



# PARTICLE MEASUREMENT PROGRAMME

PMP-IWG

## **TASK FORCE 2 – BRAKE EMISSIONS**

**CLAUSE 7 OF THE TF2 PROTOCOL**

Brake Enclosure

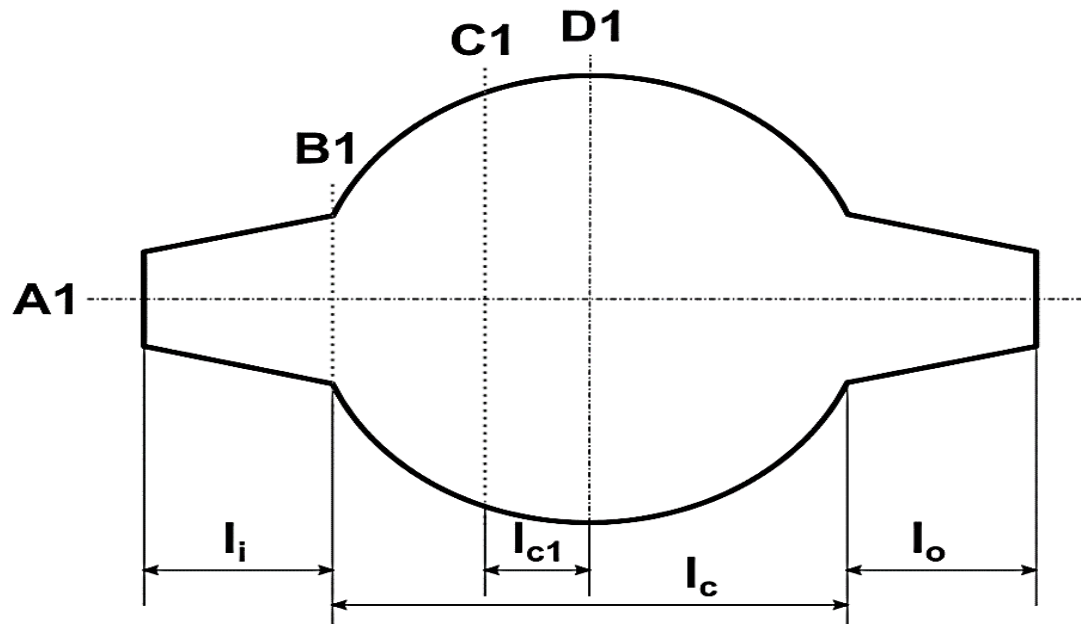
# **CLAUSE 7 – OVERVIEW**

ILS data and the TF2 protocol have been used to amend Clause 7. Additional specifications compared to the initial proposal have been introduced:

- ✓ 7.1 – Describes the general elements related to the brake enclosure – A universal shape has been proposed for harmonization purposes – Specifications regarding the materials and the surfaces have been specified – Minimum specs for the cross-section area are also defined;
- ✓ 7.2. – Describes the proposed principal dimensions of the enclosure – Specifications for the maximum length, height, and depth have been defined based on available setups used during the ILS – Other dimensions are defined and generic guidance is provided;
- ✓ 7.3. – Discusses the positioning of the brake in the enclosure and the types of fixture proposed – Discusses the rotation direction of the brake relative to the direction of the evacuation – Provides a common calliper position for harmonization purposes.

# CLAUSE 7.1 – ENCLOSURE GENERAL ELEMENTS

- ✓ No specific shape for the brake enclosure was mandated or recommended neither in the GRPE-81-12 nor in the TF2 protocol;
- ✓ As a result, different enclosure shapes were employed at the ILS from the labs. Details were requested from the labs that measured PM and PN without obvious errors.



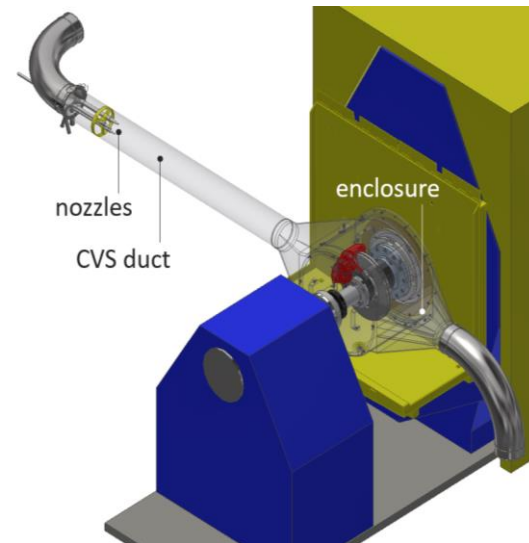
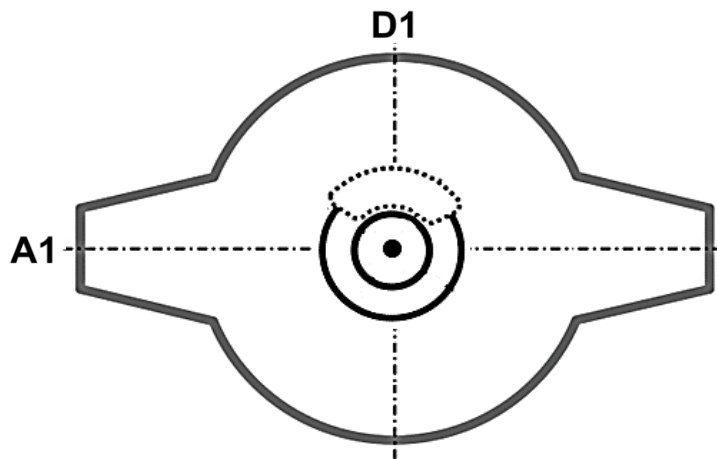
- ✓ A “universal” rhombus shape as shown below is proposed for **harmonizing** the enclosure design. Four out of six labs that provided info on their shape followed this design – other labs too have opted for a similar design.
- ✓ **The brake enclosure shall have two conical or trapezoidal sections with an intersecting cylinder in the middle** concentric to the brake assembly as shown in the Figure.

## **CLAUSE 7.1 – ENCLOSURE GENERAL ELEMENTS**

- ✓ The surfaces of the brake enclosure that come into contact with the aerosol shall be smooth and made of stainless steel with an electropolished finish (or equivalent) to avoid particle losses by electrostatic deposition;
- ✓ All materials shall ensure sufficient protection against the brake fluid. All enclosure gaps shall be air-tight sealed using gasket linings or equivalent;
- ✓ Gradual changes in the design of the cross-section shall be applied to ensure smooth transition angles (less than 30°) and avoid sudden changes in cross-section shape or size;
- ✓ The airflow at the cross-section shall remain turbulent with a Reynolds number of at least 4.000 for all airflow testing settings to ensure sufficient mixing;
- ✓ The transition points shall not have any imperfections or features that may collect brake particles that could become airborne again later during the test.

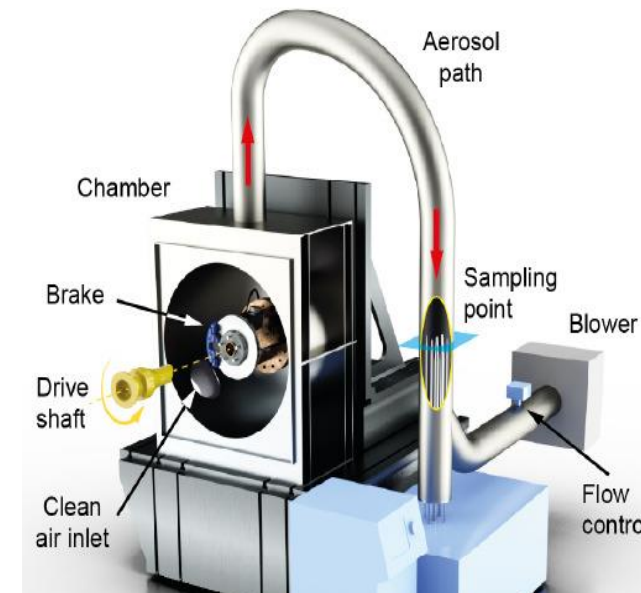
# CLAUSE 7.1 – ENCLOSURE GENERAL ELEMENTS

- ✓ There is no evidence that a vertical layout favours or penalizes emission levels compared to a horizontal layout when all other parameters are correctly applied – Gravitational losses do not seem to be a problem before the sampling plane;
- ✓ *For harmonization purposes it would be beneficial to mandate one type of layout (horizontal)* – maybe for practical reasons it would be acceptable to allow also for vertical layout – **What is the group's opinion?**



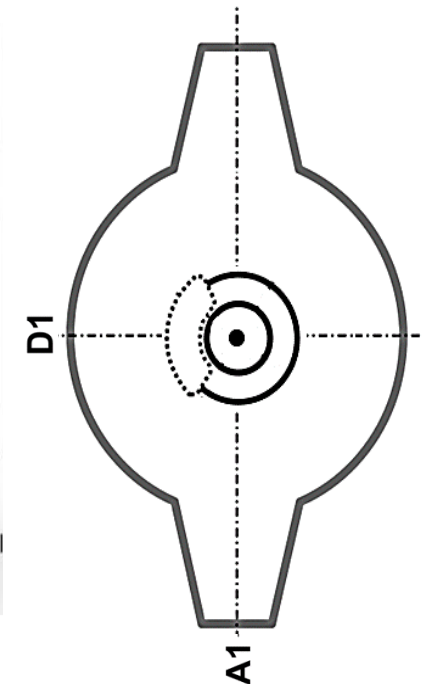
Agudelo et al. 2020 – 50<sup>th</sup> PMP Meeting

**Horizontal Layout**



Mathissen et al. 2021 – 34<sup>th</sup> TF2 Meeting

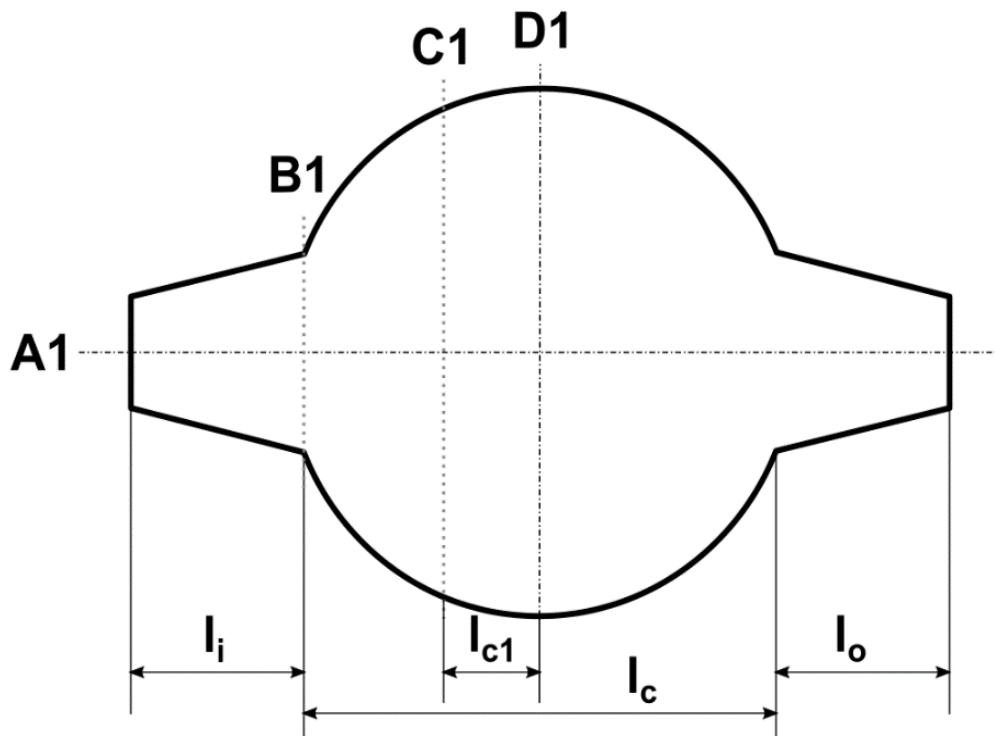
**Vertical Layout**



# CLAUSE 7.2 – ENCLOSURE DIMENSIONS

The enclosure shall fit the largest brake system in M1 and N1 vehicles, including possible parts designed to reduce particle emissions (e.g. brake filters) – Oversized enclosures shall be avoided.

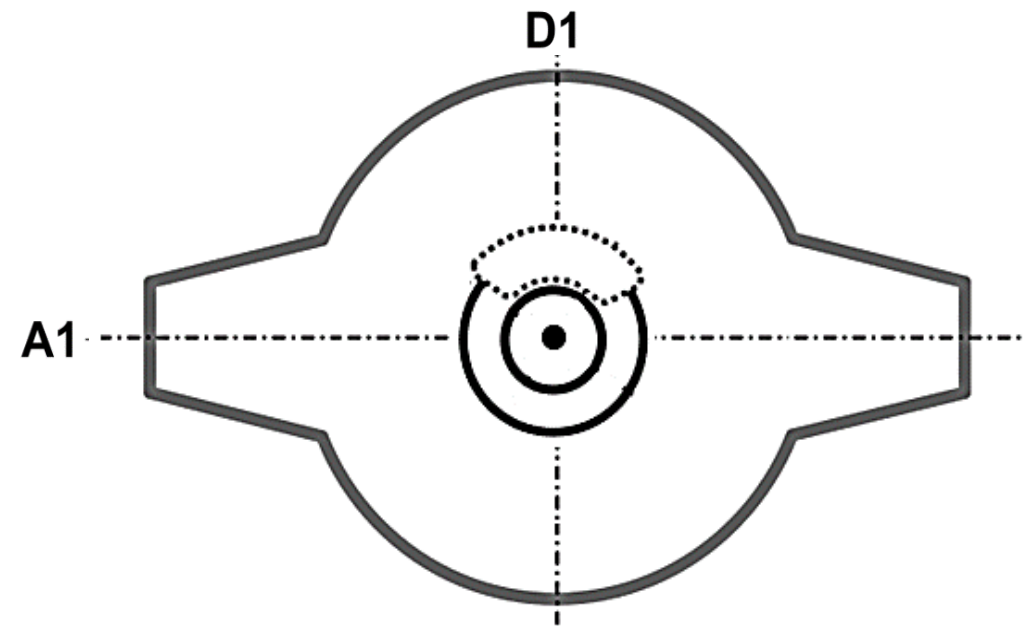
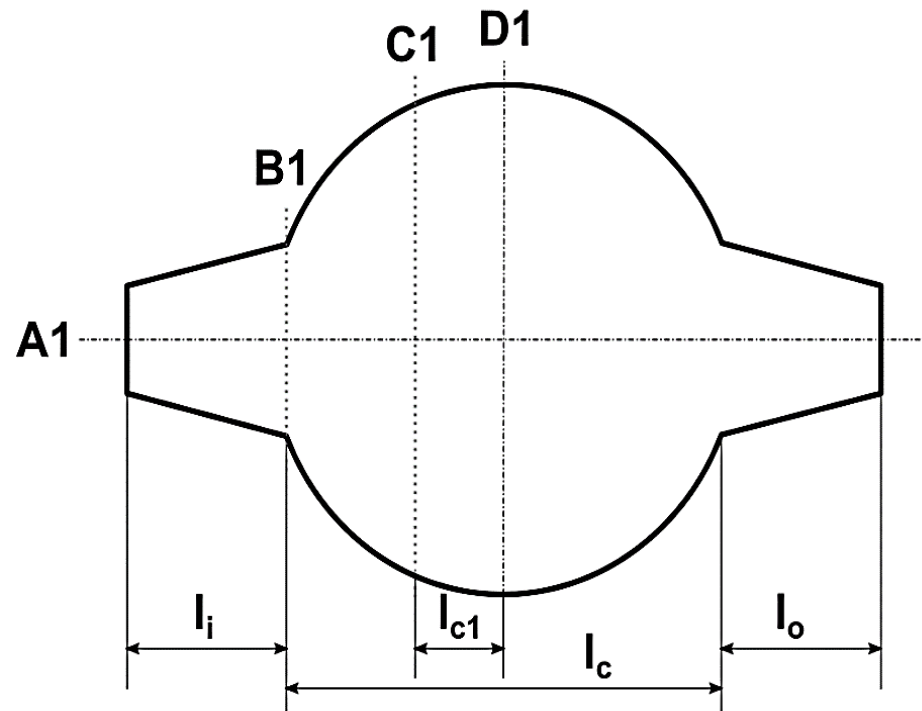
Lab – ILS	Shape	Inclination – Geometry	A1 [mm]	B1 [mm]	D1 [mm]	Depth [mm]	Materials	Fixture Position
	Mostly rhombus – Two more shapes	No inclination – Mostly horizontal	>750 - <1500 Mostly >1200	>100 - <350 Mostly >220	>500 - <800	>400 - <500	Stainless Steel – Aluminum - #400	Most in the middle of the enclosure



- ✓ The enclosure shall be designed symmetrically to plane A1. The overall length of plane A1 shall not exceed 1500 mm ( $l_i + l_c + l_o < 1500$  mm);
- ✓ The brake enclosure shall be designed symmetrically to plane D1 (**group's opinion?**). The overall length of plane D1 shall not exceed 800 mm ( $h_c < 800$  mm);
- ✓ Plane C1 is defined by the largest market available brake on an M1 and N1 vehicle;
- ✓ The input and output diameters ( $d_i$ ) shall equal to the diameter of the duct used in the brake dynamometer;
- ✓ The enclosure's maximum depth shall not exceed 500 mm.

## CLAUSE 7.3 – POSITIONING – BRAKE ASSEMBLY

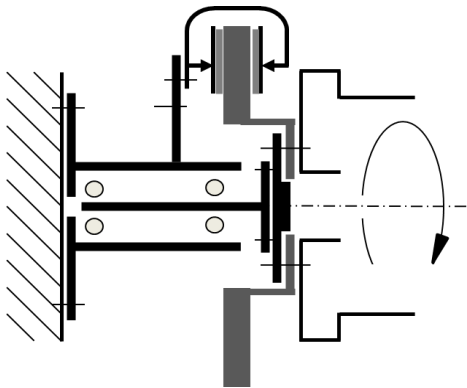
- ✓ *The installation position of the brake assembly shall always be at the centre of the brake enclosure as shown at the right-hand side figure – This has been applied by most labs during the ILS;*
- ✓ In case the conical or trapezoidal sections of the inlet and outlet are not identical in length ( $l_o \neq l_i$ ) (not recommended), again the centre of the brake assembly shall be installed at the middle of the cylinder at the point where the A1 and D1 intersect – This was applied by one lab during the ILS;



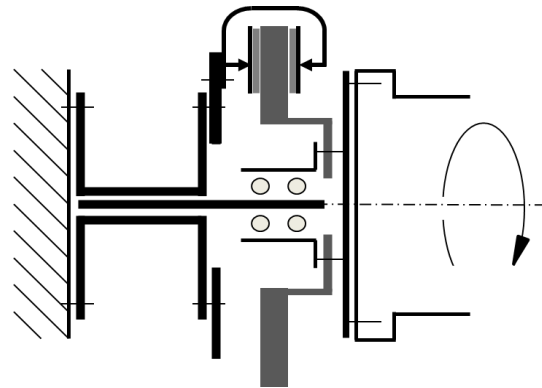
# CLAUSE 7.3 – BRAKE ASSEMBLY

- ✓ The support fixture of the brake assembly shall allow the brake to freely rotate by 360° with low friction and without exhibiting vibration or oscillations during testing;
- ✓ *The brake system shall be mounted on the dynamometer using either a Universal-style or Post-style brake fixture* – 11 of 15 labs used these types of fixture during the ILS.

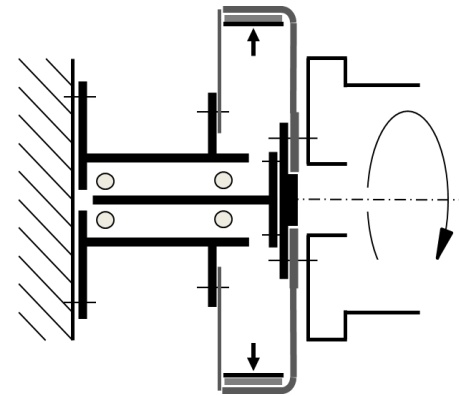
Lab-B	Lab-C	Lab-D	Lab-F	Lab-G	Lab-H	Lab-J	Lab-K	Lab-L	Lab-M	Lab-N	Lab-P	Lab-Q	Lab-R	Lab-S	Lab-T
L0-U	L0-U	L0-U	L0-U	Other	Other	L0-U	L1	L0-U	L0-U	L0-P	L1	L0-P	L0-U	?	L0-P



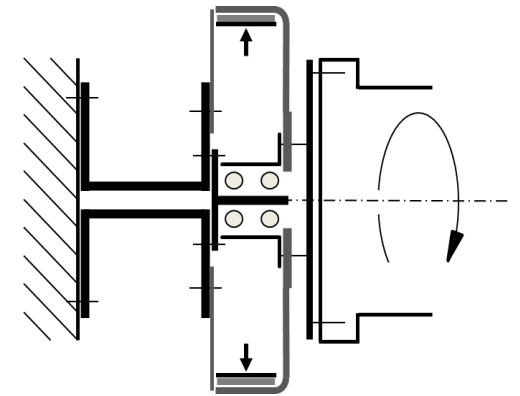
L0-U – Universal-style  
fixture **without** wheel hub



L0-P – Post-style  
fixture **with** wheel hub



L0-U – Universal-style  
fixture **without** wheel hub



L0-P – Post-style  
fixture **with** wheel hub

**Fixture styles schematics for disc brakes**

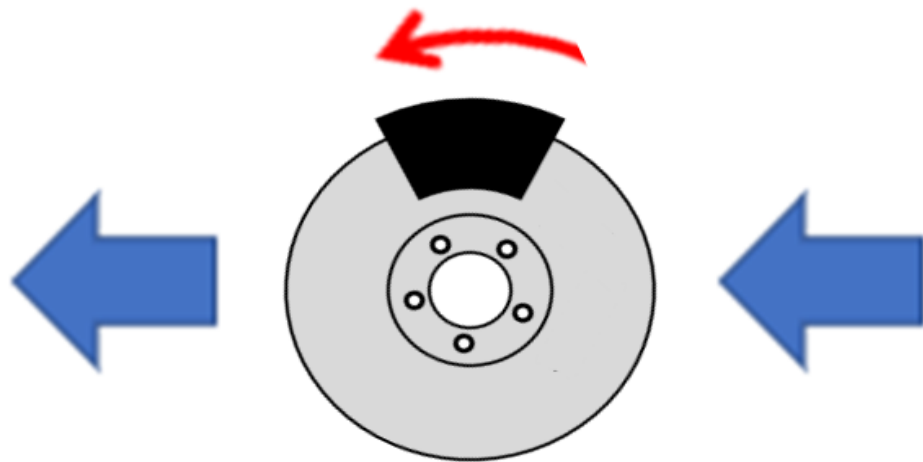
**Fixture styles schematics for drum brakes**



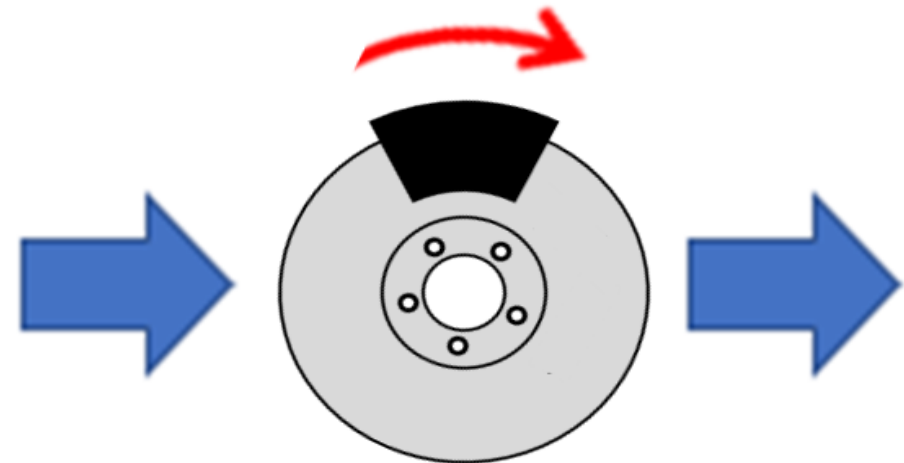
# CLAUSE 7.3 – BRAKE ROTATION

*The brake disc or drum shall always rotate in the direction of the evacuation – 15 of 16 labs followed this requirement during the ILS.*

Lab-B	Lab-C	Lab-D	Lab-F	Lab-G	Lab-H	Lab-J	Lab-K	Lab-L	Lab-M	Lab-N	Lab-P	Lab-Q	Lab-R	Lab-S	Lab-T
CCW	CCW	CCW	Stop	CCW	CCW	CCW	CCW	CW	CCW	CCW	CW	CCW	CCW	CW	CW



Airflow from right-to-left  
Disc shall rotate CCW

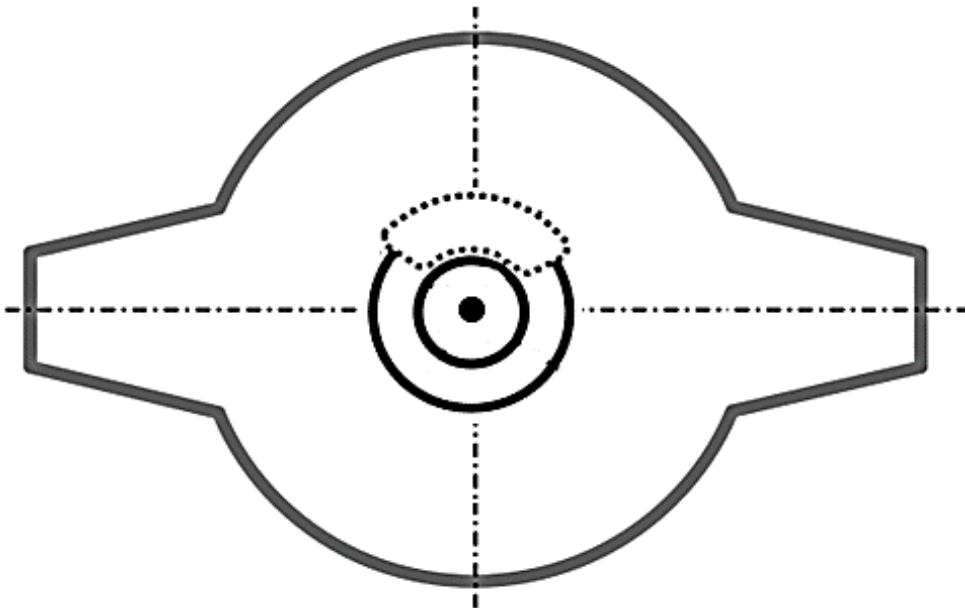


Airflow from left-to-right  
Disc shall rotate CW

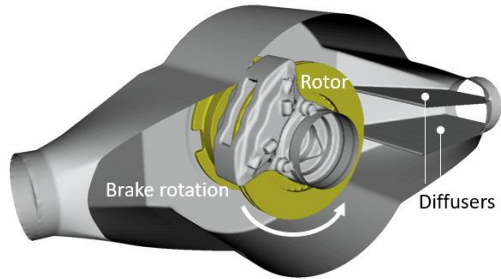
# CLAUSE 7.3 – CALIPER ORIENTATION

- ✓ The calliper shall be positioned in a way to minimize a potential interference with the incoming cooling air;
- ✓ For **harmonization** purposes it is proposed to install the calliper in a 12 o'clock position differently than recommended during the ILS – Not solid conclusion from the ILS – CFD studies show a minor effect.

Lab-B	Lab-C	Lab-D	Lab-F	Lab-G	Lab-H	Lab-J	Lab-K	Lab-L	Lab-M	Lab-N	Lab-P	Lab-Q	Lab-R	Lab-S	Lab-T
11	9	3	8	10	10	11	12	9	9	10	12	11	10	1-2	2
o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock	o'clock



# CLAUSE 7.3 – RESIDENCE TIMES



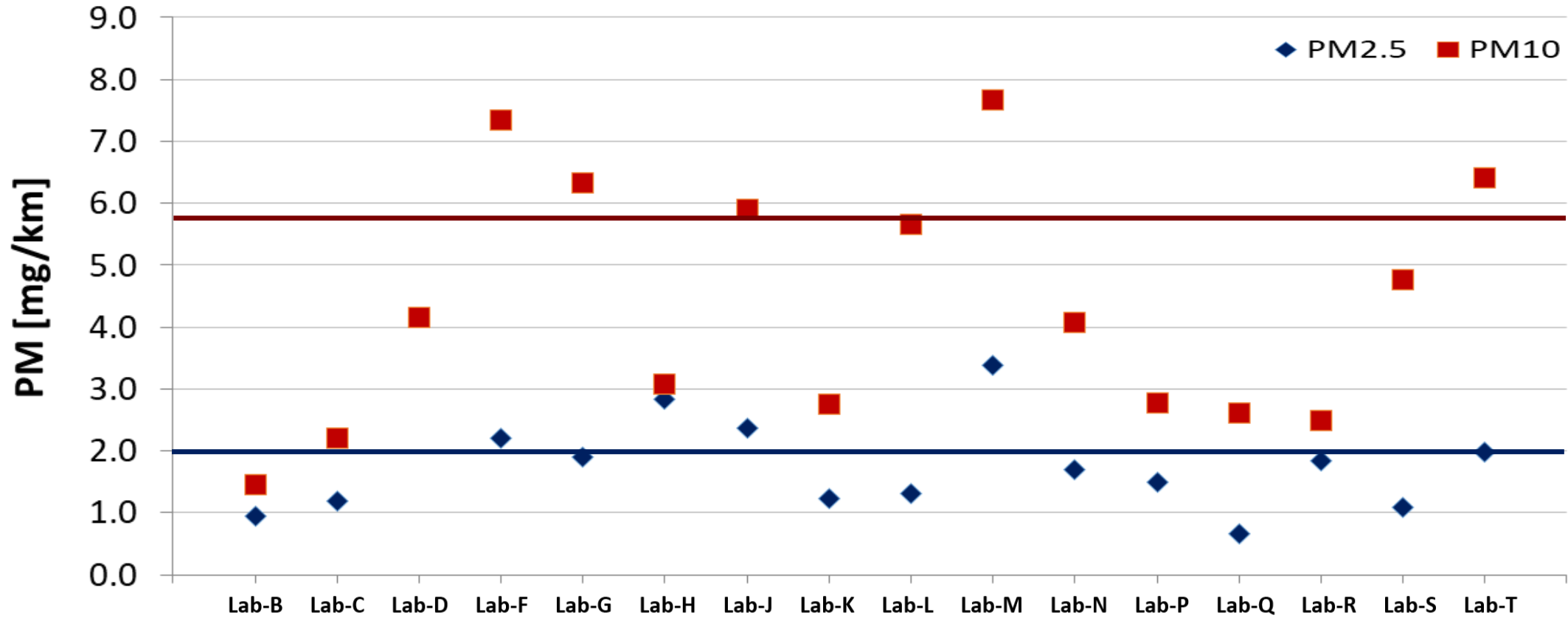
## Simulation details

- Time step size: 20  $\mu$ s
- Grid spacing: 0.125"
- Grid size: 384x192x144
- 10.6 M grid points

Run	Airflow	Brake size	Rotor design	Caliper orientation	Brake rotation	Brake speed	Fixture
1	400 m <sup>3</sup> /h	Small	Solid	Aft	CCW	900 rpm	Post
2	400 m <sup>3</sup> /h	Large	Solid	Fore	CCW	400 rpm	Knuckle
3	1000 m <sup>3</sup> /h	Large	Vented	Aft	CCW	900 rpm	Knuckle
4	400 m <sup>3</sup> /h	Large	Vented	Fore	CW	900 rpm	Post
5	1000 m <sup>3</sup> /h	Small	Solid	Fore	CW	900 rpm	Knuckle
6	1000 m <sup>3</sup> /h	Large	Solid	Aft	CW	400 rpm	Post
7	400 m <sup>3</sup> /h	Small	Vented	Aft	CW	400 rpm	Knuckle
8	1000 m <sup>3</sup> /h	Small	Vented	Fore	CCW	400 rpm	Post

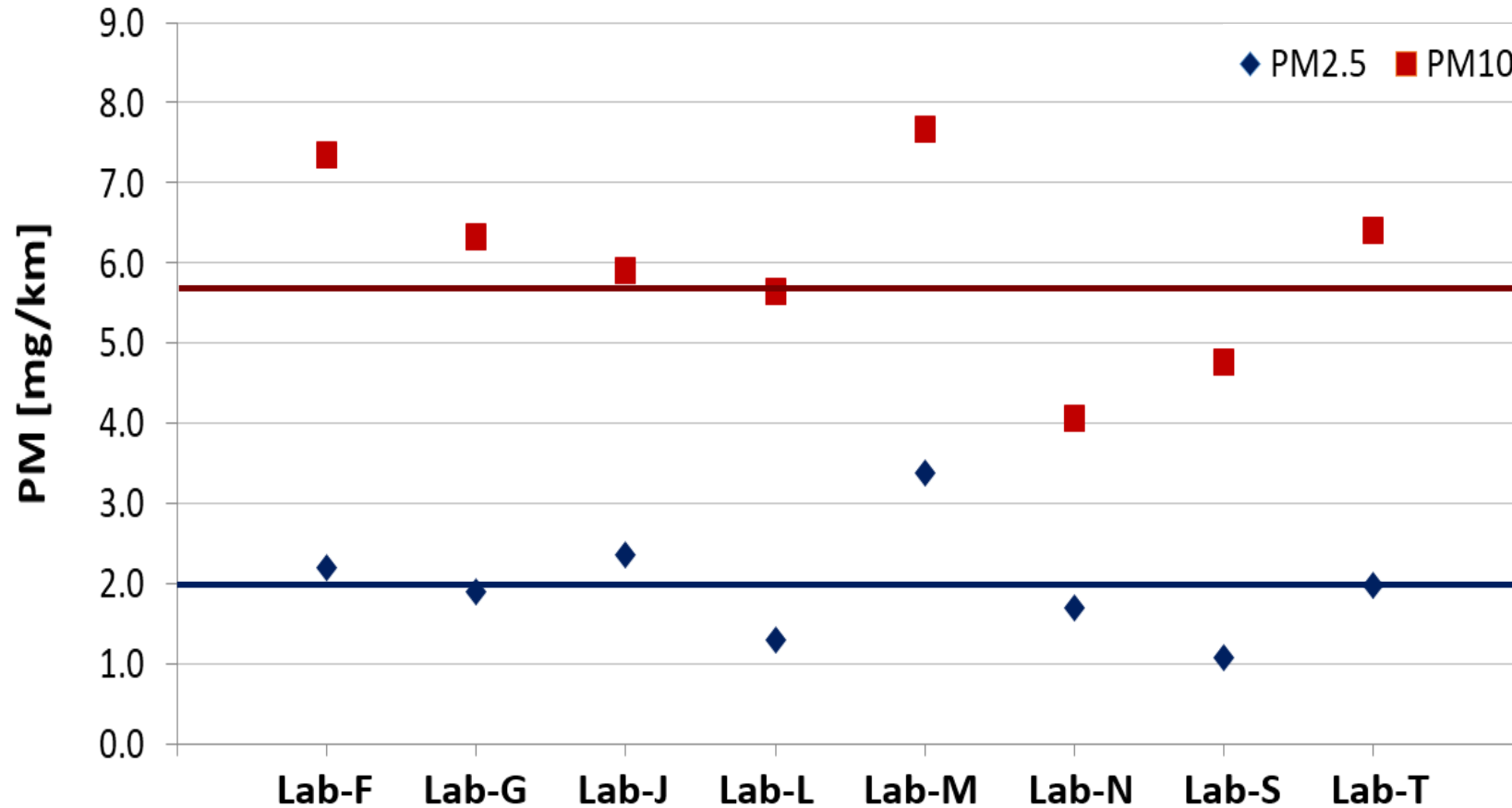
Metric	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
Turbulence intensity	0.358	0.344	0.374	0.447	0.323	0.301	0.325	0.315
Particle res. Time / s	0.40	0.35	0.22	0.35	0.17	0.20	0.37	0.23
D <sub>50</sub> @ exit / $\mu$ m	0.8588	0.8373	0.8523	0.8380	0.8419	0.8498	0.8546	0.8597
D <sub>84</sub> @ exit / $\mu$ m	1.916	1.797	1.863	1.797	1.832	1.868	1.903	1.931

# CLAUSE 7.3 – ENCLOSURE POSITIONING



Lab-B	Lab-C	Lab-D	Lab-F	Lab-G	Lab-H	Lab-J	Lab-K	Lab-L	Lab-M	Lab-N	Lab-P	Lab-Q	Lab-R	Lab-S	Lab-T
L0-U	L0-U	L0-U	L0-U	Other	Other	L0-U	L1	L0-U	L0-U	L0-P	L1	L0-P	L0-U	?	L0-P
11 o'	9 o'	3 o'	8 o'	10 o'	10 o'	11 o'	12 o'	9 o'	9 o'	10 o'	12 o'	11 o'	10 o'	1.5 o'	2 o'

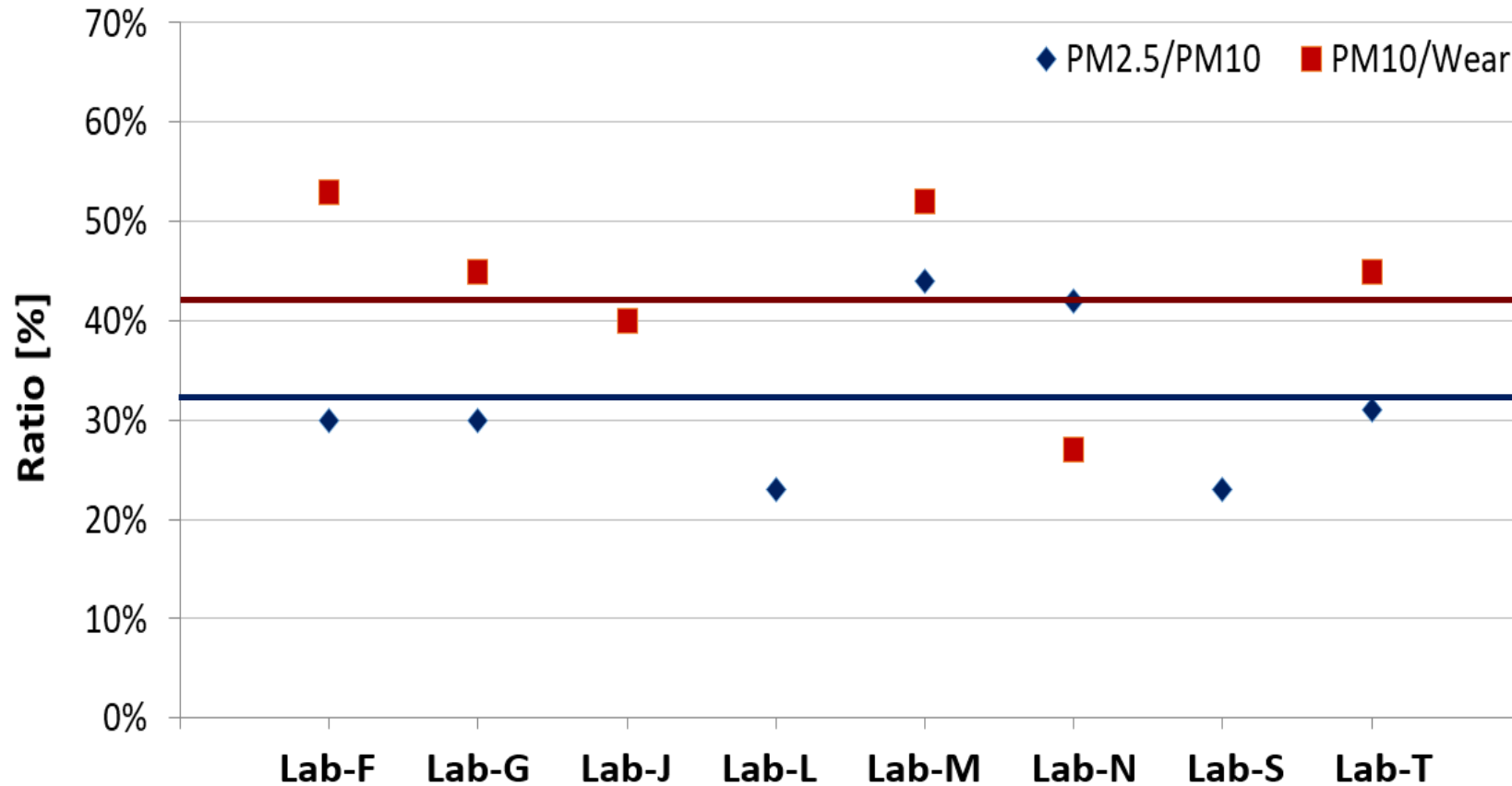
# CLAUSE 7.3 – ENCLOSURE POSITIONING



- ✓ Labs G, J, L, S, T are closer to the PM<sub>10</sub> mean;
- ✓ These labs used various orientations mostly in the upper part of the disc;
- ✓ No trend related to the type of fixture; however, no knuckle fixture applied;
- ✓ Labs F, G, J, N, T are closer to the PM<sub>2.5</sub> mean;
- ✓ These labs used various orientations mostly 10-11 or 1-2 depending on the flow orientation;
- ✓ No trend related to the type of fixture.

Lab-F	Lab-G	Lab-J	Lab-L	Lab-M	Lab-N	Lab-S	Lab-T
L0-U	Other	L0-U	L0-U	L0-U	L0-P	?	L0-P
8 o'	10 o'	11 o'	9 o'	9 o'	10 o'	1.5 o'	2 o'

# CLAUSE 7.3 – ENCLOSURE POSITIONING



- ✓ It is difficult to extract solid conclusions due to different setups and enclosures;
- ✓ Labs F, G, T are closer to the PM<sub>2.5</sub>/PM<sub>10</sub> mean;
- ✓ Labs J, M, N with slightly higher PM<sub>2.5</sub>/PM<sub>10</sub> mean cannot be linked with bigger particle losses in the enclosure;
- ✓ Labs G, J, T are closer to the PM<sub>10</sub>/Wear mean;
- ✓ Lab N with lower PM<sub>10</sub>/Wear mean cannot be linked with bigger particle losses in the enclosure.

Lab-F	Lab-G	Lab-J	Lab-L	Lab-M	Lab-N	Lab-S	Lab-T
L0-U	Other	L0-U	L0-U	L0-U	L0-P	?	L0-P
8 o'	10 o'	11 o'	9 o'	9 o'	10 o'	1.5 o'	2 o'

# Thank you



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