PMP IWG
BRAKE PARTICLE EMISSIONS

DEFINITION OF TESTING SPECIFICATIONS
COOLING ADJUSTMENT METHOD

Theo Grigoratos and TF2 members

PMP Webconference 15 July 2021

BACKGROUND – PROBLEM DEFINITION

✓ Different setups come with different design characteristics (dimensions, enclosure shape, sampling tunnel, etc.) – As a result cooling is not identical between the labs

	LAB 1	LAB 2	LAB 3	LAB 4	LAB 5	LAB 6	LAB 7	LAB 8
Duct geometry	Straight line	Horizontal π shaped	Vertical reverse U	90° bend CVS tunnel	Vertical reverse U	Vertical reverse π	"C"-shaped	Square
Duct Diameter	85 mm	160 mm	150 mm	300 mm	56 mm	250 mm	300 mm	356 mm

✓ Until the publication of the GRPE-81-12, there was no commonly accepted method for adjusting the incoming cooling air-speed – As a result each lab applied its own optimal flowrate which in most cases was identical for all tested brakes

Sustbantial differences in terms of brake temperature were observed among the labs for the same brake applications --- ***A subsequent negative effect on the quality of emission measurements as well as on the reproducibility of the results among the laboratories***

GRPE-81-12 PROPOSAL – TARGET PARAMETERS

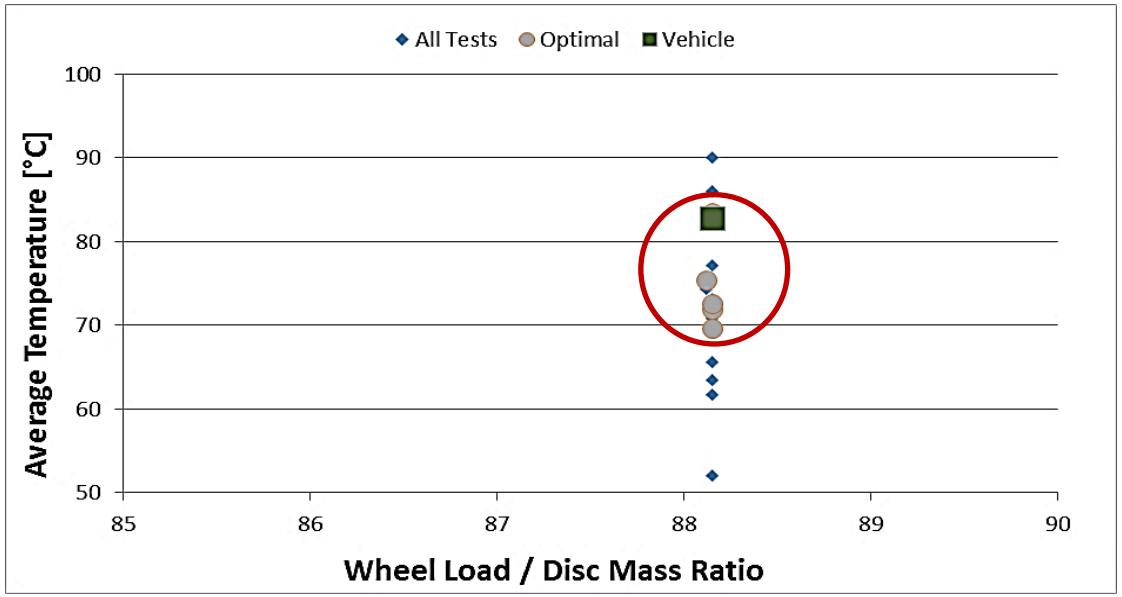
Seven vehicles were tested over the Trip #10 of the WLTP-Brake cycle on a test track. The temperature profile of the brakes was recorded. High-level statistics were extracted for the four target parameters:

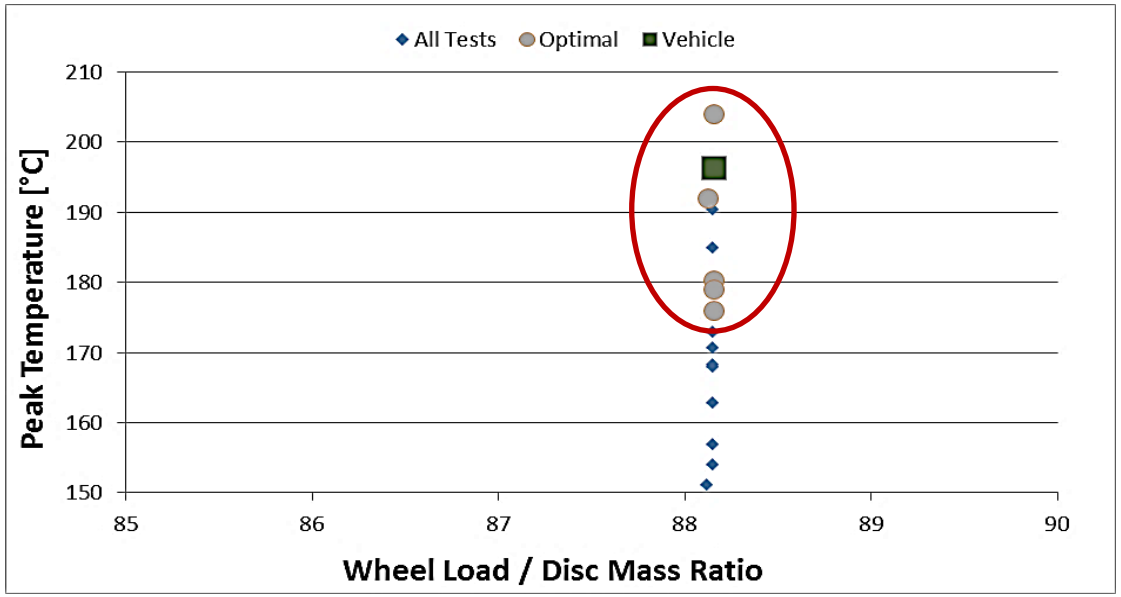
- ***Average brake temperature*** over the entire Trip #10 of the WLTP-Brake Cycle
- ***Average Initial Brake Temperature (IBT)*** of events #46, #101, #102, #103, #104, and #106 from Trip #10
- ***Average Final Brake Temperature (FBT)*** of events #46, #101, #102, #103, #104, and #106 from Trip #10
- ***Maximum brake temperature*** of the entire Trip #10 of the WLTP-Brake Cycle

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

GRPE-81-12 PROPOSAL– EVALUATION

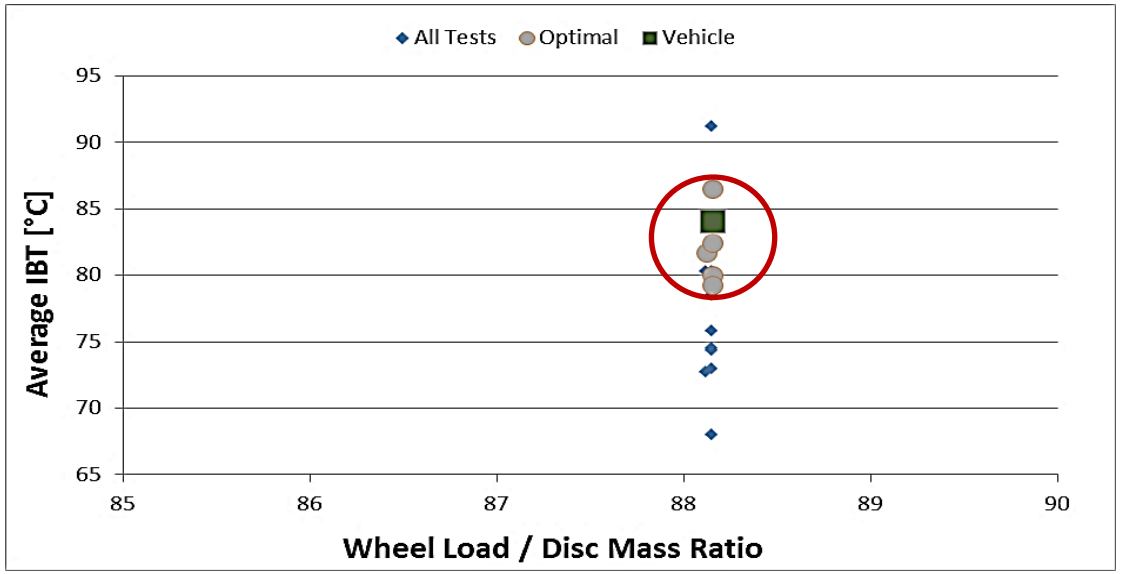
The Ford Focus brake was tested in five different labs – Different flowrates within the same lab(s) were applied – Optimal refers to the measurements best fitting the PMP protocol – Vehicle datapoints refer to the proving ground values

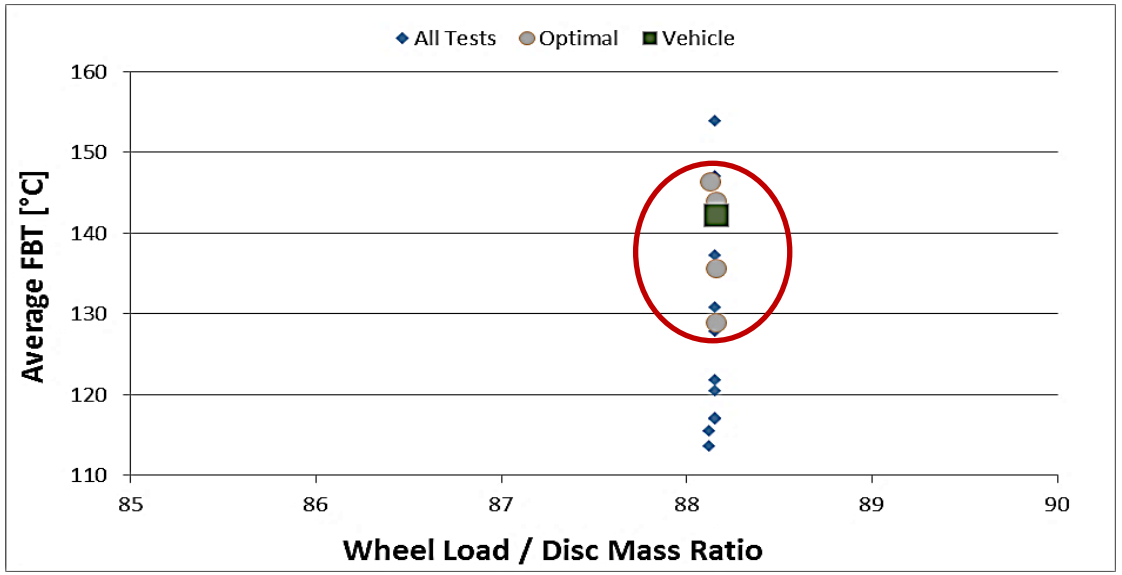




*Average temperatures for trip #10 are within a **<12°C** despite the differences in geometries and dimensions. Max temperatures fall within a wider range of **30°C** and seem to be less reproducible*

GRPE-81-12 PROPOSAL– EVALUATION





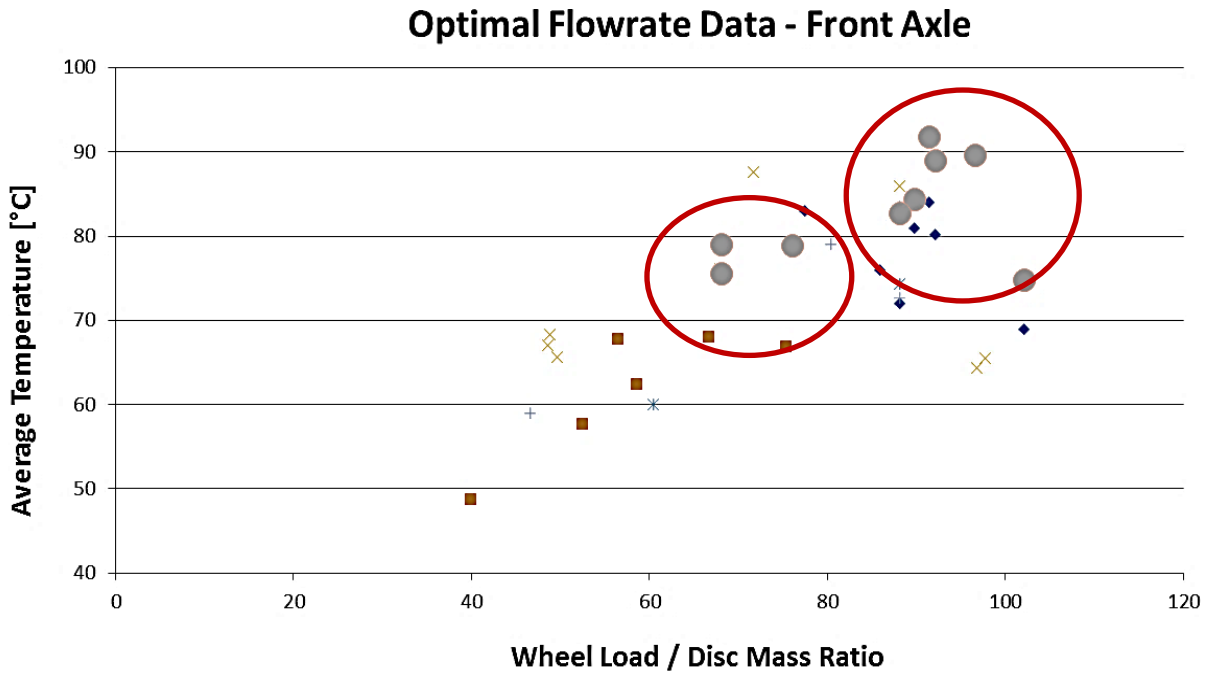
Average IBT for trip #10 are within a narrow ***<8°C****. Average FBT fall within a wider range of* ***~15°C*** *but much lower than peak temperature*

TAKE AWAY

The method seems to provide results of good accuracy for three of the target parameters; however, there are doubts for the suitability of ***the peak temperature*** – Additionally, the restriction of the peak temperature might affect the proper evaluation of lower quality brakes

GRPE-81-12 PROPOSAL– EVALUATION

Different front axle brakes were tested in six labs – Tests were carried out with the optimal flowrate for each lab – Gray circles represent the proving ground (vehicle) values



The WL/DM ratio is used to separate brakes for their temperature behaviour

Nominal Wheel Load (WL): Load applied to the dyno to represent the tested brake (front or rear) without taking into account vehicle's parasitic losses. WL is calculated from the inertia and brake force distribution of the vehicle. The mass of 0.5 occupants shall be added to the vehicle mass in running order.

Disc Mass (DM): The actual mass of the tested disc in kg.

There is a tendency for reduced temperatures with reduced WL/DM ratios. This indicates that the GRPE-81-12 proposal might not be applicable as is for the whole range of brake applications – Similar trends were also observed for the IBT and the FBT

COOLING ADJUSTMENT – POSSIBLE SOLUTIONS

- ✓ Keep the method as is with minor modifications i. Remove the peak temperature as it seems to be the less reproducible and ii. Further relax existing threshold values for the other three parameters.

  (+) Does not require further analysis, allows for a more "relaxed" selection of the optimal flowrate by the labs, and resolves the issue of coverage of a broader range of applications
  (-) Less accurate and reproducible method due to further relaxation. Brakes treated in the same way regardless size and application. Labs could run cooler resulting in "favourable" PN measurements against other labs

- ✓ Change the philosophy by i. setting a minimum acceptable average temperature to ensure that labs do not run cool and a maximum peak temperature to ensure that labs do not run too hot ii. Define IBT and FBT based on vehicle data similarly as per GRPE-81-12.

  (+) Does not require much further analysis, allows for a more "relaxed" selection of the optimal flowrate by the labs, and resolves the issue of coverage of a broader range of applications
  (-) A minimum temperature might be restrictive for certain applications (i.e. WL/DM ratio of ~40), while the peak temperature value will not allow for proper evaluation of low quality brakes

- ✓ Keep a similar philosophy to option 2 but define the threshold values for the parameters based on 4 different WL/DM ratios (i.e. ≤45; >45&≤65; >65&≤85; >85). Remove the peak temperature.

SELECTED OPTION – IN A NUTSHELL

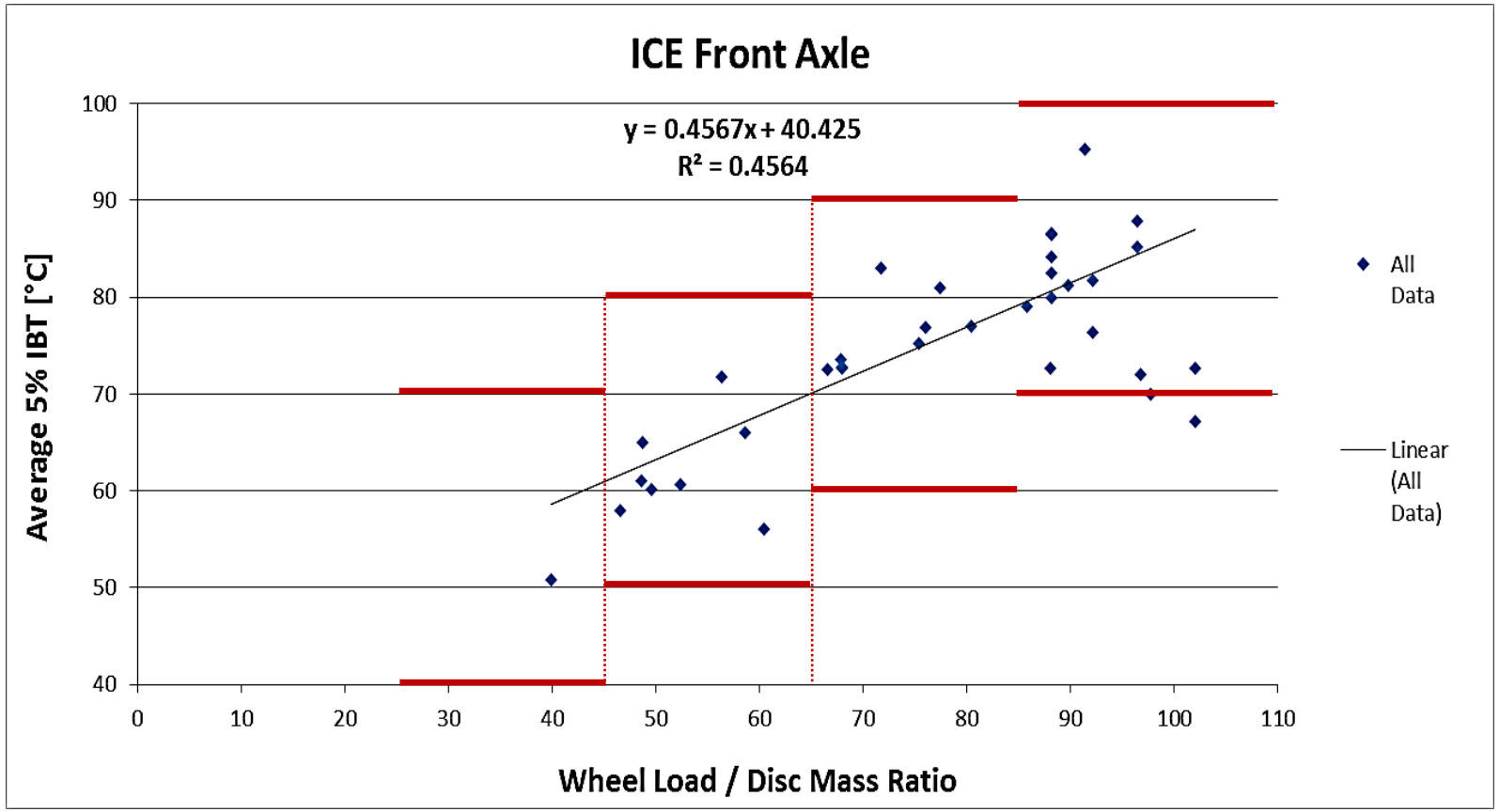
Four WL/DM groups are identified. Each group comes with its target values for IBT and FBT. Similarly, four minimum values are defined for the average temperature. Target values are adjusted based on available vehicle and dyno data

WL/DM Groups	Mean [°C]	5% IBT [°C]	5% FBT [°C]
≤45	>50*	55±15*	85±25*
>45 & ≤65	>55	65±15	105±25
>65 & ≤85	>60	75±15	120±25
>85	>65	85±15	140±25

*** To be revisited when more data from brakes are tested**

- ***Classify the tested brake according to its Wheel Load to Disc Mass (WL/DM) ratio***.
- Run Trip #10 of the WLTP-Brake cycle to obtain ***i. The Average Temperature*** of the Trip (1Hz)***, ii. The Avegare Initial Brake Temperature (IBT)*** of six predefined brake events, ***iii. The Avegare Final Brake Temperature (FBT)*** of the same six events.
- ***Check the temperatures measured in the previous step for compliance with the default temperature metrics and limits*** as defined in the Table shown in this slide.
- ***If all three temperature criteria are fulfilled the adjustment of the cooling air speed is considered successful***. If not, appropriate adjustments shall be made to meet all defined criteria.

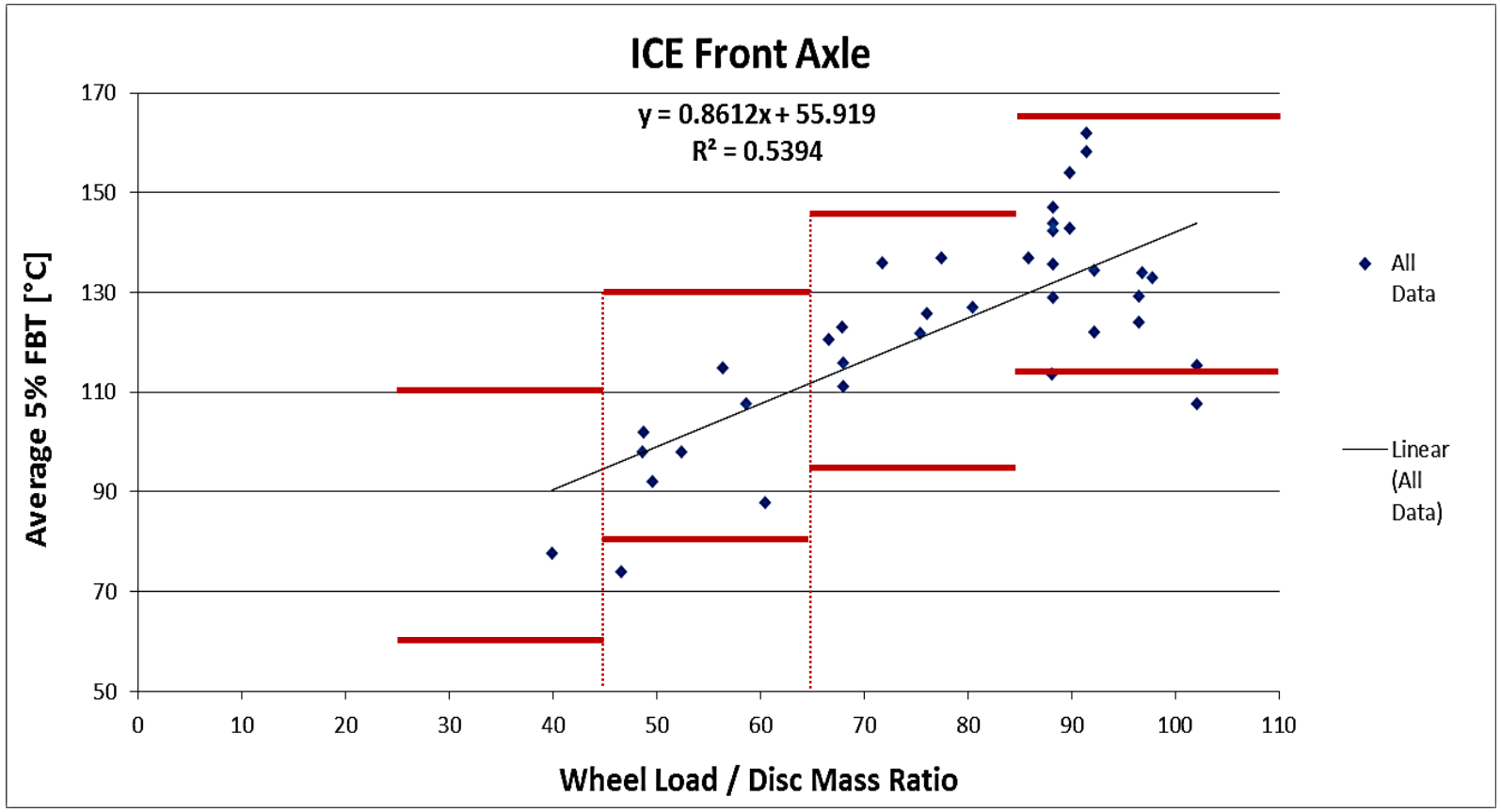
SELECTED OPTION – TOP 5% IBT



WL/DM Groups	5% IBT [°C]
≤45	55*
>45 & ≤65	65
>65 & ≤85	75
>85	85
Tolerance	±15

*** To be revisited after the ILS**

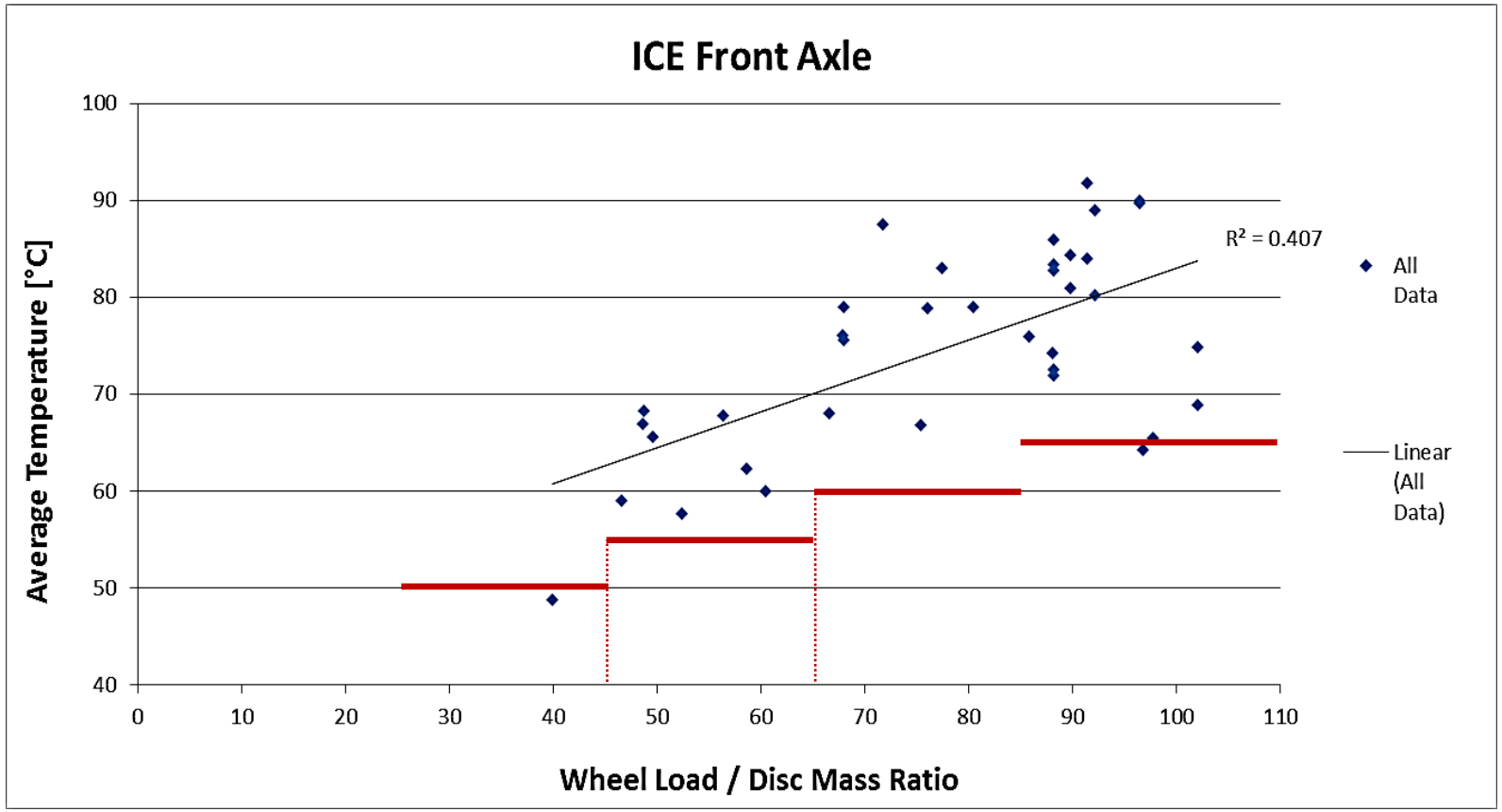
SELECTED OPTION – TOP 5% FBT



WL/DM Groups	5% FBT [°C]
≤45	85*
>45 & ≤65	105
>65 & ≤85	120
>85	140
Tolerance	±25

* To be revisited after the ILS

SELECTED OPTION – AVERAGE TEMPERATURE



WL/DM Groups	ABT [°C]
≤45	>50*
>45 & ≤65	>55
>65 & ≤85	>60
>85	>65
Tolerance	N/A

* To be revisited after the ILS

COOLING ADJUSTMENT – SELECTED OPTION

(+) Provides a more "fair" solution covering the entire range of brake applications available in the market and taking into account the vehicle and brake size combined

(+) Allows for a more "relaxed" selection of the optimal flowrate compared to other options

(+) Minimum values for the average temperature ensure that labs will not run tests much cooler than others and also than in the reality

(+) Peak temperature has been removed since it is not measured in a repeatable and reproducible manner – this allows for better characterization of lower quality brakes

(+) Can be updated with proving ground vehicle temperature data when and if these become available

(-) One specific group (WL/DM <45) relies on very few brake dyno data and not vehicle data; therefore, the target values might not be representative

(-) Might "penalise" brakes with WL/DM values closer to the lower threshold of the predefined WL/DM groups (i.e. Brakes with WL/DM = 46 need to follow the temperature specs of the >45 & ≤65 group)

WRAP-UP

- The proposed option will substitute the existing cooling adjustment protocol as described in GRPE-81-12. Target values for the lower WL/DM group might be revised when more data become available
- The proposed option applies to all front conventional brake systems (Vented Gray Cast Iron). It is suggested to apply it also to other types of available discs (i.e. Coated Discs, Carbon Ceramic, etc.). Target values for other types of discs might be revised when more data become available
- It is suggested that the cooling adjustment of rear brake systems is carried out by applying the cooling air flowrate obtained for the corresponding front brake application through the proposed option
- The allocation of a brake system into a given WL/DM group shall be done based on the actual vehicle inertia and not the reduced value that applies when labs compensate for vehicle parasitic losses by reducing inertia by 13% (GRPE-81-12)
- When more than one cooling airflow satisfies all metrics it is proposed for the labs to select the airflow which provides temperatures closer to the target values for IBT and FBT

Thank you

European Commission