OICA – Working-Group on *Ducting & Enclosure* for brake emission testing

28.09.2023

Introduction of the Working-Group *Ducting & Enclosure*

Goals:

A. Find actionable assessment methods for determination of particle distribution, transport efficiency and particle residence time.

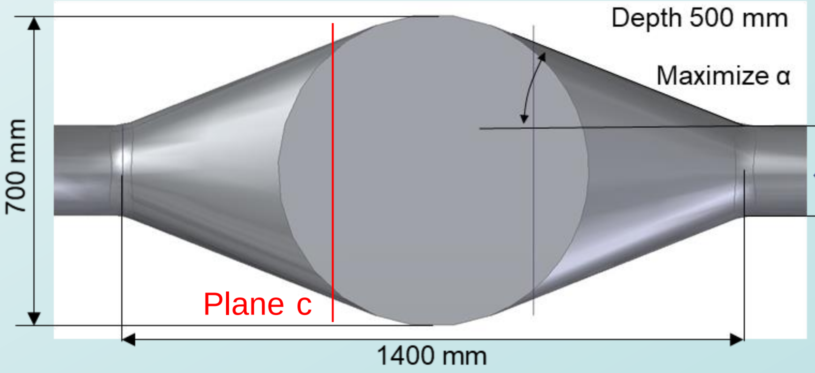
B. Generate understanding regarding particle transport and possible source of variability and particle loss

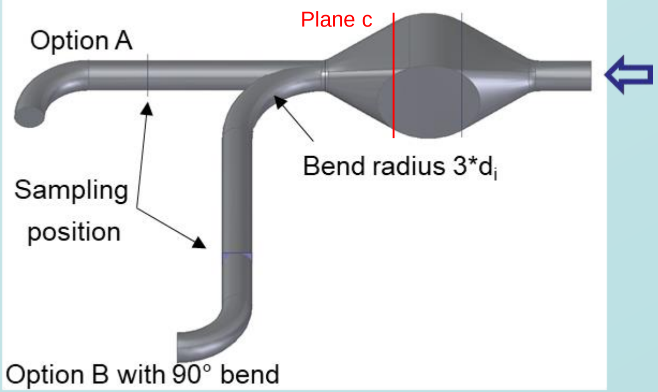
C. Conclude premises for the enclosure and ducting design and further optimization, in order to achieve robust brake emission setup, that is comparable from lab to lab and assures a high particle efficiency.

OICA proposes a recommended design within the UN-GTR No.24 that increases the comparability and allows enough flexibility to implement in existing test rigs:

- Enclosure + ducting: fixed values (e.g. duct inner diameter of 200 mm)
- Flow homogeneity (current GTR proposal 35%): reduction to XX% (to be discussed and reduced as experiments show achievability)
- For the 90° bend (current GTR proposal $2*d_i$): $3*d_i$

→ Two possible setups with limited flexibility should be recommended:
  1) straight duct and
  2) with one 90° bend

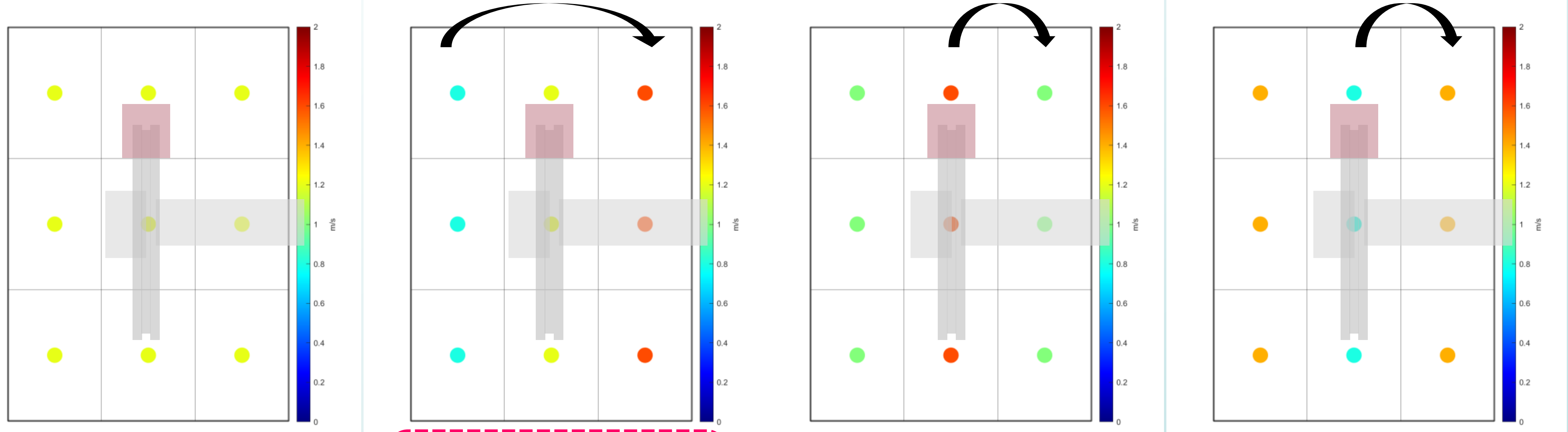


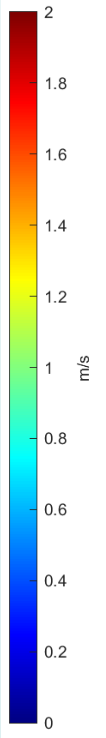


Inlet conditions - Airflow homogeneity at Plane C (CFD)

1512 m³/h with a cross section of 700 x 500 mm²
1.2 m/s average velocity in all cases

Case 1: homogeneous flow	Case 2: distribution after bend	Case 3: jet flow	Case 4: ring flow
	100%	-37.5%	75%





1.2 m/s	0.8 m/s 1.2 m/s 1.6 m/s	1 m/s 1.6 m/s 1 m/s	1.4 m/s 0.8 m/s 1.4 m/s
0%	-33.3% 0% 33.3%	-16.7% 33.3% -16.7%	16.7% -33.3% 16.7%

GTR-compliant <35%

Change in volume flux to achieve similar cooling (to 1.2 m/s in the middle section)

0%	0%	-25% to 1134 m³/h	50% to 2268 m³/h

Variation of volume flux between labs is not to restricted to 35% (airflow homogeneity) for the same brake but could much larger

- ➢ **tighter airflow homogeneity criterium**

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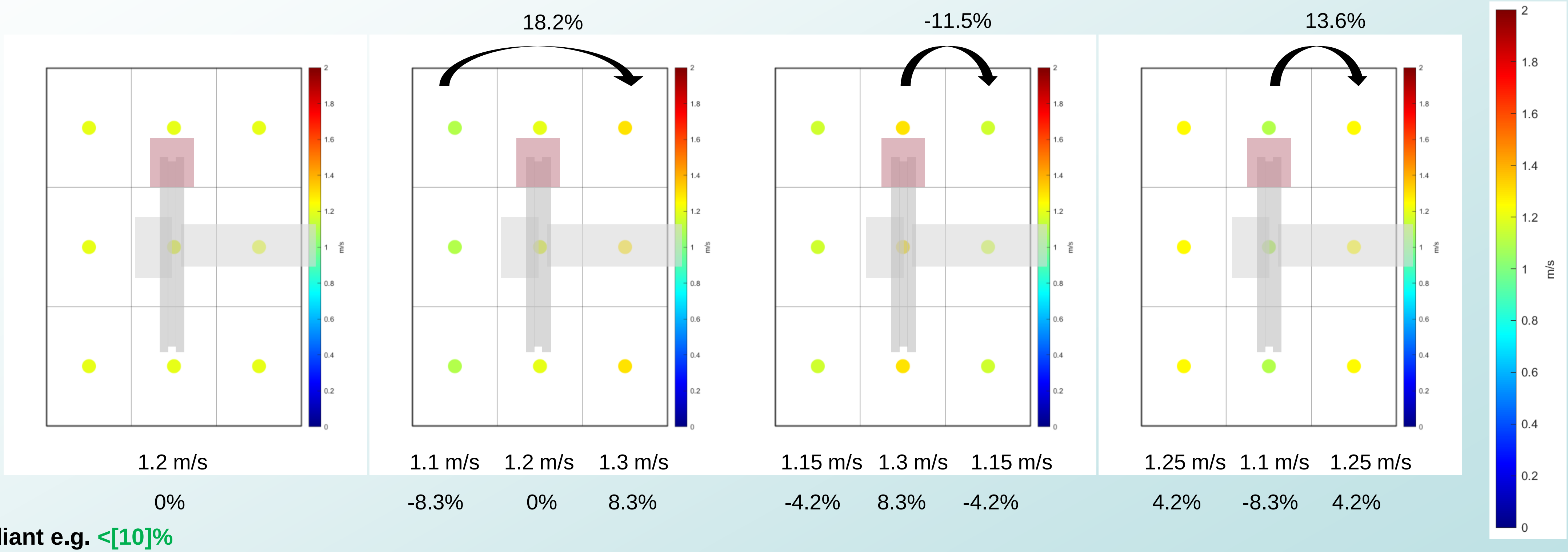


GTR-compliant e.g. <[10]%

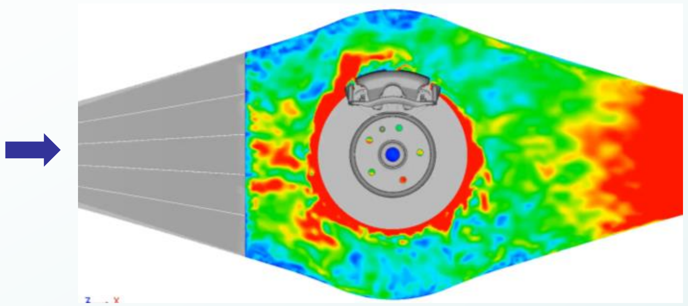
Change in volume flux to achieve similar cooling (to 1.2 m/s in the middle section)

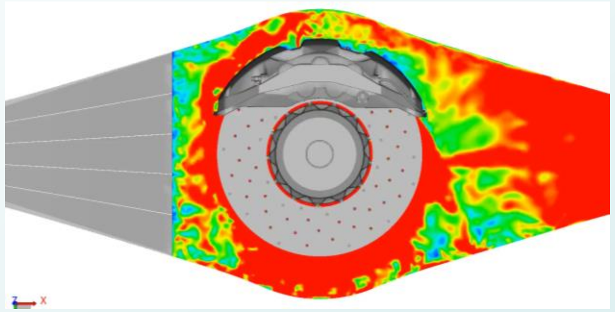
0% | 0% | -7.7% to 1396 m³/h | 13.6% to 1717 m³/h

Not only the airflow homogeneity criterium will be sufficient, enclosure dimensions and sampling ducting will still impact particle distribution and particle loss and need to be fixed

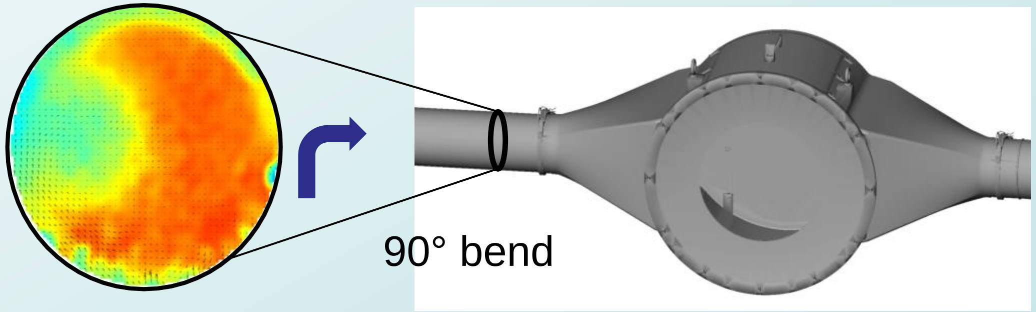
Airflow and particle transport inside the enclosure (CFD+PTV)

Influence of the brake size to the airflow

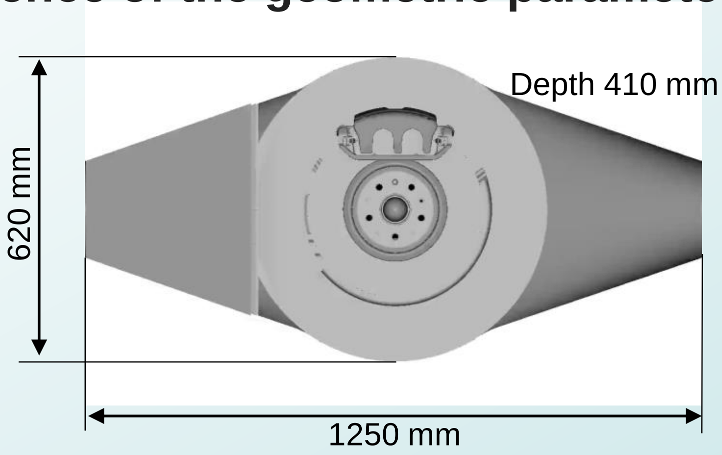


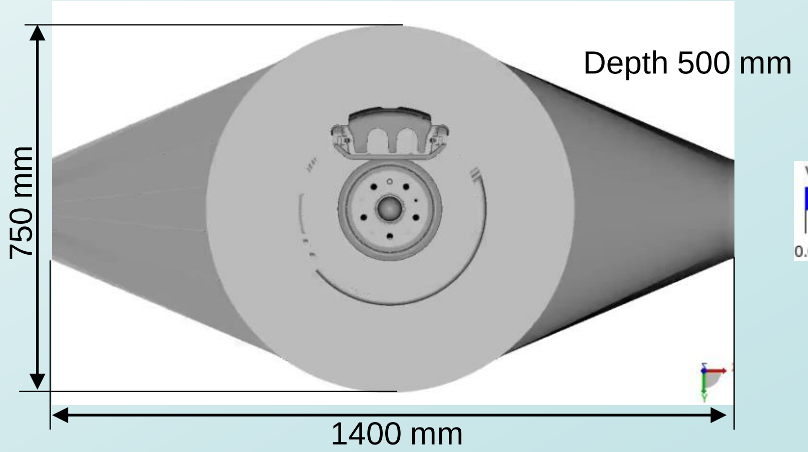


Airflow measurement (PTV)



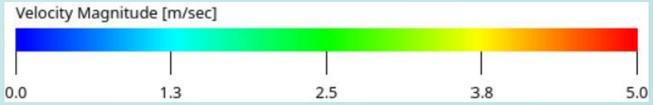
Influence of the geometric parameters on the particle transport (residence time)





CFD: Computational Fluid Dynamics

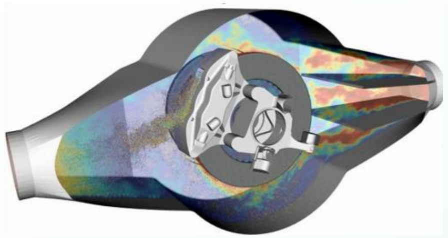
PTV: Particle Tracking Velocimetry



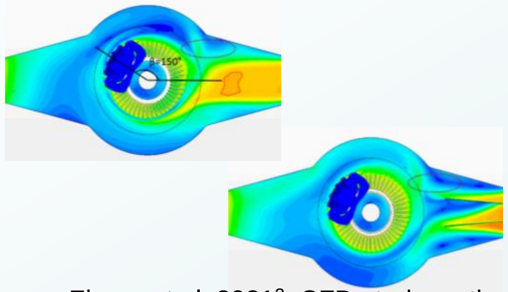
GTR conformity not confirmed

Inlet conditions, brake dimensions, enclosure design → Effect on airflow, particle distribution and potentially particle losses (next to multiple factors)

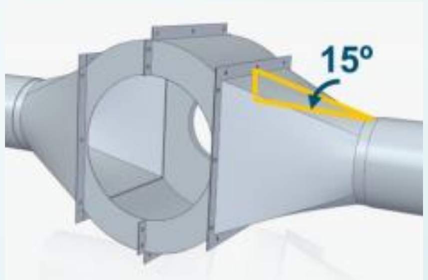
Airflow and particle transport inside the enclosure (CFD+PTV)



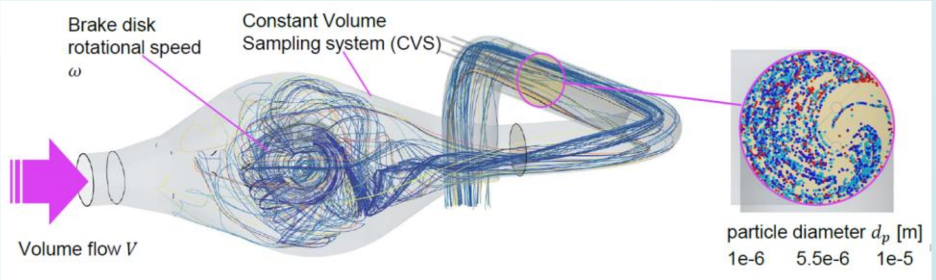
Agudelo et al. 2019[1]: DOE with CFD of influences (…) with fixed enclosure geometry



Zhang et al. 2021[2]: CFD study on the enclosure designs



Loranca 2022[3]: Experimental study on influence of enclosure on PM10



Feißel 2023[4]: Regulation of brake particle emissions by Euro 7

Influence of the enclosure design on the variability of emission measurements has not been proven

- Particle distribution in sampling duct is dependent of the particle injection and the particle transport in enclosure (brake geometry, brake cycle, particle size, inlet conditions, enclosure design, etc.)
  - ➢ no certainty about representative sampling even in straight duct or after 90° bends
- A homogeneous airflow and a clear correlation with particle distribution were not found in any study; the determination of transport efficiency was based on major simplifications

Influence of flow conditions on particle transport, distribution uniformity and loss has not been assessed.
(in a complex system e.g. an brake enclosure with a rotating brake disc)

Summary

1. **Inlet conditions**, **design of enclosure**, **brake dimensions** + **rotation** and **fixture dimensions** have a direct impact on the airflow.→ Influence of the factors hasn't been assessed and might not have been uniquely covered in UN-GTR
2. **Particle distribution**, **particle loss** and thus representativeness of measurement through sampling principle is highly dependent on design of **brake enclosure** + **sampling duct** and the **brake** itself
3. **Although various** (analytical and simulative) **studies** are **available** on the particle deposition and distribution, no experimental confirmation has been performed to **assess** the **impact** of the **mentioned factors**
4. **A higher comparability** could be achieved with a **unique design** of the sampling duct → nevertheless **flexibility** is **needed** to implement new UN-GTR in current and recently acquired brake test benches

⟶ **Proposed next steps**

- **(Re-)activate TF 3** to plan and organize **the ILS**. Ask for active participants and define a proposal for brakes to test, schedule, testing equipment and procedure. (Current technology to be included)
- Schedule meetings of **TF 4** with interested participants to discuss different positions and come up with a **proposal for the implementation to the GTR 24**.
- Present and discuss the findings of TF 3 and TF 4 during the **next PMP-meetings**
  - ➢ Evaluate if an adaptation of the GTR seems reasonable due to high measurement deviations

Timeline for implementation of recommendations

Steps for implementation:

Q4 2022-Q2 2023	1. Definition of qualified recommendations within GTR based on literature research, CFD and DOE/CFD
	2. Implementation of proposed design in existing test rigs
Q3/Q4 2023	**3. Planning of ILS 2 (labs, brakes, etc.) must start as soon as possible**
Q4 2023	4. Proof of GTR-conformity of test rigs with/without recommended design
Q1 2024	5. Calibration of cooling airflow, brake bedding and emissions measurement
Q1/Q2 2024	6. Analysis of data
	7. Evaluation of variability (overall and comparison between labs with/without the recommended design)
	• If PM_{10} variability overall is <[10]%, then no recommended values are needed
Goal: June 2024	• If PM_{10} variability is >[10]%, but with recommended values is <[10]% → recommended values should be in UN-GTR

Steps 4–7: **ILS 2**

- A description of the test rig (enclosure, ducting and sampling) and the results from airflow homogeneity should be given
- Qualified recommendations should be included in ILS 2 to assess their performance and evaluate their possible benefit
- Recommendation will not affect existing setups and are intended to further harmonize the design across the industry

Literature

[1] Agudelo, C., Vedula, R. T., Capecelatro, J., & Wang, Q. (2019). *Design of Experiments for Effects and Interactions During Brake Emissions Testing Using High-Fidelity Computational Fluid Dynamics* (No. 2019-01-2139). SAE Technical Paper.

[2] Zhang, T., Choi, S., Ahn, S., Nam, C., & Lee, G. (2021). Enclosure Design for Brake Wear Particle Measurement Using Computational Fluid Dynamics. *Energies*, *14*(9), 2356.

[3] Loranca, C. (2022). Experimental Influence Analysis of the Sampling of Passenger Car Brake Particle Emissions on a Dynamometer (Master Thesis, Technical University of Darmstadt).

[4] Feißel, T. (2023, June 20-23). Regulation of brake particle emissions by Euro 7 [Conference presentation]. Chassis.tech plus 2023, München, Deutschland.

Summary of Proposed Changes

Change no.	Excerpt from	Current text	Discussion Item - Proposed Change
1	7.4.2. (c)	The inlet and outlet cross-sections shall be designed to ensure smooth transition angles (15° ≤ a ≤ 30°) in order to avoid sudden changes in cross-section shape or size;	Request for addition: Recommendation: Angle should be maximized to avoid recirculation areas in the upper and lower part of the enclosure
2	7.4.2. (d)	The transition points between the segments shall not have any imperfections or features that may collect brake particles that could become airborne later during the test;	Request for clarification and addition: Specify what tolerance is permitted.
3	7.4.2. (e)	If fasteners are applied at the transition points, they shall not protrude into the enclosure area;	Request for clarification and addition: Specify what tolerance is permitted.
4	7.4.2. (j)	Plane C is tangential to an arbitrary disc of a diameter of 450 mm. Design the cross-section area at the enclosure inlet so that the airspeed at Plane C remains below the maximum permissible tolerance for speed uniformity defined in point (l) of this paragraph. If necessary, use flow straighteners or diffusion plates at the inlet's side upstream of Plane B to ensure the highest possible level of uniform flow at Plane C;	Request for addition: Add filter meshes as a possibility to achieve flow homogeneity.
5	7.4.2. (l)	Measure the airspeed values at the nine positions of Plane C without a brake assembly or a brake fixture installed. All the cooling air ducting utilized for the brake emissions test shall remain connected to the enclosure during these measurements. Carry out the measurement at the minimum and maximum operational flows of the test system. Let the flow stabilise for at least 2 minutes before conducting each measurement. The airflow is considered stabilized when the average measured flow in the sampling tunnel is within ±5 per cent of the set value. Perform the airspeed measurement for at least 2 minutes after the stabilisation. The measurement time shall be of sufficient duration to detect any instability in the airspeed pattern that may affect the airspeed values. Airspeed at each position shall not vary by more than ±35 per cent of the arithmetic mean of all measurements for a given flow.	Request for addition: Airspeed at each position shall not vary by more than **±XX** per cent of the arithmetic mean of all measurements for a given flow;

Summary of Proposed Changes

Change no.	Excerpt from	Current text	Discussion Item - Proposed Change
6	7.4.3. (a)	Design the brake enclosure symmetrically to Plane A1. The length of Plane A1 (lA1) represents the most extended length of the enclosure along the flow direction. Plane A1's length shall be between 1200 mm and 1400 mm (1200 mm ≤ lA1 ≤ 1400 mm);	Request for addition: It is recommended to design an enclosure with a length close to **1400 mm**;
7	7.4.3. (b)	Design the brake enclosure symmetrically to Plane D. The length of Plane D (hD) represents the longest distance (height) of the enclosure perpendicular to the flow direction. Plane D's height shall be between 600 mm and 750 mm (600 mm ≤ hD ≤ 750 mm);	Request for addition: It is recommended to design an enclosure with a height close to **700 mm**;
8	7.4.3. (g)	The maximum axial depth of the brake enclosure at Plane D (parallel to the brake rotation axis) shall be between 400 mm and 500 mm.	Request for addition: It is recommended to design an enclosure with an axial depth close to **500 mm**;
9	7.5. (d)	Ducts shall have a constant inner diameter di of at least 175 mm and a maximum of 225 mm (175 mm ≤ di ≤ 225 mm). The duct inner diameter di is defined as shown in Figure 7.6.;	Request for addition: It is recommended to implement a duct with an inner diameter of **200 mm**;
10	7.5. (e)	A maximum of one bend of 90° or less may be applied in the sampling tunnel (i.e. downstream of the brake enclosure and upstream of the sampling plane) provided that the specifications described in (f) and (g) are met;	Request for addition: Two configurations (straight and with a 90° bend) with fixed values should be recommended.

Summary of Proposed Changes

Change no.	Excerpt from	Current text	Discussion Item - Proposed Change
11	7.5 (f)	If a bend is applied in the sampling tunnel, the bending radius rb shall be at least two times the duct inner diameter (2·di). The bending radius is defined as shown in Figure 7.6.;	Request for addition: It is recommended to implement a bending radius of three times the duct diameter **(3·di)**;
12	7.6 (b)	Select a three-probe or four-probe configuration depending on the duct diameter as defined in points (e) and (f) of this paragraph. Figure 7.7. illustrates the proper positioning of the PM and PN sampling probes for both the three and four sampling probes layout;	Request for addition: It is recommended to use the position of the four-probe configuration. OPEN POINT TO BE DISCUSSED
13	Figure 7.7		Request for addition: OPEN POINT TO BE DISCUSSED