clothed with any apparel that will be worn during testing, including a helmet, if used. Ballast may be added to the vehicle to bring the total weight of the driver/rider plus ballast to 80 kg if necessary. For vehicles without an enclosed passenger compartment, the driver/rider must be at least 1.7 m tall when measured with bare feet and no head gear. To validate values of maximum speed published by the manufacturer, the driver/rider weight and height shall not exceed 80 kg and 1.7 m, respectively.[2]

2.2 Attire. For vehicles in which the driver/rider is not enclosed, the driver/rider shall wear a form-fitting riding suit, boots, gloves, and a helmet that complies with the latest U.S. Department of Transportation or Economic Commission for Europe standards for motorcycle helmets.

2.3 The driver/rider shall be positioned on the seat of the vehicle in a normal upright position with the driver's/rider's arms normally extended. However, the driver/rider may be in a tucked position in cases where the maximum speed of vehicle is in excess of 120 km/h. The rider's feet must remain on the footpegs for vehicles equipped with footpegs. Both of the rider's hands must remain on the handlebars for vehicles equipped with handlebars.

3. Test Track/Roadway

3.1 Road Surface. The roadway or test track surface shall be smooth asphalt or concrete and should be clean and dry.

3.2 Grade. If the testing is performed on a track with travel in only one direction, the portion of the track where the vehicle speed is measured must have an absolute value of grade of not more than 0.5%. If the testing is performed in both directions, the maximum grade shall be 1.5%. The maximum grade for the portion of the roadway

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[2] The specified minimum weight and height of the rider are changed to maximum weight and height for the purposes of validating test results reported by a vehicle manufacturer. This is to ensure that the rider used for validation testing is not heavier or taller than the rider used to produce the results being evaluated.

used to accelerate the vehicle to maximum speed shall also be an absolute value of 1.5% unless maximum speed can be achieved with some initial portion of the roadway being a positive (uphill) grade of more than 1.5%.

3.3 Curvature. The portion of the roadway over which speed is measured shall have less than 1 degree of curvature, where the degree of curvature is defined as the central angle which subtends a 100 foot (30.48 m) arc. Portions of the roadway before or after the speed measurement section may have greater curvature. For curved roadways, it is recommended that the superelevation (banking) of the roadway be used to counteract the centrifugal force associated with the speed at which the roadway is traversed to the extent that side friction is insufficient for safe vehicle operation.

3.4 Length. The portion of the roadway or track over which the maximum speed is measured must be at least 50 meters in length. An additional portion of roadway or track at both ends of the minimum 50-meter segment must be of sufficient length to allow for a speed measurement immediately prior to and immediately after the speed measured in the minimum 50-meter segment. The minimum length of these two roadway segments will depend on the length required to achieve the minimum measurement accuracy for the speed measurement technology used.

4. Atmospheric Conditions

4.1 Wind Speed. Wind speed shall be recorded based on measurement using an anemometer with steady-state accuracy of ±1 m/s over the range of allowable wind speeds. No testing shall be conducted during periods of time when the wind speed measured at the test site is varying by more than 1 m/s during the period of time that the vehicle speed is actually being measured. For bidirectional testing, maximum wind speed allowable without the use of a correction factor shall be 3 m/s. For unidirectional testing, the maximum wind speed allowable without the use of a correction factor shall be 1 m/s. With the use of the correction factor described in 6.1 below, speed may be measured with wind speeds of up to 5 m/s for bidirectional testing and 3 m/s for unidirectional testing. However, the use of the wind speed correction factor requires the use of a measurement system that measures both wind speed and direction and enables the calculation of wind speed in the direction of vehicle travel based on the cosine of the angle between the wind direction and the direction of vehicle travel.

4.2 Temperature. Testing may be conducted at any temperature equal to or greater than 5°C. Temperature at the time of the speed measurement must be measured with an accuracy of ±0.5°C and recorded.

4.3 Atmospheric Pressure. Testing may be conducted at any atmospheric pressure; however, the atmospheric pressure at the time of the speed measurement must be measured with an accuracy of ±10 millibars and recorded.

4.4 Relative Humidity. Testing may be conducted at any level of relative humidity provided the air is clear of fog and rain. The relative humidity at the time of the speed measurement must be measured with an accuracy of ±2% and recorded.

5. Speed Measurement

5.1 The vehicle shall be accelerated under its own power from a point sufficiently distant from the portion of the road or track over which the speed is measured so that the maximum speed is achieved prior to the measurement.

5.2 Whether maximum speed has been achieved in the minimum 50 m roadway segment shall be based on a comparison of speed measurements made immediately preceding and following the minimum 50 m segment. The average speed immediately following the 50 m segment shall not exceed the average speed immediately preceding the 50 m segment by more than 1 mph (1.6 km/h). For bidirectional testing, the speed difference shall be based on the average of runs in each direction.

5.3 The speed of the vehicle may be measured by any technique that is demonstrated to be accurate to within 1.0 mph (1.6 km/h), including the following:

- *Elapsed time to cover a measured distance;*
- *A radar device listed by the International Association of Chiefs of Police (IACP);*[3]
- *A laser device listed by IACP;*
- *On-board speed measurement via a GPS receiver with an accuracy of ±1.0 mph under steady-state conditions.*

5.4 Speed measurement based on elapsed time shall utilize photocells or equivalent technology to start and stop the time measurement. Both the time and distance shall be reported. Speed measurement based on GPS shall be electronically recorded and reported. Speed measurement based on radar or laser need not be electronically recorded provided a "peak hold" function is incorporated in the system and the peak value is manually recorded. A cosine correction for radar or laser measurements made from the side of the roadway may be incorporated (i.e., the measured speed may be adjusted by dividing it by the cosine of the angle between the direction that the device is pointed and the path of the vehicle).

5.5 For bidirectional testing, the portion of the track or roadway where the measurement is made shall be traversed a minimum of two times (once in each direction) with no recharging allowed between the successive speed measurements. For unidirectional testing, the portion of the track or roadway where the measurement is made may be traversed more than once.

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[3] CONFORMING PRODUCT LIST (CPL), Enforcement Technology Program, International Association of Chiefs of Police (IACP), September 21, 2010

6. Adjustment and Reporting

6.1 Wind Speed Correction. For unidirectional speed measurements with measured wind speed in excess of 1 m/s, subtract the wind speed in the direction of vehicle travel from the measured vehicle speed. (Note: a headwind will be considered to have a negative value in the direction of vehicle travel, and subtraction of the headwind will therefore increase measured vehicle speed.) For bidirectional testing with measured wind speed in excess of 3 m/s, subtract the wind speed in the direction of vehicle travel from the measured vehicle speed for each run.

6.2 Air Density Correction. Multiply the wind speed-corrected maximum speed by the following term:

$$\frac{\sqrt[3]{\rho}}{1.0545}$$

Where: ρ is the calculated air density in kg/m^3 calculated using the following equation:

$$\rho = \left[\frac{P}{R_d \times T}\right] \times \left[1 - \frac{0.378 \times P_v}{P}\right]$$

Where: ρ is the air density in kg/m^3
P = total air pressure in Pascals;
*R_d = gas constant for dry air, 287.05 J/(kg*degK);*
T = temperature in °K; and
P_v= pressure of water vapor (partial pressure) in Pascals calculated using the following equation:

$$P_v = RH \times E_s$$

Where: RH is the relative humidity; and
E_s is the saturation pressure of water vapor in Pascals calculated using the following equation:

$$E_s = c_0 \times 10^{\frac{c_1 \times T_c}{c_2 + T_c}}$$

Where: $c_0 = 610.78$
$c_1 = 7.5$
$c_2 = 237.3$
T_c = temperature in °C

6.3 Reporting. Average corrected results for bidirectional testing and report the maximum speed to the nearest mph or km/h. Report corrected results for unidirectional testing to the nearest mph or km/h. Averaging of multiple bidirectional or unidirectional test runs is allowable, but not required.

Justification for Proposed Procedure

General – The proposed top speed test procedure was designed to avoid unnecessary conflicts with the "maximum design speed" measurement procedure for two- and three-wheel vehicles contained in Directive 95/1/EC of the European Parliament and the Council of the European Union, while simultaneously addressing certain problems with the European procedure. Foremost among the problems with the European procedure are the relatively wide tolerances provided for atmospheric pressure and temperature. As described in more detail below, the wide range of atmospheric conditions allowed under the European procedure allows for significant variations in measured top speed.

Vehicle Applicability and Preparation – The definition of "motorcycle" that applies to Directive 95/1/EC is the definition contained in Directive 92/61/EEC, which says "This Directive applies to all two or three-wheel motor vehicles, twin-wheeled or otherwise, intended to travel on the road...." However, the following vehicles are specifically excluded:

- Vehicles with a maximum design speed not exceeding 6 km/h;
- Vehicles intended for pedestrian control;
- Vehicles intended for use by the physically handicapped;
- Vehicles intended for use in competitions, on roads or whatever the terrain;
- Vehicles already in use before the application date of this Directive;
- Tractors and machines, used for agricultural or similar purposes; and
- Vehicles designed primarily for off-road leisure use having wheels arranged symmetrically with one wheel at the front of the vehicle and two at the rear.

Additional language appears to exclude motorcycles with a maximum design speed of 45 km/h or less. In addition, there is language that specifically includes "quadricycles" if they meet certain weight and maximum power criteria.

One concern with the above-described definition is that it specifically excludes off-highway motorcycles and competition motorcycles. To make the proposed test procedure more generally applicable, a broader definition is proposed. By making the definition of a motorcycle consistent with SAE J213, the procedure can be applied to a broader range of electric motorcycles, including models designed for off-highway or competition use.

The vehicle preparation provisions of the European test procedure include elements that are inapplicable to electric vehicles, such as requirements for fuel supply and ignition settings to be in accordance with the manufacturer's specifications. Another inapplicable provision relates to the engine break-in period. Such provisions have been removed and other provisions have been added to address issues unique to electric vehicles. A provision in the European procedure for all parts to be thermally stable was also deleted because of the likelihood that maximum speed operation will result in increasing temperatures of batteries and motors in electric vehicles. A vague provision regarding the vehicle mass being in "running order" was replaced with a provision that vehicles be equipped as they are delivered to the ultimate purchaser.

A battery preconditioning provision is patterned after a similar provision contained in the previously developed range test procedure. A provision is also added specifying the battery shall be at a full state of charge at the beginning of the test and the vehicle shall have been stored prior to testing at a temperature not lower than 20°C, which is also the proposed minimum storage temperature for the range test.

A provision unique to motorcycles has been added that provides for the removal of detachable luggage, such as saddlebags or a top case.

Other routine provisions include a requirement that the exterior of the vehicle be clean and that tire pressures be set as recommended by the manufacturer. Consistent with the European test procedure, it is specified that accessories not required for high-speed driving may be switched off.

Driver/Rider – Provisions in the European procedure for the driver/rider to weigh 75 ±5 kg and 1.75 ±0.5 m in height are replaced with a requirement for the driver/rider to weigh at least 80 kg when fully clothed with any apparel that will be worn during testing, including a helmet, if worn. (For comparison, available data indicate that the mean body mass for the average adult in the U.S. is 86.1 kg for males and 74.0 kg for females.[4]) This language clarifies that the rider weight includes apparel and gives manufacturers the flexibility to use a heavier rider. To provide the flexibility to use lighter riders, a provision allowing the use of ballast to achieve the 80 kg minimum is included. Similarly, the height requirement is changed from a narrow range to a minimum which is at the bottom of the range in the European procedure and close to the mean height for adults in the U.S., based on the previously referenced CDC document.

The provision in the European procedure regarding rider attire has been supplemented to require that riders of unenclosed vehicles wear a helmet, boots, and gloves, in addition to a riding suit. If the vehicle has a top speed in excess of 120 km/hr, the proposed procedure also allows for the rider to be in a tucked position regardless of whether such a position is specifically recommended by the manufacturer.

Test Track/Roadway – As under the European test procedure, the proposed procedure specifies that the roadway surface shall be clean and dry; however, a concrete surface is specifically allowed, in addition to asphalt. The European test procedure specifies bidirectional testing over a roadway surface with a maximum gradient of 1%, which means that a true grade of 1.49%

[4] Cynthia L. Ogden, et al., "Mean Body Weight, Height, and Body Mass Index, United States1960–2002," Advance Data from Vital Health Statistics, Number 347, October 27, Center for Disease Control, 2004.

would be acceptable because it would round to 1%. For consistency, the maximum allowable gradient in the proposed procedure is specified at 1.5%; however, the grade specification is tightened to 0.5% for unidirectional testing. This is necessary to reduce the error in maximum speed to 1%. As described below, a 1.0% grade reduces the top speed of a typical motorcycle with the ability to deliver 27 kW to the tire-road interface by 2%.

The effect of grade on maximum speed can be determined using the following equation, which is based on the section of the Bosch Automotive Handbook dealing with motor vehicle dynamics:

$$kW = ((C_{rr} \times kg \times g) + (0.0386\rho \times C_d \times A_f \times v^2) + (0.01 \times kg \times g \times grade)) \times v/3600$$

where: kW = the power required at the tire-road interface to achieve a specified speed
C_{rr} = coefficient of rolling resistance (≈0.01 for pneumatic tires on pavement)
kg = loaded vehicle mass in kilograms
g = gravitational constant, 9.8 m/s^2
ρ = air density in kg/m^3
C_d = aerodynamic drag coefficient (≈0.6-0.7 for a motorcycle with a fairing)
A_f = frontal area in m^2
v = velocity in km/h
grade = roadway grade in percent

The equation defines the power required at the tire-road interface to propel a vehicle at a constant speed. The terms within the three sets of parentheses calculate the force required to overcome rolling resistance, aerodynamic drag, and roadway grade. Multiplying the sum of these force terms by the velocity provides the power. (The constant of 3600 in the denominator is required for unit conversion.)

Using 1.225 kg/m^3 for the density of dry air at sea level and 15°C, the above equation estimates a power requirement of 28.1 kW to propel a typical sport-touring motorcycle[5] at a constant speed of 100 mph on a flat road. With the addition of 1% grade, the same level of power will achieve only 98 mph, hence the requirement for 0.5% maximum grade for unidirectional testing.

To maintain consistency with the European procedure, the proposed procedure specifies that the portion of the roadway or track over which the maximum speed is measured must be at least 50 meters in length with less than 1° of curvature.[6] For vehicles travelling at 100 mph, this provides only 1.1 seconds during which speed must be measured; however, this is considered adequate given the availability of fast-response speed measurement technology. The alternative track configurations were considered unnecessary given the changes in speed measurement technology incorporated in proposed section 5.

To eliminate the possibility of speed being exaggerated by running a vehicle downhill immediately prior to the speed measurement, a provision is proposed to limit the maximum

[5] 800 pound loaded vehicle weight, 0.65 aerodynamic drag coefficient, 8 ft^2 frontal area.
[6] The European procedure implies that speed should be measured over a straight section of roadway; however, no specification is provided regarding the extent to which the roadway may be less than perfectly straight.

grade for the portion of the roadway used to accelerate the vehicle to an absolute value of 1.5%. For safety reasons, it is recommended that superelevation (banking) be used where necessary to at least partially counteract the effects of centrifugal force associated with traversing curved sections of the roadway.

<u>Atmospheric Conditions</u> – Atmospheric conditions affect maximum vehicle speed in several ways. For vehicles with internal combustion engines that are not turbocharged, the amount of power the engine can produce is affected by the air density, which is related to atmospheric pressure, temperature, and relative humidity. The higher the atmospheric pressure, the lower the temperature, and the lower the humidity, the higher the horsepower that can be produced. However, higher air density also increases the power required to overcome aerodynamic drag. So, for vehicles powered by non-turbocharged combustion engines, the net effect of changes in air density on top speed is balanced by the counteracting effects on engine power and the power required to overcome aerodynamic drag. However, for electric vehicles, maximum motor output is unaffected by air density, and differences in air density therefore have a more significant effect on differences in maximum vehicle speed.

Under the European test procedure, atmospheric conditions must be in the ranges listed below.

- Atmospheric Pressure: 97 ±6 kPa (0.898 to 1.017 atm., 26.87 to 30.42 inches mercury)
- Temperature: 278 to 308°K (5 to 35°C, 41 to 95°F)
- Relative Humidity: 30 to 90%
- Maximum Wind Speed: 3 m/s (6.7 mph)

To understand how atmospheric conditions affect maximum vehicle speed, it is useful to examine a simplified version of the above-described equation from the Bosch Automotive Handbook. The equation appears below with the grade term removed:

$$\text{kW} = ((C_{rr} \cdot \text{kg} \cdot 9.8\ \text{m/s}^2) + (0.0386\rho \cdot C_d \cdot A_f \cdot v^2)) \cdot v/3600$$

Because the power required to overcome aerodynamic drag is proportional to the cube of velocity, aerodynamic drag becomes the dominant factor at high velocities. For example, using 1.225 kg/m^3 for the density of dry air at sea level and 15°C, the above equation calculates a power requirement of only 0.81 kW (1.09 hp) to propel the previously described motorcycle at a constant speed of 25 mph on a flat road. At this speed, almost exactly half of the power is required to overcome rolling resistance and half is required to overcome aerodynamic drag. However, at 55 mph, the power demand increases to 5.3 kW and 83% of the power is required to overcome aerodynamic drag. At 100 mph, the power demand increases to 28.1 kW, 94% of which is required to overcome aerodynamic drag.

Because of the significance of aerodynamic drag, accurate measurements of top speed require representative values of air density at the time of testing. As noted above, the European test procedure allows testing to be conducted when atmospheric pressure is 97 ± 6 kPa. This allows a 12.4% variation in air pressure relative to the nominal value 97 kPa. The effect of the variation in air pressure on air density can be calculated using the following equation[7]:

$$\rho = \left[\frac{P}{R_d \times T}\right] \times \left[1 - \frac{0.378 \times P_v}{P}\right]$$

Where: ρ is the air density in kg/m^3

P = total air pressure in Pascals;

R_d = gas constant for dry air, 287.05 J/(kg*degK);

T = temperature in °K; and

P_v= pressure of water vapor (partial pressure) in Pascals calculated using the following equation:

$$P_v = RH \times E_s$$

Where: RH is the relative humidity; and

E_s is the saturation pressure of water vapor in Pascals calculated using the following equation[8]:

$$E_s = c_0 \times 10^{\frac{c_1 \times T_c}{c_2 + T_c}}$$

Where: c_0 = 610.78

c_1 = 7.5

c_2 = 237.3

T_c = temperature in °C

Using the above equations, the effect of variations in atmospheric pressure, temperature, and relative humidity and air density can be calculated. The equation from the Bosch Automotive Handbook can then be used to estimate the effect on maximum vehicle speed for any specified power delivered to the tire-road interface. Holding temperature and relative humidity constant, the effect of the range of atmospheric pressures allowed under the European test procedure has been calculated for the size, shape, and weight of motorcycle previously described. A motor output sufficient to achieve 100 mph at the low end of the allowable atmospheric pressure range (91 kPa) would achieve only 96 mph at the high end of the atmospheric pressure range (103 kPa).

The allowable variation in ambient temperature further increases the variation in maximum speed associated with the range of atmospheric conditions allowed under the European test

[7] Wilfried Brutsaert, "Evaporation into the Atmosphere: Theory, History and Applications," Kluwer Academic Publishers, 1982.

[8] David Bolton, "The Computation of Equivalent Potential Temperature," Monthly Weather Review, Vol. 108, No. 7, July 1980, as reported by Thomas W. Schlatter and Donald V. Baker, NOAA Environmental Research Laboratories, June 12, 1991.

procedure. When the low end of the atmospheric pressure range is combined with the high end of the temperature range, the power required to achieve 100 mph with the above-described motorcycle is 23.5 kW. With the same amount of power, the vehicle will achieve only 92.5 mph when the low end of the temperature range is combined with the high end of the pressure range.

Based on the calculations described above, it is apparent that the variations in atmospheric conditions allowed under the European test procedure are likely to contribute to significant variations in maximum speed measurements for electric motorcycles. To avoid severe restrictions on the conditions under which vehicles may be tested, an alternative approach is proposed under which a correction factor is applied to the measured speed based on the difference between the air density during the speed measurement and a nominal air density.

Because a correction factor is specified for atmospheric pressure, a broader range of atmospheric conditions is allowed during vehicle testing under the proposed procedure. No constraints are placed on atmospheric pressure or relative humidity. The maximum allowable wind speed is increased from 3 m/s to 5 m/s for bidirectional testing. The range of allowable ambient temperature is changed from 278 to 308°K (5°C to 35°C) to any temperature equal to or greater than 5°C.

Speed Measurement – The speed measurement portion of the proposed procedure is consistent with the European test procedure to the extent that one of the alternative "measuring bases" is specified for use. However, there are numerous changes, including those outlined below.

1. Unnecessary references to gear ratios; inapplicable references to throttle controls, enrichment devices, fuels, and lubricants; and references to driver position and wind speed duplicative of information provided in earlier sections are eliminated.

2. The requirement for speed measurement to be based on the elapsed time over a measured distance is replaced with a more general requirement that speed be measured with a system that can be demonstrated to be accurate to within 1 mph or 1.6 km/h. Radar, laser (Lidar), and on-board GPS measurements are specifically identified as acceptable options.

3. Rather than providing specific equations for converting elapsed time over a known distance to a vehicle speed, it is presumed that anyone using the test procedure is capable of properly calculating the speed value.

4. The requirement that unidirectional speed measurements be repeated five times in succession and the requirement for bidirectional speed measurements to be duplicated are eliminated.

Adjustment and Reporting – Corrections are specified for wind speed and air density. The wind speed correction is applied only in cases where the measured wind speed exceeds 1 m/s for unidirectional testing or 3 m/s for bidirectional testing. The more critical correction for air density is always applied.

As discussed above under the subsection on Atmospheric Conditions, the maximum speed of an electric motorcycle is significantly affected by air density, which, in turn, is affected by air pressure, temperature, and relative humidity. To avoid specifying a narrow range of atmospheric conditions, the proposed procedure incorporates a correction factor to normalize measured maximum speed values to a standard air density.

The use of such a correction is feasible because of the dominant role of aerodynamic drag at speeds of 55 mph or higher. At such speeds, the power required is proportional to the air density multiplied by the cube of the vehicle speed. As a result, the speed that can be achieved for any given motor power is proportional to the cube root of the air density. Although this may not be intuitively obvious, it can be demonstrated by rearranging a simplified version of the road load power equation as shown below. In the following equation, the rolling resistance term, which becomes increasingly insignificant as speed increases, and the grade term, which equates to zero for a flat road, have been removed:

$$kW = ((0.0386\rho \times C_d \times A_f \times v^2)) \times v/3600$$

Rearranging this equation to solve for velocity is shown in the following three steps:

$$kW = \frac{0.0386\rho \times C_d \times A_f \times v^3}{3600}$$

$$\frac{3600 \times kW}{0.0386\rho \times C_d \times A_f} = v^3$$

$$\sqrt[3]{\frac{3600 \times kW}{0.0386\rho \times C_d \times A_f}} = v$$

For any given vehicle, the terms kW, C_d, and A_f are constants, so the velocity is equal to the cube root of a constant divided by the air density, ρ. Regardless of the value of the constant, the value of "v" ends up being proportional to the reciprocal of the cube root of ρ. To find the "normalized" speed, v_{norm}, associated with measured speed, v_{meas}, at a standardized air density ρ_{std}, the equation can be written as follows:

$$v_{norm} = v_{meas} \times \frac{\sqrt[3]{\frac{1}{\rho_{std}}}}{\sqrt[3]{\frac{1}{\rho_{meas}}}}$$

This is mathematically equal to the following:

$$v_{norm} = v_{meas} \times \frac{\sqrt[3]{\rho_{meas}}}{\sqrt[3]{\rho_{std}}}$$

The standard air density recommended for the proposed maximum-speed test procedure has been calculated by assuming an absolute air pressure representative of an altitude of 200 m (98.95 kPa) along with the mid-range of the temperature (20°C) and low end of the relative humidity values (30%) used in the European test procedure. This results in a standard air density of 1.1727 kg/m^3. Substituting this value into the above equation results in the following simplified equation:

$$v_{norm} = v_{meas} \times \frac{\sqrt[3]{\rho_{meas}}}{1.0545}$$

The accuracy of the air density correction factor is illustrated using the following example. For a level road, the road load equation from the Bosch Automotive Handbook is:

$$kW = ((C_{rr} \cdot kg \cdot 9.8\ m/s^2) + (0.0386\rho \cdot C_d \cdot A_f \cdot v^2)) \cdot v/3600$$

With an air density of 1.1727 kg/m^3, a motorcycle with a loaded weight of 800 pounds (363.2 kg), a drag coefficient of 0.65, a frontal area of 8 square feet (0.7432 m^2), and a rolling resistance coefficient of 0.01 would require 26.94 kW at the tire-road interface to achieve 100.0 mph (160.9 km/h). Tested at the extreme end of the allowable ranges of atmospheric conditions allowed by Directive 95/1/EC (35°C, 90% RH, 91 kPa), the air density decreases to 1.0073 kg/m^3. The road load equation indicates that 26.94 kW would result in a top speed of 105.1 mph.

Based on a speed measured with an air density of 1.0073 kg/m^3, the air density-corrected top speed is calculated as follows:

$$v_{norm} = 105.1 \times \frac{\sqrt[3]{1.0073}}{1.0545}$$

$$v_{norm} = 105.1 \times \frac{1.0024}{1.0545}$$

$$v_{norm} = 105.1 \times 0.9506 = 99.9$$

As shown, the air density correction corrects the measured top speed to 99.9 mph, just 0.1% lower than the 100 mph value calculated using the road load equation with the recommended "standard" conditions.

The accuracy of the air density correction factor will obviously be reduced at lower speeds because aerodynamic drag is less of a factor. Based on the same two sets of atmospheric conditions, a vehicle with a top speed of 55 mph with 1.1727 kg/m^3 air density would be producing 5.09 kW at the tire-road interface. If the air density drops to 1.0073 kg/m^3, the top speed achievable with 5.09 kW would increase to 57.7. Applying the air density correction, the adjusted top speed would be 54.8:

$$v_{norm} = 57.7 \times 0.9506 = 54.8$$

The error has increased, but it is still only 0.36%.

If the vehicle had a top speed of just 25 mph with 1.1727 kg/m^3 air density, the top speed would increase to 26.0 mph at 1.0073 kg/m^3 air density. Application of the air density correction would result in an adjusted top speed of 24.7:

$$v_{norm} = 26.0 \times 0.9506 = 24.7$$

The error has increased to 1.2%, which is still significantly less than the 4% increase in speed associated with using the measured value under atmospheric conditions that result in low air density.