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BRAKE PARTICLE EMISSIONS

COOLING AIR FLOWRATE ADJUSTMENT
INTRODUCTION TO THE PROPOSED METHOD
PART 1

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COOLING AIR ADJUSTMENT METHOD NEED FOR HARMONIZATION

✓ Different laboratories feature brake dynamometers with **different design characteristics** (enclosure, sampling tunnel, and air speed or airflow measurement locations)

	LAB 1	LAB 2	LAB 3	LAB 4	LAB 5	LAB 6	LAB 7	LAB 8
Duct geometry and Diameter	Straight line D = 84.9 mm	Horizontal п shaped D = 160 mm	Vertical reverse U D =150 mm	90° bend CVS tunnel D = 300 mm	Vertical reverse U D = 56 mm	Vertical reverse п D = 100 – 250 mm	"C"-shaped D =300 mm	Square D =356mm
Inlet air Flowrate	Adjustable Optimal 60 m^3/h	Adjustable $PM_{2.5}$ at 850 m^3/h	Optimal 250 m^3/h	Adjustable Max 3300 m^3/h	Adjustable Optimal 1175 m^3/h	Adjustable 250 – 2500 m^3/h	Adjustable Max. 2500 m^3/h	Adjustable

✓ Laboratories apply a wide variety of methodologies for the **adjustment of cooling air flowrate** at different brake dynamometers.

As a result differences in brake temperature regimes among labs are observed. This has a negative effect on the quality of emission measurements as well as on the reproducibility of the results among the laboratories

COOLING AIR ADJUSTMENT METHOD FUNDAMENTAL REQUIREMENTS

- ✓ **Constant flowrate -** Emission measurements require the application of a **constant cooling air flowrate**. Constant flowrate introduces an error as it is not possible to accurately reproduce braking events at completely different vehicle speeds with the same flowrate

- ✓ **Vehicle dynamics –** The method should take into account – to the extend possible – **specific features of the vehicle** (brake tested) such as mass, inertia split and parasitic losses. Once more a compromise is required as all vehicle related parameters cannot be accurately replicated at a dyno level

- ✓ **Repeatability & reproducibility –** The application of the method shall not only ensure **repeatable results** within a given lab but also **reproducible results** among different dyno configurations

- ✓ **Accesible to laboratories –** The method should be relatively **simple** (not simplistic), **not** too much **time and resource consuming** but also **accesible to all labs** with a certain level of technical capacity

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COOLING AIR ADJUSTMENT METHOD
STEP 1 - PREPARATION PHASE (1/2)

✓ 6 CARB + 1 Ford Focus vehicles were tested over trip #10 of the novel WLTP-Brake cycle on a test track. Tested vehicles featured different brake systems (Table). The temperature profile of the brakes has been recorded by means of embedded thermocouples and basic statistics have been extracted

Vehicle	Axle [-]	Pad [-]	Disc [-]	DO Diameter [mm]	Disc Thickness [mm]	Inertia [kg·m²]	Vehicle test mass [kg]	Road Load Coefficients		
								A / f0 [N]	B / f1 [N/(km/h)]	C / f2 [N/(km/h)²]
Veh #1	Front	NAO	Vented	260	20	52.6	1347	94.698	0.3287	0.0321
	Rear	N/A	N/A	N/A	N/A	18.9				
Veh #2	Front	NAO	Vented	295	28	79.7	1665	159.765	-0.0332	0.0344
	Rear	NAO	Solid	280	10	28.6				
Veh #3	Front	NAO	Vented	290	26	84.6	1651	158.304	-0.4360	0.0481
	Rear	NAO	Vented	290	16	30.4				
Veh #4	Front	NAO	Vented	330	28	99.0	2182	166.284	0.1055	0.0508
	Rear	NAO	Solid	310	10	48.0				
Veh #5	Front	NAO	Vented	350	34	165.0	2617	208.300	2.1170	0.0538
	Rear	NAO	Vented	335	22	60.0				
Veh #6	Front	LS	Vented	278	25	56.7	1600	118.400	1.5700	0.0300
	Rear	LS	Solid	271	11	22.4				

COOLING AIR ADJUSTMENT METHOD
STEP 1 - PREPARATION PHASE (2/2)

The target parameters recorded with the vehicles over trip #10 are: **Average disc temperature**; **Average Initial Brake Temperature (IBT) of top 5% high power* events**; **Average Final Brake Temperature (FBT) of top 5% high power* events**; **Maximum disc temperature**

Axle [-]	Disc type [-]	Average Temperature [°C]	Average Top 5% IBT [°C]	Average Top 5% FBT [°C]	Maximum Temperature [°C]
Front	Vented	85	85	135	170
Rear	Vented	65	65	95	115
Rear	Solid	80	85	135	180
Tolerance		**±10**	**±15**	**±25**	**±25**

Summary of average values of the target parameters recorded for the different brakes over the vehicle testing campaigns – Proposed tolerances to be respected

***Top 5% high power events refer to 6 out of the total of 114 events of trip #10 with the highest energy dissipation accounting for parasitic losses**

COOLING AIR ADJUSTMENT METHOD
STEP 2 – EXECUTION PHASE (1/3)

The brake couple of Vehicle #1 (Front/Rear) or an acceptable equivalent* is mounted on the brake dyno and tested over trip #10 of the WLTP-Brake cycle applying the best available flowrate

✓ Cooling air **temperature and Relative Humidity** shall be adjusted to 20±2°C** and 50±5%**, respectively. Labs need to make sure they stay as close to the target values as possible (20°C and 50% RH)

✓ **Dyno inertia** shall be adjusted allocating the nominal inertia split for the tested vehicle (Default method) or alternatively allocating the proposed inertia values from the matrix provided in SAE J2789 Standard. The lab will need to report which method has applied for the inertia allocation

✓ Correction accounting for **parasitic losses** shall be performed. The default option requires the use of A (f0), B (f1), and C (f2) vehicle parameters. Alternatively, a constant correction of 13% shall be applied to the applied inertia values. The lab shall report the method applied for the consideration of parasitic losses

***Acceptable equivalent: Brake disc of same type. Dimensions within 8 mm OD and within 4 mm DT (vented) and 2 mm (solid) discs**

**** 20±5°C** and 50±10% RH are allowed for no longer than the 10% duration of the trip #10**

COOLING AIR ADJUSTMENT METHOD
STEP 2 – EXECUTION PHASE (2/3)

The disc temperature profile is recorded by means of embedded TC and the target parameters are calculated. These values are compared to the values of the generic target parameters

		Column A Vehicle/Target/Generic	Column B Brake Dyno	Column C Difference	Column D Acceptance
Target #1	**Average Temperature**	**A = 85°C**	**X = 80°C**	**|A-X|°C = 5°C**	**K=5°C≤10°C**
#46			Y_1 = 49	n/a	n/a
#101			Y_2 = 33	n/a	n/a
#102			Y_3 = 93	n/a	n/a
#103			Y_4 = 89	n/a	n/a
#104			Y_5 = 109	n/a	n/a
#106			Y_6 = 85	n/a	n/a
Target #2	**Average Top 5% IBT**	**B = 85°C**	**AVG(Y_1:Y_6) = 76°C**	**|B-Y|°C = 9°C**	**L=9°C≤15°C**
#46			Z_1 = 148	n/a	n/a
#101			Z_2 = 101	n/a	n/a
#102			Z_3 = 127	n/a	n/a
#103			Z_4 = 115	n/a	n/a
#104			Z_5 = 148	n/a	n/a
#106			Z_6 = 94	n/a	n/a
Target #3	**Average Top 5% FBT**	**C = 135°C**	**AVG(Z_1-Z_6) = 122°C**	**|C-Z|°C = 13°C**	**M=13°C≤25°C**
Target #4	**Maximum Temperature**	**D = 170°C**	**Ω = 157°C**	**|D-Ω|°C = 13°C**	**N=13°C≤25°C**

COOLING AIR ADJUSTMENT METHOD
STEP 2 – EXECUTION PHASE (3/3)

- ✓ If all parameters are within the given tolerance then the adjustment has been completed. It is advised that max temperature does not reach the higher levels of the tolerance as this will compromise PN emission tests

The optimal flowrate for the specific Vehicle/Axle application has been determined. This flowrate can be used for emissions testing of the specific Vehicle/Axle as well as for acceptable equivalents

- ✓ If one or more of the measured parameters are outside the given tolerances then the lab shall run again the execution step adjusting the flowrate accordingly

- ✓ In case non-compliant parameters have higher temperature values compared to the targets the lab shall increase the cooling air speed. If non-compliant parameters have lower temperature values compared to the targets the lab shall decrease the cooling air speed

COOLING AIR ADJUSTMENT METHOD
STEP 3 – OTHER BRAKES

- ✓ Run the execution step for the brake couple of Vehicle #2 (Front/Rear) or an acceptable equivalent by applying the cooling air flowrate and brake setup conditions (caliper orientation and brake rotation) established for Vehicle #1

- ✓ Record the disc temperature profile and calculate the target parameters. Campare to the values of the generic target parameters making sure that the correct values have been selected from the Table

- ✓ If one or more of the measured parameters are outside the given values and tolerances, adjust the cooling air accordingly to remain within the temperature tolerances. The adjustment should be done by modifying the cooling air speed

The optimal flowrate for the specific Vehicle/Axle application has been determined. This flowrate can be used for emissions testing of the specific Vehicle/Axle as well as for acceptable equivalents

COOLING AIR ADJUSTMENT METHOD ADVANTAGES

- ✓ The application of the proposed methodology will allow for laboratories with different setups to reproduce at a satisfactorily level the temperature regimes of the tested brake couples. This is a very important step towards comparable and reproducible emissions measurements

- ✓ The proposed methodology is rather simple and not too much time and resources consuming, while at the same time it accounts for important parameters like the allocation of inertia, parasitic losses, etc. It can be applied by all labs with a certain level of technical capacity

- ✓ The proposed methodology gives the opportunity to a laboratory to satisfactorily define the optimal flowrates for a wide variety of existing brake couples in the LDV sector. Of course deviations are expected – particularly when brakes not considered during vehicle testing (different dimensions) are tested – but the table can be updated regularly to include any new vehicle data

COOLING AIR ADJUSTMENT METHOD ACKNOWLEDGMENTS

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Any questions?

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