TEST PROCEDURE

Driving Resistance

Version 1.0.0 February 2019

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Green NCAP Driving resistance test procedure

Road load determination

- **Option 1 (priority) :** The road load parameters used for the Green NCAP tests carried out on chassis dynamometer must first come from the **Certificate of Conformity (CoC)** of the tested vehicle.
- **Option 2 :** If the Certificate of Conformity of the tested vehicle is not available, the road load parameters have to be determined according to the Global Technical Regulation No. 15 (UN GTR No 15), of which annex 4 below describes the method and conditions of tests on a proving ground.

⇨ **GTR15 - Annex 4 - Road load determination**

1. Scope

This Annex describes the determination of the road load of a test vehicle.

2. Terms and definitions

2.1. For the purpose of this document, the terms and definitions given in paragraph 3. of this UN gtr shall have primacy. Where definitions are not provided in paragraph 3. of this UN gtr, definitions given in ISO 3833:1977 "Road vehicles -- Types -- Terms and definitions" shall apply.

2.2. Reference speed points shall start at 20 km/h in incremental steps of 10 km/h and with the highest reference speed according to the following provisions:

(a) The highest reference speed point shall be 130 km/h or the reference speed point immediately above the maximum speed of the applicable test cycle if this value is less than 130 km/h. In the case that the applicable test cycle contains less than the 4 cycle phases (Low, Medium, High and Extra High), the highest reference speed may be increased to the reference speed point immediately above the maximum speed of the next higher phase, but no higher than 130 km/h; in this case road load determination and chassis dynamometer setting shall be done with the same reference speed points;

(b) If a reference speed point applicable for the cycle plus 14 km/h is more than or equal to the maximum vehicle speed v_{max}, this reference speed point shall be excluded from the coast down test and from chassis dynamometer setting. The next lower reference speed point shall become the highest reference speed point for the vehicle.

2.3. Unless otherwise specified, a cycle energy demand shall be calculated according to paragraph 5. of Annex 7 over the target speed trace of the applicable drive cycle.

2.4. f0, fp fj are the road load coefficients of the road load equation F = f0 +fj xv + fj xv2, determined according to this annex.

f_0 is the constant road load coefficient and shall be rounded to one place of decimal, N;

f_1 is the first order road load coefficient and shall be rounded to three places of decimal, N/(km/h);

f2 is the second order road load coefficient and shall be rounded to five places of decimal, $N/(km/h)^2$.

Unless otherwise stated, the road load coefficients shall be calculated with a least square regression analysis over the range of the reference speed points.

2.5. Additional masses for setting the test mass shall be applied such that the weight distribution of that vehicle is approximately the same as that of the vehicle with its mass in running order. In the case of category 2 vehicles or passenger vehicles derived from category 2 vehicles, the additional masses shall be located in a representative manner and shall be justified to the responsible authority upon their request. The weight distribution of the vehicle shall be recorded and shall be used for any subsequent road load determination testing.

3. Overall measurement accuracy, precision, resolution and frequency

The required overall measurement accuracy shall be as follows:

(a) Vehicle speed accuracy: ±0.2 km/h with a measurement frequency of at least 10 Hz;

(b) Time: min. accuracy: ±10 ms; min. precision and resolution:10 ms;

(c) Wind speed accuracy: ±0.3 m/s, with a measurement frequency of at least 1 Hz;

(d) Wind direction accuracy: ±3°, with a measurement frequency of at least 1 Hz;

(e) Atmospheric temperature accuracy: ±1 °C, with a measurement frequency of at least 0.1 Hz;

(f) Atmospheric pressure accuracy: ±0.3 kPa, with a measurement frequency of at least 0.1 Hz;

(g) Vehicle mass accuracy measured on the same weighing scale before and after the test: ±10 kg (±20 kg for vehicles > 4,000 kg);

(h) Tyre pressure accuracy: ±5 kPa;

(i) Wheel rotational speed accuracy: ±0.05 s^{-1} or 1 per cent, whichever is greater.

4. Road load measurement on road

4.1. Requirements for road test

4.1.1. Atmospheric conditions for road test

4.1.1.1. Permissible wind conditions

In order to determine the applicability of the type of anemometry to be used, the arithmetic average of the wind speed shall be determined by

continuous wind speed measurement, using a recognized meteorological instrument, at a location and height above the road level alongside the test road where the most representative wind conditions will be experienced.

If tests in opposite directions cannot be performed at the same part of the test track (e.g. on an oval test track with an obligatory driving

direction), wind speed and direction at each part of the test track shall be measured. In this case the higher measured arithmetic average wind

speed determines the type of anemometry to be used and the lower arithmetic average wind speed the criterion for the allowance of waiving of a wind correction.

4.1.1.1.1. Permissible wind conditions when using stationary anemometry

Stationary anemometry shall be used only when wind speeds over a period of 5 seconds average less than 5 m/s and peak wind speeds are less than 8 m/s for less than 2 seconds. In addition, the average vector component of the wind speed across the test road shall be less than 2 m/s during each valid run pair. Run pairs that do not meet the above criteria shall be excluded from the analysis. Any wind correction shall be calculated as given in paragraph 4.5.3. of this annex. Wind correction may be waived when the lowest arithmetic average wind speed is 2 m/s or less.

4.1.1.1.2. Permissible wind conditions when using on-board anemometry

For testing with an on-board anemometer, a device as described in paragraph 4.3.2. of this annex shall be used. The arithmetic average of the wind speed during each valid run pair over the test road shall be less than 7 m/s with peak wind speeds of less than 10 m/s for more than 2 seconds. In addition, the average vector component of the wind speed across the road shall be less than 4 m/s during each valid run pair. Run pairs that do not meet the above criteria shall be excluded from the analysis.

4.1.1.2. Atmospheric temperature

The atmospheric temperature should be within the range of 5 °C up to and including 40 °C.

If the difference between the highest and the lowest measured temperature during the coast down test is more than 5 °C, the temperature correction shall be applied separately for each run with the arithmetic average of the ambient temperature of that run.

In that case the values of the road load coefficients f_0, f_1 and f_2 shall be determined and corrected for each individual run. The final set of f_0, f_1 and f_2 values shall be the arithmetic average of the individually corrected coefficients f_0, f_1 and f_2 respectively. Contracting Parties may deviate from the upper range by ±5 °C on a regional level.

4.1.2. Test road

The road surface shall be flat, even, clean, dry and free of obstacles or wind barriers that might impede the measurement of the road load, and its texture and composition shall be representative of current urban and highway road surfaces, i.e. no airstrip-specific surface. The longitudinal slope of the test road shall not exceed ±1 per cent. The local slope between any points 3 metres apart shall not deviate more than ±0.5 per cent from this longitudinal slope. If tests in opposite directions cannot be performed at the same part of the test track (e.g. on an oval test track with an obligatory driving direction), the sum of the longitudinal slopes of the parallel test track segments shall be between 0 and an upward slope of 0.1 per cent. The maximum camber of the test road shall be 1.5 per cent.

4.2. Preparation

4.2.1. Test vehicle

Each test vehicle shall conform in all its components with the production series, or, if the vehicle is different from the production vehicle, a full description shall be recorded.

4.2.1.1. Requirements for test vehicle selection

A test vehicle with the combination of road load relevant characteristics (i.e. mass, aerodynamic drag and tyre rolling resistance) producing the highest cycle energy demand shall be selected from the family (see paragraphs 5.6. and 5.7. of this UN GTR).

If the aerodynamic influence of the different wheels within one interpolation family is not known, the selection shall be based on the highest expected aerodynamic drag. As a guideline, the highest aerodynamic drag may be expected for wheels with (a) the largest width, (b) the largest diameter, and (c) the most open structure design (in that order of importance).

The wheel selection shall be performed additional to the requirement of the highest cycle energy demand.

4.2.1.2. Movable aerodynamic body parts

Movable aerodynamic body parts on the test vehicles shall operate during road load determination as intended under WLTP Type 1 test conditions (test temperature, vehicle speed and acceleration range, engine load, etc.).

Every vehicle system that dynamically modifies the vehicle's aerodynamic drag (e.g. vehicle height control) shall be considered to be a movable aerodynamic body part. Appropriate requirements shall be added if future vehicles are equipped with movable aerodynamic items of optional equipment whose influence on aerodynamic drag justifies the need for further requirements.

4.2.1.3. Weighing

Before and after the road load determination procedure, the selected vehicle shall be weighed, including the test driver and equipment, to determine the arithmetic average mass, m_{av}. The mass of the vehicle shall be greater than or equal to the test mass of vehicle at the start of the road load determination procedure.

4.2.1.4. Test vehicle configuration

The test vehicle configuration shall be recorded and shall be used for any subsequent coast down testing.

4.2.1.5. Test vehicle condition

4.2.1.5.1. Run-in

The test vehicle shall be suitably run-in for the purpose of the subsequent test for at least 3,000 but no more than 10,000 km (same criteria as emissions test program).

4.2.1.5.2. Wheel alignment

Toe and camber shall be set to the maximum deviation from the longitudinal axis of the vehicle in the range defined by the manufacturer. If a manufacturer prescribes values for toe and camber for the vehicle, these values shall be used. Other adjustable wheel alignment parameters (such as caster) shall be set to the values recommended by the manufacturer. In the absence of recommended values, they shall be set to the arithmetic average of the range defined by the manufacturer.

Such adjustable parameters and set values shall be recorded.

4.2.1.5.3. Closed panels

During the road load determination, the engine compartment cover, luggage compartment cover, manually-operated movable panels and all windows shall be closed.

4.2.2. Tyres

4.2.2.1. Tyre condition

Tyres used for the test shall:

(a) Not be older than 2 years after the production date;

(b) Not be specially conditioned or treated (e.g. heated or artificially aged), with the exception of grinding in the original shape of the tread;

(c) Be run-in on a road for at least 200 km before road load determination;

(d) Have a constant tread depth before the test between 100 and 80 per cent of the original tread depth at any point over the full tread width of the tyre.

After measurement of tread depth, the driving distance shall be limited to 500 km. If 500 km are exceeded, the tread depth shall be measured again.

4.2.2.2. Tyre pressure

The front and rear tyres shall be inflated to the lower limit of the tyre pressure range for the respective axle for the selected tyre at the coast down test mass, as specified by the vehicle manufacturer.

If the difference between ambient and soak temperature is more than 5 °C, the tyre pressure shall be adjusted as follows:

(a) The tyres shall be soaked for more than 1 hour at 10 per cent above the target pressure;

(b) Prior to testing, the tyre pressure shall be reduced to the inflation pressure, adjusted for difference between the soaking environment temperature and the ambient test temperature at a rate of 0.8 kPa per 1 °C using the following equation:

$\Delta pt = 0.8 \times {}^{(}T_{soak} - T_{amb})$

where:

Δp_t is the tyre pressure adjustment added to the tyre pressure defined in paragraph 4.2.2.3. of this Annex, kPa;

0.8 is the pressure adjustment factor, kPa/°C;

T_{soak} is the tyre soaking temperature, °C;

T_{amb} is the test ambient temperature, °C;

(c) Between the pressure adjustment and the vehicle warm-up, the tyres shall be shielded from external heat sources including sun radiation.

4.2.3. Instrumentation

Any instruments shall be installed in such a manner as to minimise their effects on the aerodynamic characteristics of the vehicle. If the effect of the installed instrument on (C_D x Af) is expected to be greater than 0.015 m^2,the vehicle with and without the instrument shall be measured in a wind tunnel fulfilling the criteria in paragraph 3.2. of this annex. The corresponding difference shall be subtracted from f_2.

4.2.4. Vehicle warm-up

4.2.4.1. On the road

Warming up shall be performed by driving the vehicle only.

4.2.4.1.1. Before warm-up, the vehicle shall be decelerated with the clutch disengaged or an automatic transmission placed in neutral by moderate braking from 80 to 20 km/h within 5 to 10 seconds. After this braking, there shall be no further actuation or manual adjustment of the braking system.

4.2.4.1.2. Warming up and stabilization

All vehicles shall be driven at 90 per cent of the maximum speed of the applicable WLTC. The vehicle may be driven at 90 per cent of the maximum speed of the next higher phase (see Table A4/3) if this phase is added to the applicable WLTC warm-up procedure as defined in paragraph 7.3.4. of this annex. The vehicle shall be warmed up for at least 20 minutes until stable conditions are reached.

TableA4/3

Warming up and stabilization across phases

Vehicle class	*Applicable WLTC*	*90 per cent of maximum speed*	*Next higher phase*
Class 3	Low_3+ $Medium_3$+ $High_3$+ Extra $High_3$	118 km/h	NA
	Low_3+ $Medium_3$+ $High_3$	88 km/h	Extra High (118 km/h)

4.3. Measurement and calculation of road load by the coast down method

The road load shall be determined by using either the stationary anemometry or the on-board anemometry method.

4.3.1. Coast down method with stationary anemometry

4.3.1.1. Selection of reference speeds for road load curve determination

Reference speeds for road load determination shall be selected according to paragraph 2.2. of this annex.

4.3.1.2. Data collection

During the test, elapsed time and vehicle speed shall be measured at a minimum frequency of 10 Hz.

4.3.1.3. Vehicle coast down procedure

4.3.1.3.1. Following the vehicle warm-up procedure, the vehicle shall be accelerated to 10 to 15 km/h above the highest reference speed and shall be driven at that speed for a maximum of 1 minute. After that, the coast down shall be started immediately.

4.3.1.3.2. During coast down, the transmission shall be in neutral. Any movement of the steering wheel shall be avoided as much as possible, and the vehicle brakes shall not be operated. .

4.3.1.3.3. The test shall be repeated until the coast down data satisfy the statistical precision requirements.

4.3.1.3.4. Although it is recommended that each coast down run be performed without interruption, split runs may be performed if data cannot be collected in a single run for all the reference speed points. For split runs, the following additional requirements shall apply:

(a) Care shall be taken to keep the vehicle condition as constant as possible at each split point;

(b) At least one speed point shall overlap with the higher speed range coast down;

(c) At each of all overlapped speed point, the average force of the lower speed range coast down shall not deviate from the average force of the higher speed range coast down by ±10 N or ±5 percent, whichever is greater;

(d) If the track length does not allow fulfilling requirement (b) in this paragraph, one additional speed point shall be added to serve as overlapping speed point.

4.3.1.4. Coast down time measurement

4.3.1.4.1. The coast down time corresponding to reference speed vj as the elapsed time from vehicle speed (vj + 5 km/h) to (vj - 5 km/h) shall be measured.

4.3.1.4.2. These measurements shall be carried out in opposite directions until a minimum of three pairs of measurements have been obtained that satisfy the statistical precision pj, defined in the following equation:

Pj = h x Sj / (^n x Δt_pj) < 0,03

where:

P_j is the statistical Precision of the measurements made at reference speed v_j;

n is the number of Pairs of measurements;

Δt_{Pj} is the harmonic average of the coast down time at reference sPeed v_j in seconds, given by the following equation:

$$\Delta t_{pj} = \frac{n}{\sum_{i=1}^{n} \frac{1}{\Delta t_{ji}}}$$

where:

Dtji is the harmony average coast down time of the i^{th} pair of measurements at velocity vj, seconds, s, given by the following equation:

Δtji = 2 / (1/Δtjai + 1/Δtjbi)

where:

Δtj_{ai} and Δtibi are the coast down times of the i^{th} measurement at reference speed j in seconds, s, in the respective directions a and b;

$б_j$ is the standard deviation, expressed in seconds, s, defined by:

$$\sigma_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (\Delta t_{ji} - \Delta t_{pj})^2}$$

h is a coefficient given in Table A4/4.

TableA4/4

Coefficient h as a function of n

n	**h**	**n**	**h**
3	4.3	17	2.1
4	3.2	18	2.1
5	2.8	19	2.1
6	2.6	20	2.1
7	2.5	21	2.1
8	2.4	22	2.1
9	2.3	23	2.1
10	2.3	24	2.1
11	2.2	25	2.1
12	2.2	26	2.1
13	2.2	27	2.1
14	2.2	28	2.1
15	2.2	29	2.0
16	2.1	30	2.0

4.3.1.4.3. If during a measurement in one direction any external factor or driver action occurs that obviously influences the road load test, that measurement and the corresponding measurement in the opposite direction shall be rejected. All the rejected data and the reason for rejection shall be recorded, and the number of rejected pairs of measurement shall not exceed 1/3 of the total number of measurement pairs. The maximum number of pairs that still fulfil the statistical precision shall be evaluated. In the case of exclusion, pairs shall be excluded from the evaluations starting with the pair having the maximum deviation from the average.

4.3.1.4.4. The following equation shall be used to compute the average of the road load where the harmonic arithmetic average of the alternate coast down times shall be used.

$Fj = (1/3.6) \times (m_{av} + m_r) \times 2 \times \Delta v / \Delta tj$

where:

Δtj is the harmony average of alternate coastdown time measurements at velocity Vj, seconds, s, given by:

Δtj = 2 / (1/Atja + 1/Atjb)

where:

Δt_{ja} and Δt_{jb} are the harmonic average coastdown times in directions a and b, respectively, corresponding to reference speed v_j, in seconds, s, given by the following two equations:

$$\Delta t_{ja} = \frac{n}{\sum_{i=1}^{n} \frac{1}{t_{jai}}}$$

and:

$$\Delta t_{jb} = \frac{n}{\sum_{i=1}^{n} \frac{1}{t_{jbi}}}$$

where:

m_{av} is the arithmetic average of the test vehicle masses at the beginning and end of road load determination, kg;

m_r is the equivalent effective mass of rotating components;

The coefficients f_0, fi and f2 in the road load equation shall be calculated with a least square's regression analysis.

In the case that the tested vehicle is the representative vehicle of a road load matrix family, the coefficient f_1 shall be set to zero and the coefficients f_0 and f_2 shall be recalculated with a least square's regression analysis.

4.3.2. Coastdown method with on-board anemometry

The vehicle shall be warmed up and stabilised according to paragraph 4.2.4. of this annex.

4.3.2.1. Additional instrumentation for on-board anemometry

The on-board anemometer and instrumentation shall be calibrated by means of operation on the test vehicle where such calibration occurs during the warm-up for the test.

4.3.2.1.1. Relative wind speed shall be measured at a minimum frequency of 1 Hz and to an accuracy of 0.3 m/s. Vehicle blockage shall be accounted for in the calibration of the anemometer.

4.3.2.1.2. Wind direction shall be relative to the direction of the vehicle. The relative wind direction (yaw) shall be measured with a resolution of 1 degree and an accuracy of 3 degrees; the dead band of the instrument shall not exceed 10 degrees and shall be directed towards the rear of the vehicle.

4.3.2.1.3. Before the coastdown, the anemometer shall be calibrated for speed and yaw offset as specified in ISO 10521-1:2006(E) AnnexA .

4.3.2.1.4. Anemometer blockage shall be corrected for in the calibration procedure as described in ISO 10521-1:2006(E) AnnexA in order to minimise its effect.

4.3.2.2. Selection of vehicle speed range for road load curve determination

The test vehicle speed range shall be selected according to paragraph 2.2. of this annex.

4.3.2.3. Data collection

During the procedure, elapsed time, vehicle speed, and air velocity (speed, direction) relative to the vehicle, shall be measured at a minimum frequency of 5 Hz. Ambient temperature shall be synchronised and sampled at a minimum frequency of 0.1 Hz.

4.3.2.4. Vehicle coastdown procedure

The measurements shall be carried out in opposite directions until a minimum of ten consecutive runs (five in each direction) have been obtained. Should an individual run fail to satisfy the required on-board anemometry test conditions, that run and the corresponding run in the opposite direction shall be rejected. All valid pairs shall be included in the final analysis with a minimum of 5 pairs of coastdown runs.

The anemometer shall be installed in a position such that the effect on the operating characteristics of the vehicle is minimised.

The anemometer shall be installed according to one of the options below:

(a) Using a boom approximately 2 metres in front of the vehicle's forward aerodynamic stagnation point;

(b) On the roof of the vehicle at its centreline. If possible, the anemometer shall be mounted within 30 cm from the top of the windshield;

(c) On the engine compartment cover of the vehicle at its centreline, mounted at the midpoint position between the vehicle front and the base of the windshield.

In all cases, the anemometer shall be mounted parallel to the road surface. In the event that positions (b) or (c) are used, the coastdown results shall be analytically adjusted for the additional aerodynamic drag induced by the anemometer. The adjustment shall be made by testing the coastdown vehicle in a wind tunnel both with and without the anemometer installed in the same position as used on the track., The calculated difference shall be the incremental aerodynamic drag coefficient C_D combined with the frontal area, which shall be used to correct the coastdown results.

4.3.2.4.1. Following the vehicle warm-up procedure described in paragraph 4.2.4. of this annex and immediately prior to each test measurement, the vehicle shall be accelerated to 10 to 15 km/h above the highest reference speed and shall be driven at that speed for a maximum of 1 minute. After that, the coastdown shall be started immediately.

4.3.2.4.2. During a coastdown, the transmission shall be in neutral. Any steering wheel movement shall be avoided as much as possible, and the vehicle's brakes shall not be operated.

4.3.2.4.3. Although it is recommended that each coastdown run be performed without interruption, split runs may be performed if data cannot be collected in a single run for all the reference speed points. For split runs, the following additional requirements shall apply:

(a) Care shall be taken to keep the vehicle condition as constant as possible at each split point;

(b) At least one speed point shall be overlapped with the higher speed range coastdown;

(c) At each of all overlapped speed point(s), the average force of the lower speed range coastdown shall not deviate from the average force of the higher speed range coastdown by ±10 N or ±5 percent, whichever is greater;

(d) If the track length does not allow fulfilling requirement (b) in this paragraph, one additional speed point shall be added to serve as overlapping speed point.

4.3.2.5. Determination of the equation of motion

Symbols used in the on-board anemometer equations of motion are listed in Table A4/5.

TableA4/5

Symbols used in the on-board anemometer equations of motion

Symbol	**Units**	**Description**
^{A}f	m^2	frontal area of the vehicle
a0 ... an	$degrees^{-1}$	aerodynamic drag coefficients as a function of yaw angle
Am	N	mechanical drag coefficient
Bm	N/(km/h)	mechanical drag coefficient
Cm	$N/(km/h)^2$	mechanical drag coefficient
Cd(Y)		aerodynamic drag coefficient at yaw angle Y
D	N	drag
$^{D}aero$	N	aerodynamic drag
^{D}f	N	front axle drag (including driveline)
$^{D}grav$	N	gravitational drag
$^{D}mech$	N	mechanical drag

Symbol	Units	Description
D_r	N	rear axle drag (including driveline)
D_{tyre}	N	tyre rolling resistance
(dh/ds)	-	sine of the slope of the track in the direction of travel (+ indicates
(dv/dt)	m/s²	acceleration
g	m/s²	gravitational constant
m_{av}	kg	arithmetic average mass of the test vehicle before and after road
m_e	kg	effective vehicle mass including rotating components
r	kg/m3	air density
t	s	time
T	K	temperature
v	km/h	vehicle speed
v_r	km/h	relative wind speed
Y	degrees	yaw angle of apparent wind relative to direction of vehicle travel

4.3.2.5.1. General form

The general form of the equation of motion is as follows:

$-m_e(dv/dt) = D_{mech} + D_{aero} + D_{grav}$

where:

$D_{mech} = D_{tyre} + Df + Dr$;

$D_{aero} = (1/2)\ r\ C_d(Y)\ A\ v_r^2$;

$D_{grav} = m \times g \times (dh/ds)$;

In the case that the slope of the test track is equal to or less than 0.1 per cent over its length, D_{grav} may be set to zero.

4.3.2.5.2. Mechanical drag modelling

Mechanical drag consisting of separate components representing tyre D_{tyre} and front and rear axle frictional losses D_f and D_r, including transmission losses) shall be modelled as a three-term polynomial as a function of vehicle speed v as in the equation below:

$D_{mech} = A_m + B_m v + C_m v^2$

where:

A_m, B_m and C_m are determined in the data analysis using the least squares method. These constants reflect the combined driveline and tyre drag.

In the case that the tested vehicle is the representative vehicle of a road load matrix family, the coefficient B_m shall be set to zero and the coefficients A_m and C_m shall be recalculated with a least square's regression analysis.

4.3.2.5.3. Aerodynamic drag modelling

The aerodynamic drag coefficient $C_d(Y)$ shall be modelled as a four-term polynomial as a function of yaw angle Y as in the equation below:

$C_d(Y) = a_0 + a_1Y + a_2Y^2 + a_3Y^3 + a_4Y^4$

a_0 to a_4 are constant coefficients whose values are determined in the data analysis.

The aerodynamic drag shall be determined by combining the drag coefficient with the vehicle's frontal area A_f and the relative wind velocity v_r:

Daero = (1/2) r Af vr^2 Cd(Y)

Daero = (1/2) r Af vr^2 (a0 + a1Y + $a2Y^2$ + $a3Y^3$ + $a4Y^4$)

4.3.2.5.4. Final equation of motion

Through substitution, the final form of the equation of motion becomes:

$m_e(dv/dt) = A_m + B_m v + C_m v^2 + \%\ x\ p\ x\ A_f\ x\ v_r^2\ x\ (a_Q + ajY + a_2Y^2 + a_3Y^3 + a_4Y^4) + m\ x\ g\ x\ dh/ds$

4.3.2.6. Data reduction

A three-term equation shall be generated to describe the road load force as a function of velocity, F = A + Bv + Cv^2, corrected to standard ambient temperature and pressure conditions, and in still air.

4.3.2.6.1. Determining calibration coefficients

If not previously determined, calibration factors to correct for vehicle blockage shall be determined for relative wind speed and yaw angle. Vehicle speed v relative wind velocity v_r and yaw Y measurements during the warm-up phase of the test procedure shall be recorded. Paired runs in alternate directions on the test track at a constant velocity of 80 km/h shall be performed, and the arithmetic average values of v, v_r and Y for each run shall be determined. Calibration factors that minimize the total errors in head and cross winds over all the run pairs, i.e. the sum of $(head_i - head_{i+1})^2$, etc., shall be selected where $head_i$ and $head_{i+1}$ refer to wind speed and wind direction from the paired test runs in opposing directions during the vehicle warm-up/stabilization prior to testing.

4.3.2.6.2. Deriving second by second observations

From the data collected during the coastdown runs, values for v, (dh/ds), (dv/dt), vr2, and Y shall be determined by applying calibration factors. Data filtering shall be used to adjust samples to a frequency of 1 Hz.

4.3.2.6.3. Preliminary analysis

Using a linear least squares regression technique, all data points shall be analysed at once to determine Am, Bm, Cm, a0, a1, a2, a3 and a4 given Me, (dh/ds), (dv/dt), v, vr and p.

4.3.2.6.4. Data"outliers"

A predicted force, Me (dv/dt), shall be calculated and compared to the observed data points. Data points with excessive deviations, e.g., over three standard deviations, shall be flagged.

4.3.2.6.5. Data filtering (optional)

Appropriate data filtering techniques may be applied and the remaining data points shall be smoothed out.

4.3.2.6.6. Data elimination

Data points gathered where yaw angles are greater than ±20 degrees from the direction of vehicle travel shall be flagged. Data points gathered where relative wind is less than + 5 km/h (to avoid conditions where tailwind speed is higher than vehicle speed) shall also be flagged.

4.3.2.6.7. Final data analysis

All data that has not been flagged shall be analysed using a linear least squares regression technique. Given Me, (dh/ds), (dv/dt), v, vr and r, Am, Bm, Cm, a0, a1, a2, a3 and a4 shall be determined.

4.3.2.6.8. Constrained analysis (optional)

To better separate the vehicle aerodynamic and mechanical drag, a constrained analysis may be applied such that the vehicle's frontal area Af and the drag coefficient, Cd, may be fixed if they have been previously determined.

4.3.2.6.9. Correction to reference conditions

Equations of motion shall be corrected to reference conditions as specified in paragraph 4.5. of this Annex.

4.3.2.6.10. Statistical criteria for on-board anemometry

The exclusion of each single pair of coastdown runs shall change the calculated road load for each coastdown reference speed vj less than the convergence requirement, for all i and j:

$AF_i(v_j)/F(v_j) \le 0.03 / \sqrt{(n-1)}$

where:

$DF_i(v_j)$ is the difference between the calculated road load with all coastdown runs and the calculated road load with the i^{th} pair of coastdown runs excluded, N;

$F(v_j)$ is the calculated road load with all coastdown runs included, N; v_j is the reference speed, km/h;

n is the number of pairs of coastdown runs, all valid pairs are included.

In the case that the convergence requirement is not met, pairs shall be removed from the analysis, starting with the pair giving the highest change in calculated road load, until the convergence requirement is met, as long as a minimum of 5 valid pairs are used for the final road load determination.

4.4. Correction to reference conditions and measurement equipment

4.4.1. Air resistance correction factor

The correction factor for air resistance K_2 shall be determined using the following equation:

$K_2 = (T / 293 K) x (100 kPa / P)$

where:

T is the arithmetic average atmospheric temperature of all individual runs, Kelvin (K);

P is the arithmetic average atmospheric pressure, kPa.

4.4.2. Rolling resistance correction factor

The correction factor, K_0, for rolling resistance, in $Kelvin^{-1}$ (K^{-1}), may be determined based on empirical data and approved by the responsible authority for the particular vehicle and tyre test, or may be assumed to be as follows:

$K_0 = 8,6 x 10-^{3} K'^{1}$

4.4.3. Wind correction

4.4.3.1. Wind correction with stationary anemometry

4.4.3.1.1. A wind correction for the absolute wind speed alongside the test road shall be made by subtracting the difference that cannot be cancelled out by alternate runs from the coefficient f0 determined according to paragraph 4.3.1.4.4. of this annex, or from c0 determined according to paragraph 4.4.4. of this annex.

4.4.3.1.2. The wind correction resistance w1 for the coastdown method or w2 for the torque meter method shall be calculated using the following equations:

$w_1 = 3,6^2 x f_2 x v_w^2$

where:

w_1 is the wind correction resistance for the coastdown method, N;

f2 is the coefficient of the aerodynamic term

v_w is the lower arithmetic average wind speed of opposite directions alongside the test road during the test, m/s;

4.4.3.2. Wind correction with on-board anemometry

In the case that the coastdown method is based on on-board anemometry, w1 and w2 shall be set to zero, as the wind correction is already applied.

4.4.4. Test mass correction factor

The correction factor K_1 for the test mass of the test vehicle shall be determined using the following equation:

K1 = f0 x (1 - TM/mav)

where:

f_0 is a constant term, N;

TM is the test mass of the test vehicle, kg;

m_{av} is the arithmetic average of the test vehicle masses at the beginning and end of road load determination, kg.

4.4.5. Road load curve correction

4.4.5.1. The curve shall be corrected to reference conditions as follows:

$F^* = (f_0 - w_1 - K_1 + f_1 v) \times (1 + K_0(T - 20)) + K_2 f_2 v^2$

where:

F^* is the corrected road load, N; f_0 is the constant term, N;

f_1 is the coefficient of the first-order term, N/(km/h); f_2 is the coefficient of the second-order term, N/(km/h)^2;

K_o is the correction factor for rolling résistance as defined in paragraph 4.5.2.of this Annex;

K| is the test mass correction as defined in paragraph 4.5.4.of this Annex;

K2 is the correction factor for air resistance as defined in paragraph 4.5.1.of this Annex;

T is the arithmetic average ambient atmospheric temperature, °C; v is vehicle velocity, km/h;

W1 is the wind resistance correction as defined in paragraph 4.5.3. of this Annex, N.

The result of the calculation ((f_Q - Wi - Ki) x (1 + K_o x (T-20))) shall be used as the target road load coefficient A_t in the calculation of the chassis dynamometer load setting described in paragraph 8.1. of this annex.

The result of the calculation (f_1 x (1 + K_0 x (T-20))) shall be used as the target road load coefficient B_t in the calculation of the chassis dynamometer load setting described in paragraph 8.1. of this annex.

The result of the calculation (K_2 x f_2)shall be used as the target road load coefficient C_t in the calculation of the chassis dynamometer load setting described in paragraph 8.1. of this annex.

4.4.5.2. The curve shall be corrected to reference conditions and measurement equipment installed according to the following procedure.

4.4.5.2.1. Correction to reference conditions:

$C^* = (c_0 - w_2 - K_1 + c_1 v) \times (1 + K_0(T - 20)) + K_2 c_2 v^2$

where:

C* is the corrected running resistance, Nm;

Co is the constant term, Nm;

C1 is the coefficient of the first-order term, Nm (h/km);

C2 is the coefficient of the second-order term, Nm $(h/km)^2$;

Ko is the correction factor for rolling resistance;

K1 is the test mass correction;

K2 is the correction factor for air resistance;

v is the vehicle velocity, km/h;

T is the arithmetic average atmospheric temperature, °C;

W2 is the wind correction résistance.