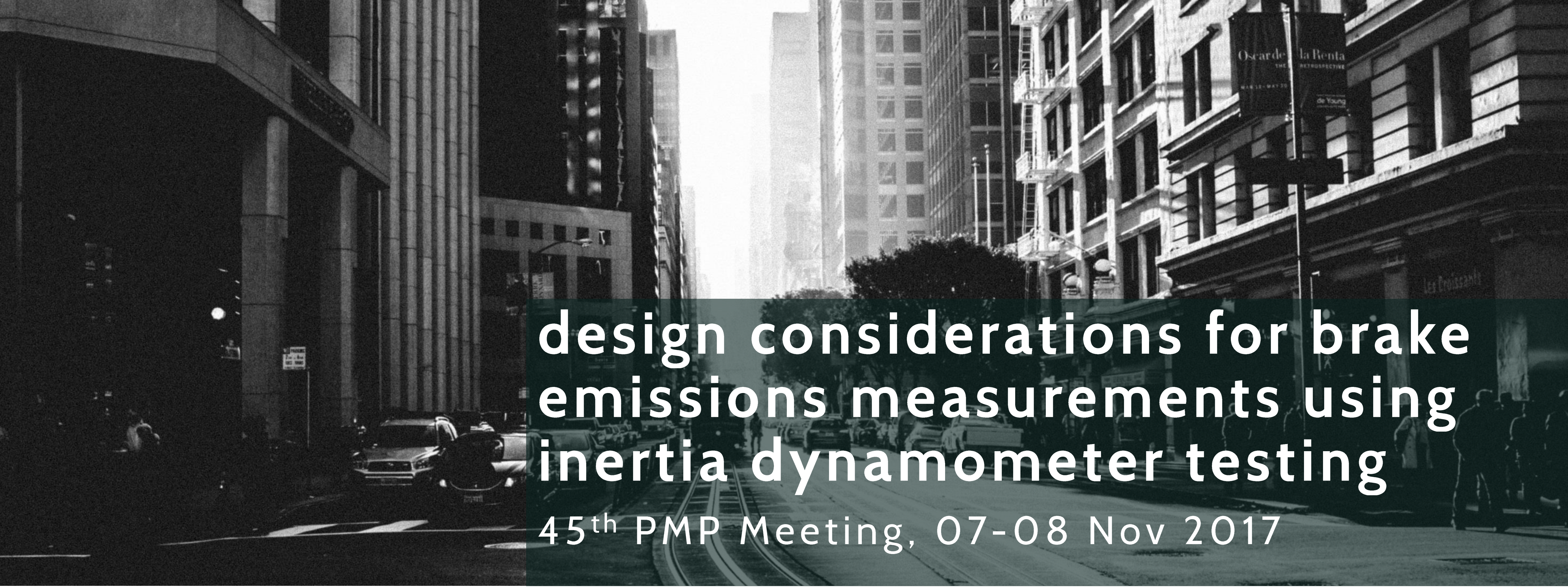


design considerations for brake emissions measurements using inertia dynamometer testing

45th PMP Meeting, 07-08 Nov 2017

LINK

Carlos Agudelo

why?

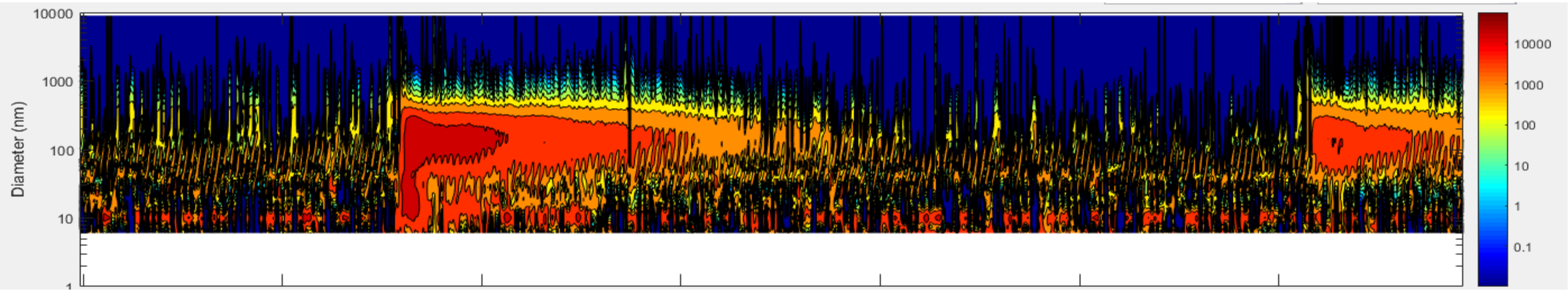

it is a journey...


learning + collaboration + harmonization

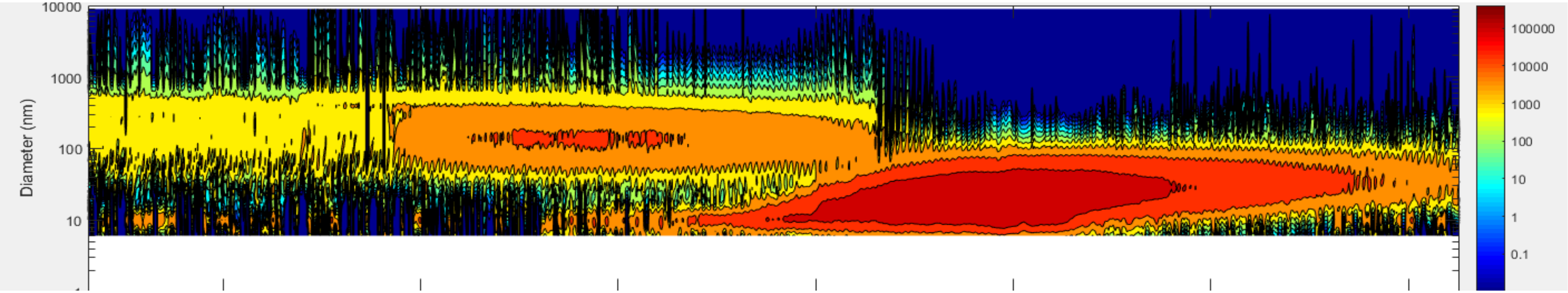

2704
“If a test is not repeatable, it is only an anecdote”
Nature – International weekly journal of science

challenge 1 – continuous data recording

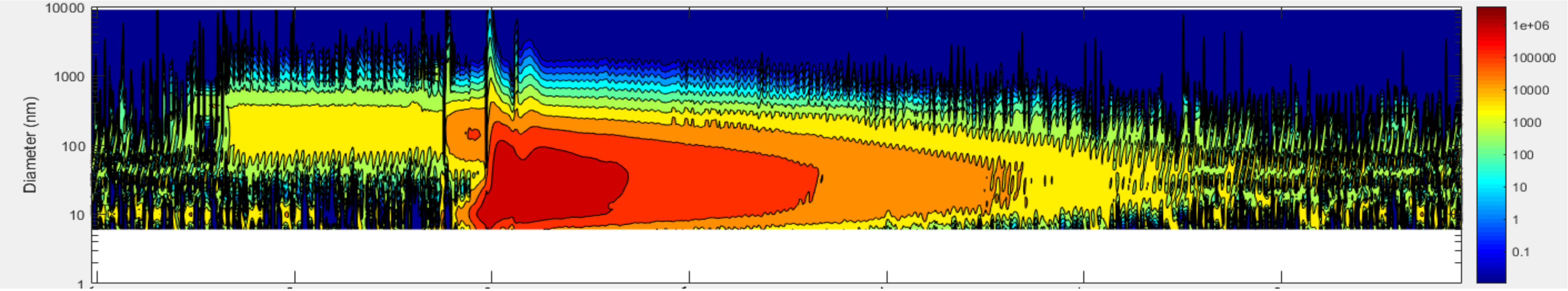
LACT



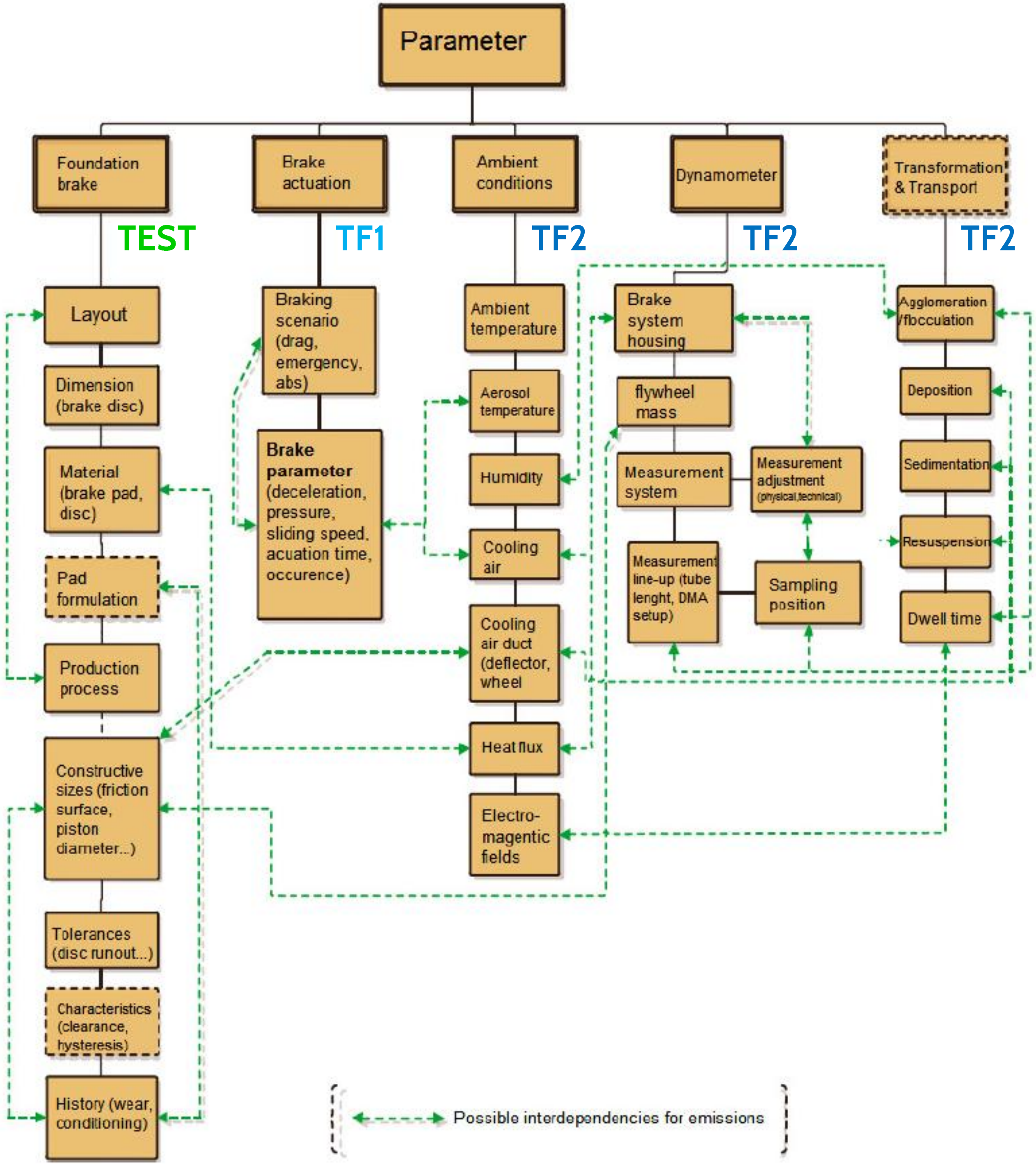
WLTP



ISO 26867



challenge 2 – variability



Sachse, H. et al. TU Ilmenau

challenge 2 – variability

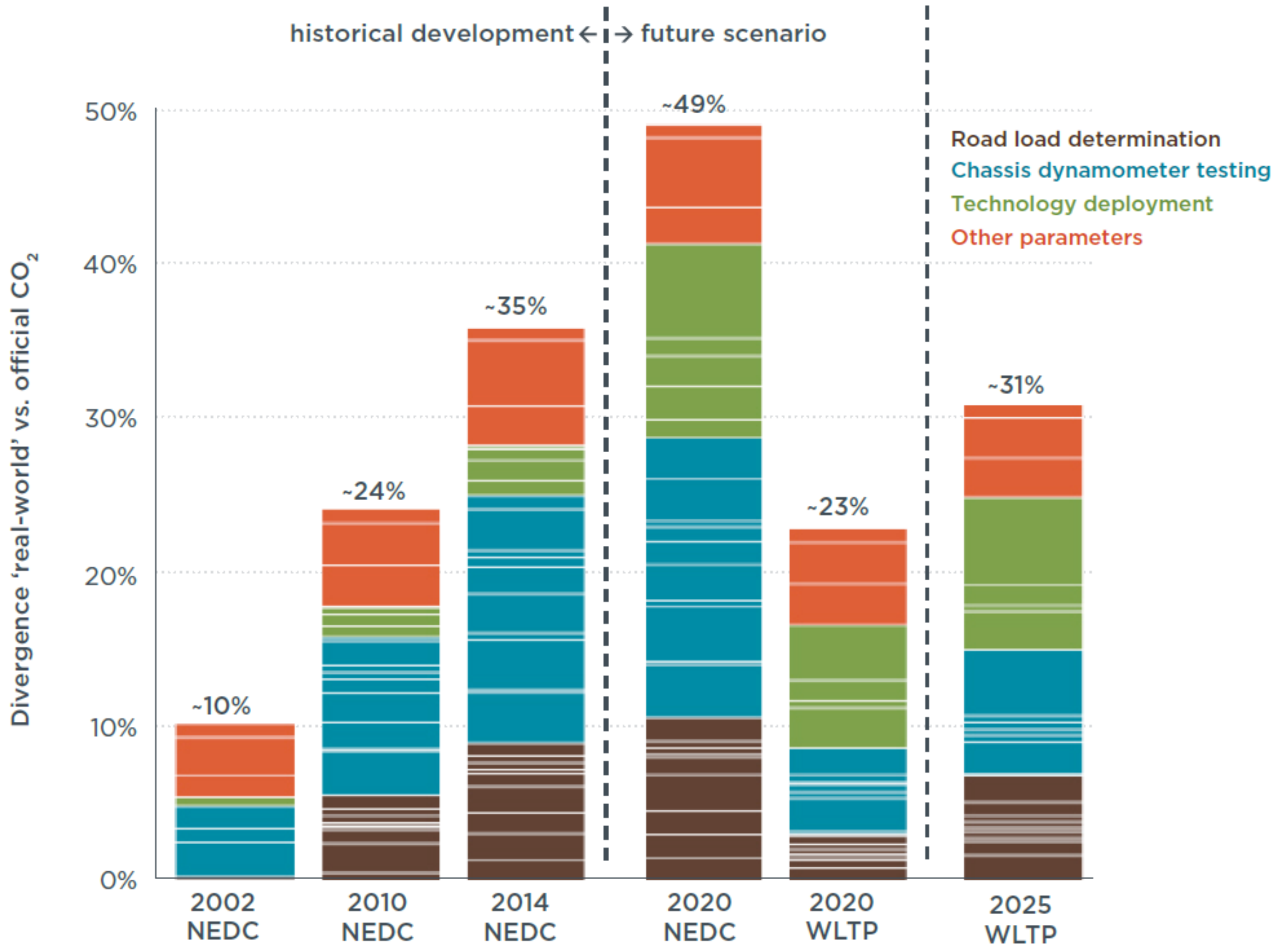
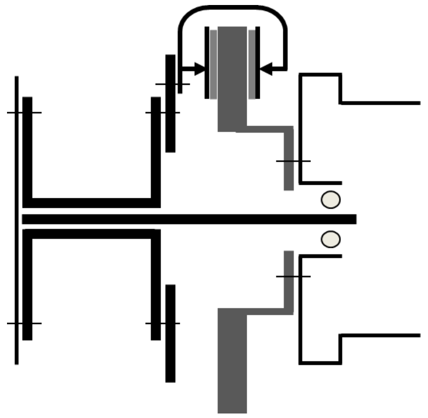
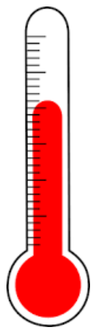


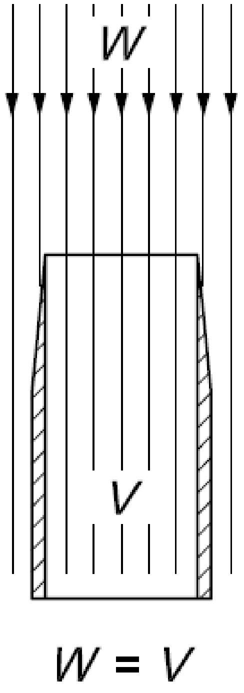
Figure 2: Estimate of the reasons for the divergence between type-approval and real-world CO_2 emission levels for new passenger cars in the past as well as in the future, with and without introduction of the WLTP (for details, see Stewart, Hope-Morley, Mock, & Tietge, 2015).

source: ICCT- From Lab To Road – 2015 Update

challenge 3 – air handling







η gravitational settling

η diffusional deposition

η turbuphoretic

η constrictions

η bends

η aspiration

η thermophoretic

polydisperse coagulation

resuspension

etc, etc,

challenge 3 – on coagulation

various initial concentrations. The concentration remains almost constant at low initial concentrations ($<10^7$ p/cm^3) but it may reduce significantly at higher concentrations.

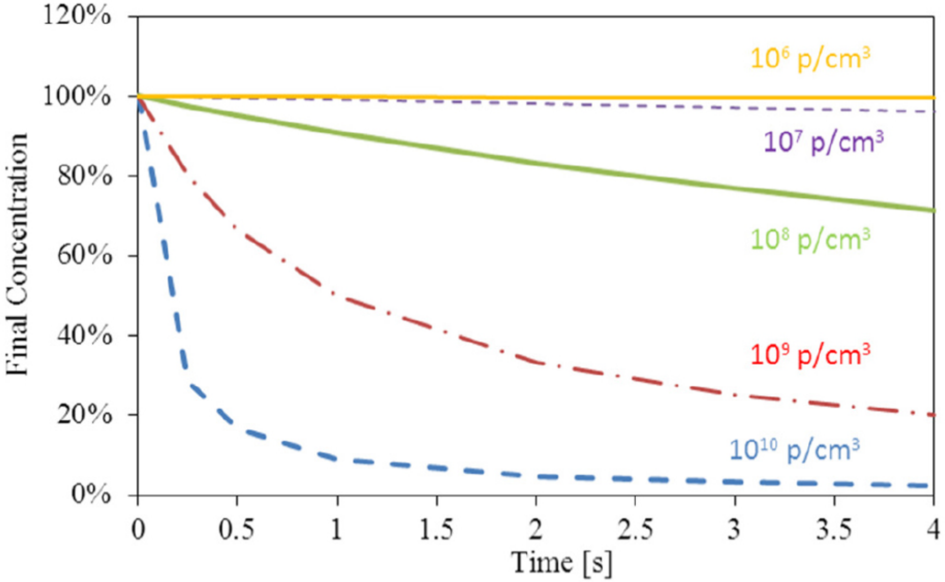


Figure 5. Effect of agglomeration on particle number concentration ($K=10^{-15}$ m^3/s).

source: Giechaskiel, B. et al – SAE 2012-01-0443

Alemani, Mattia, et al. 2015. *A Study on the Load Level Influence on Particulate Matter Emissions From the Sliding Contact Between a Low Steel Friction Material and Cast Iron*

Hannes, Sachse; Prof Dr.-Ing. Klaus Augsburg Automotive Engineering Group, TU Ilmenau, Germany. *Study on Appropriate Measurement Methods and Test Procedures for Assessment of Brake-Induced Emissions*

Horiba, March 2016, *39th Annual PMP Meeting, Day 2, Non-Exhaust Emissions, Chamber Design for Particles Emission*

Kukutschová, J., et al. 2012. *On Character of Coarse, fine, and Ultrafine Particles in Automotive Wear Debris*

Matějka, Vlastimil, et al. 2017. *On the Running-in Of Brake Pads and Discs for Dyno Bench Tests*

Perricone, Guido, et al. 2015. *A Novel Dyno Bench Design Focusing on Measurements in Controlled Air of Particle Emission From Brakes*

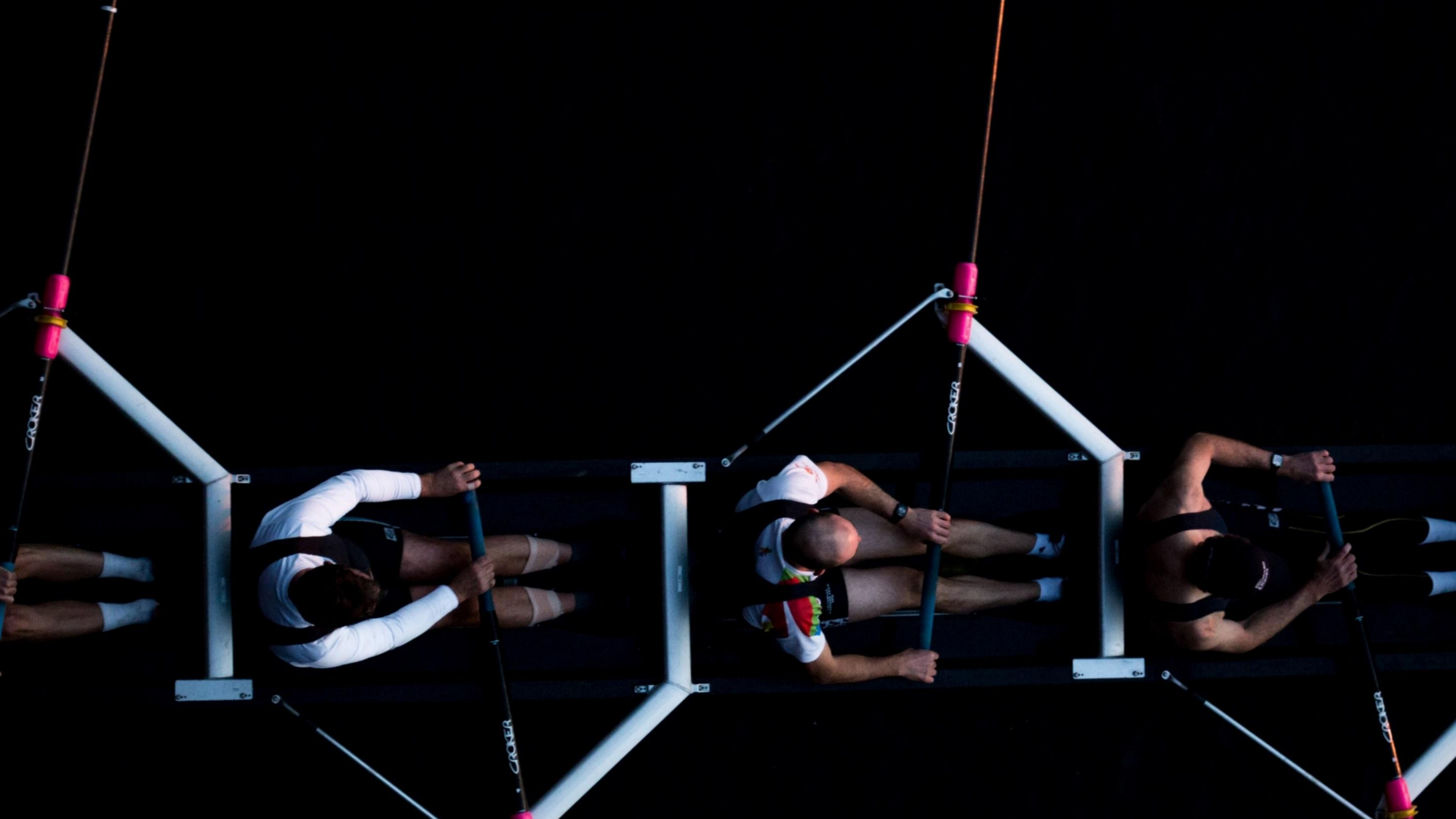
Sanders, Paul G., et al. 2003. *Airborne Brake Wear Debris: Size Distributions, Composition, and Comparison of Dynamometer and Vehicle Tests*

Wahlström, Jens, et al. 2008. *Airborne Wear Particle Emissions of Commercial Disc Brake Materials.*

Wirtz, Michael, et al. 2015. *Inertia Brake Dynamometer Dust Particle Measurement*

Yli-Tuomi, Tarja, et al. 2005. *Emissions of fine particles, NOx, and CO from On-Road Vehicles in Finland*

how


CROKER
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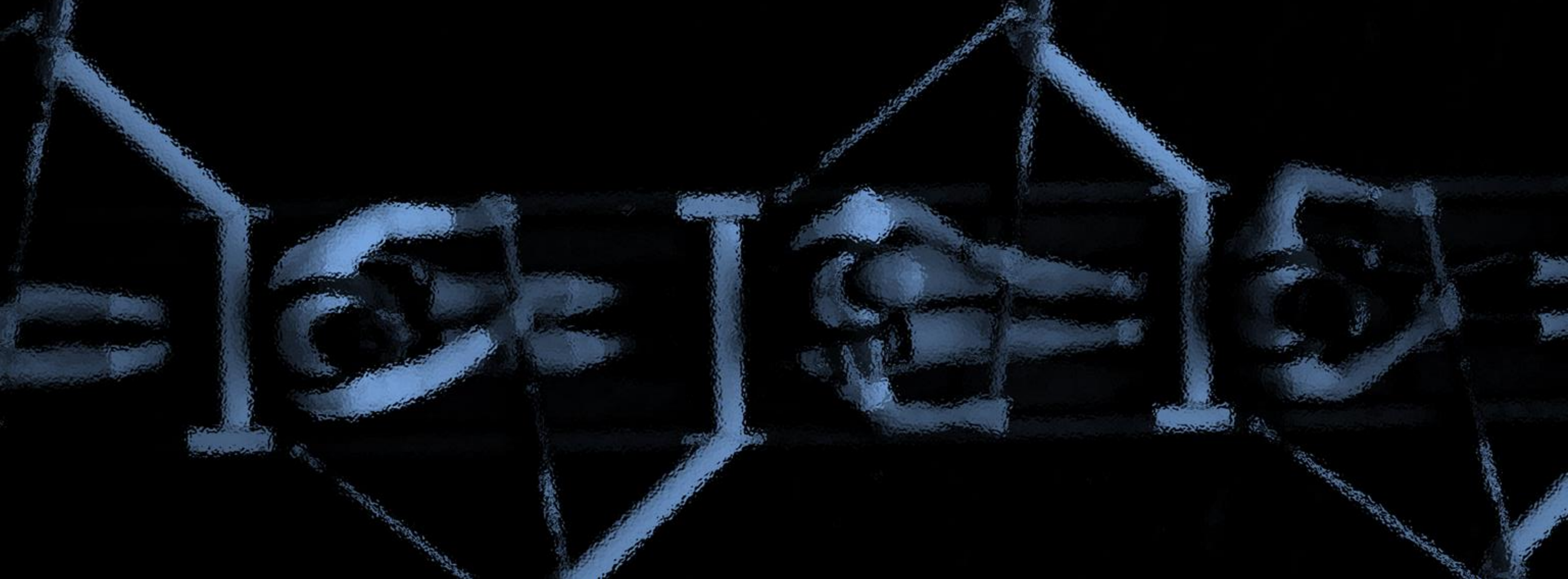
questions

1. emission’s metrics, indexes
2. size ranges
3. measurement principles

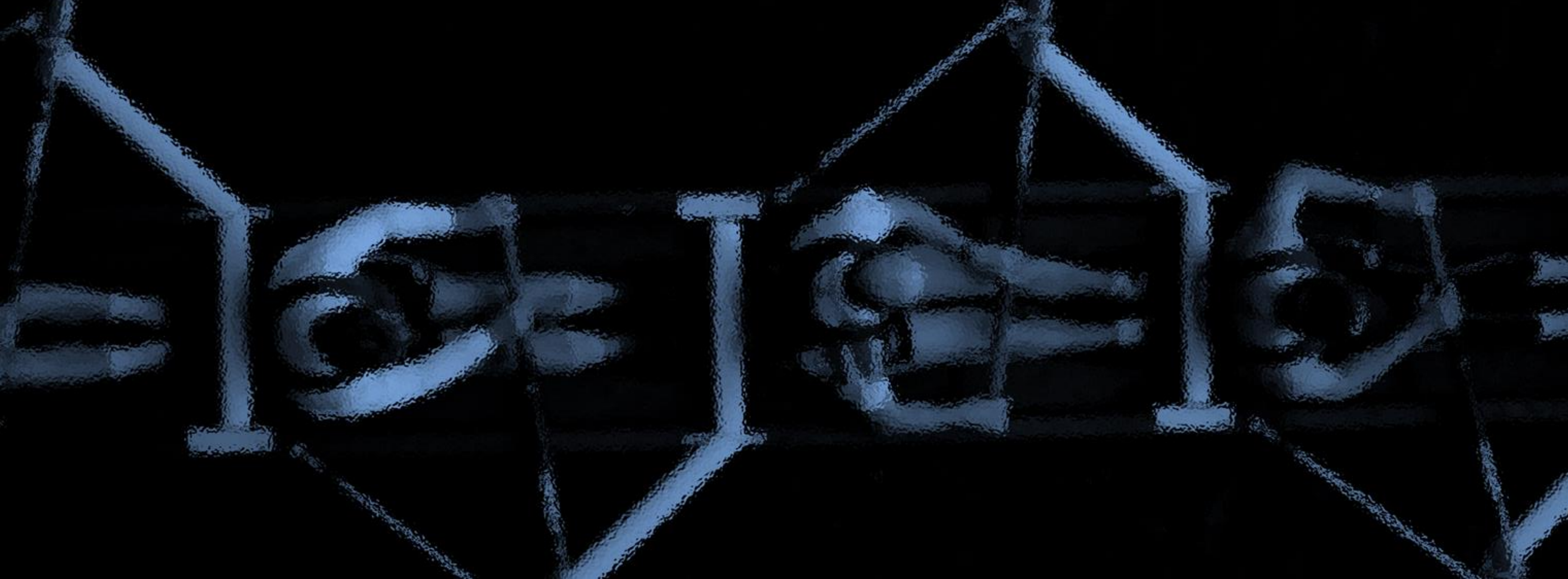


questions

1. emission's metrics, indexes
2. size range
3. measurement principles

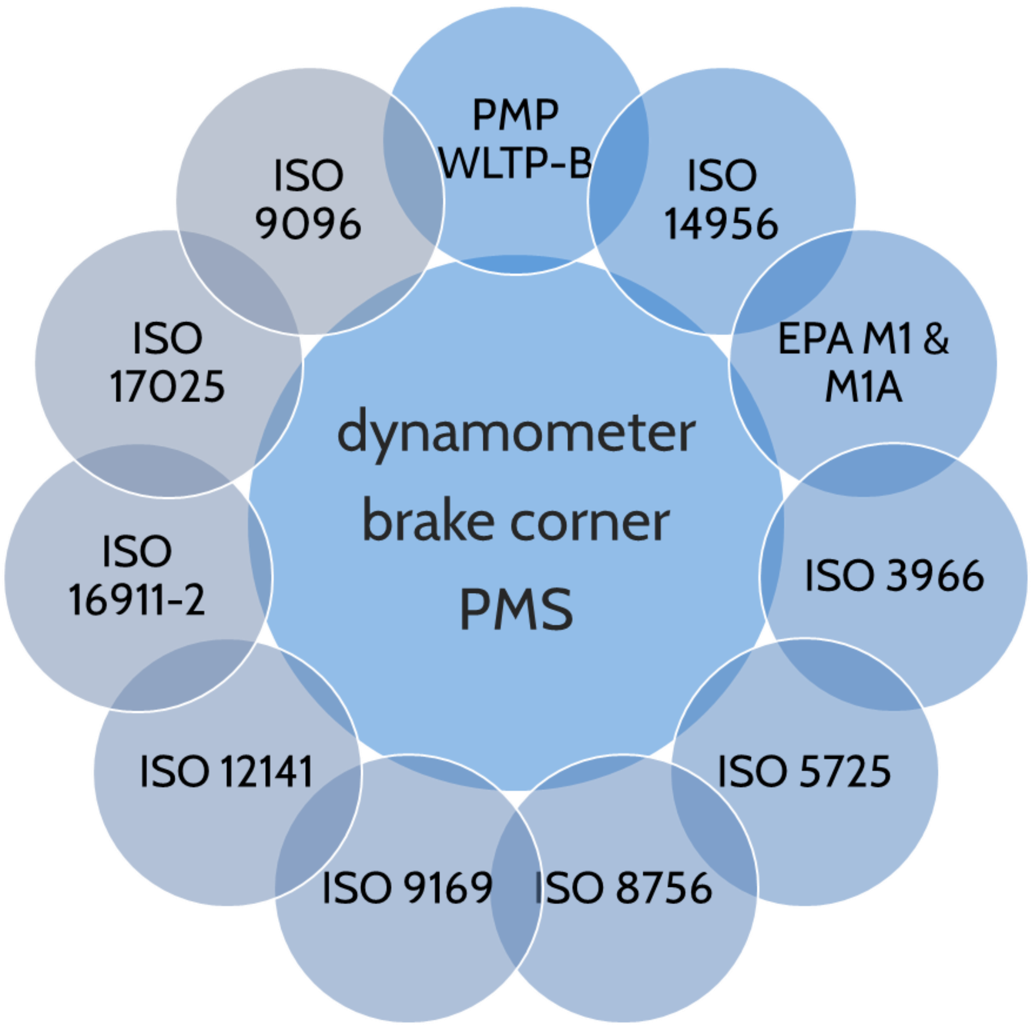
potential WPs

1. air handling, losses, isokinetics
2. minimum specs for PMS
3. calibration, uncertainty, sign-off



testing environment

- ☒ toxicology & V2R
- ☒ commercial vehicles
- ☒ regulation & rulemaking



examples only

- ☑ open data
- ☑ sync with other SDOs
- ☑ brake, dyno, PMS agnostic

what

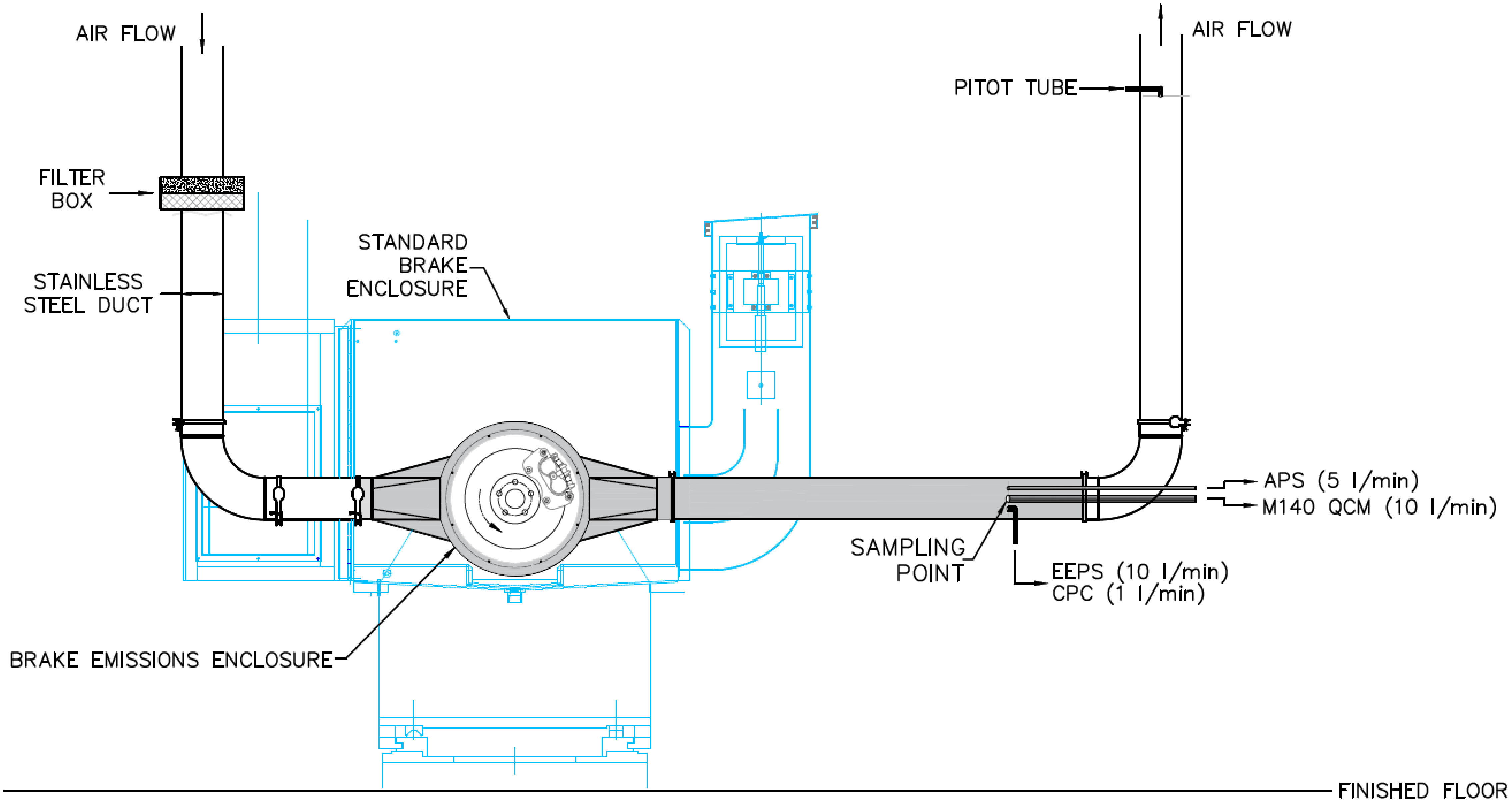
LINK's approach

available as upgrade to current dyno designs

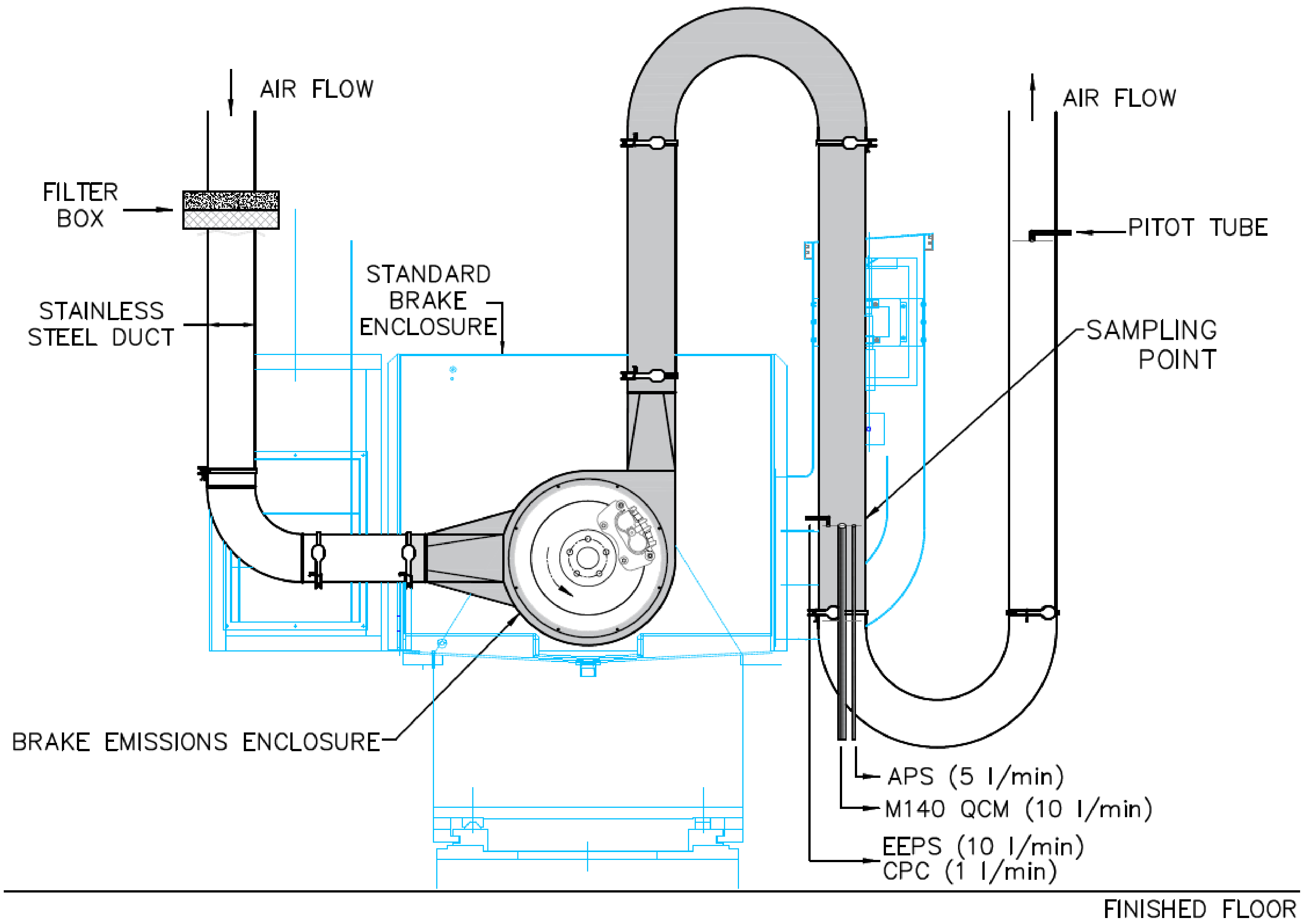
ruggedness (data fusion, 8d/2d/isok/round duct)

r&R (fixture, environmental, duct finish)

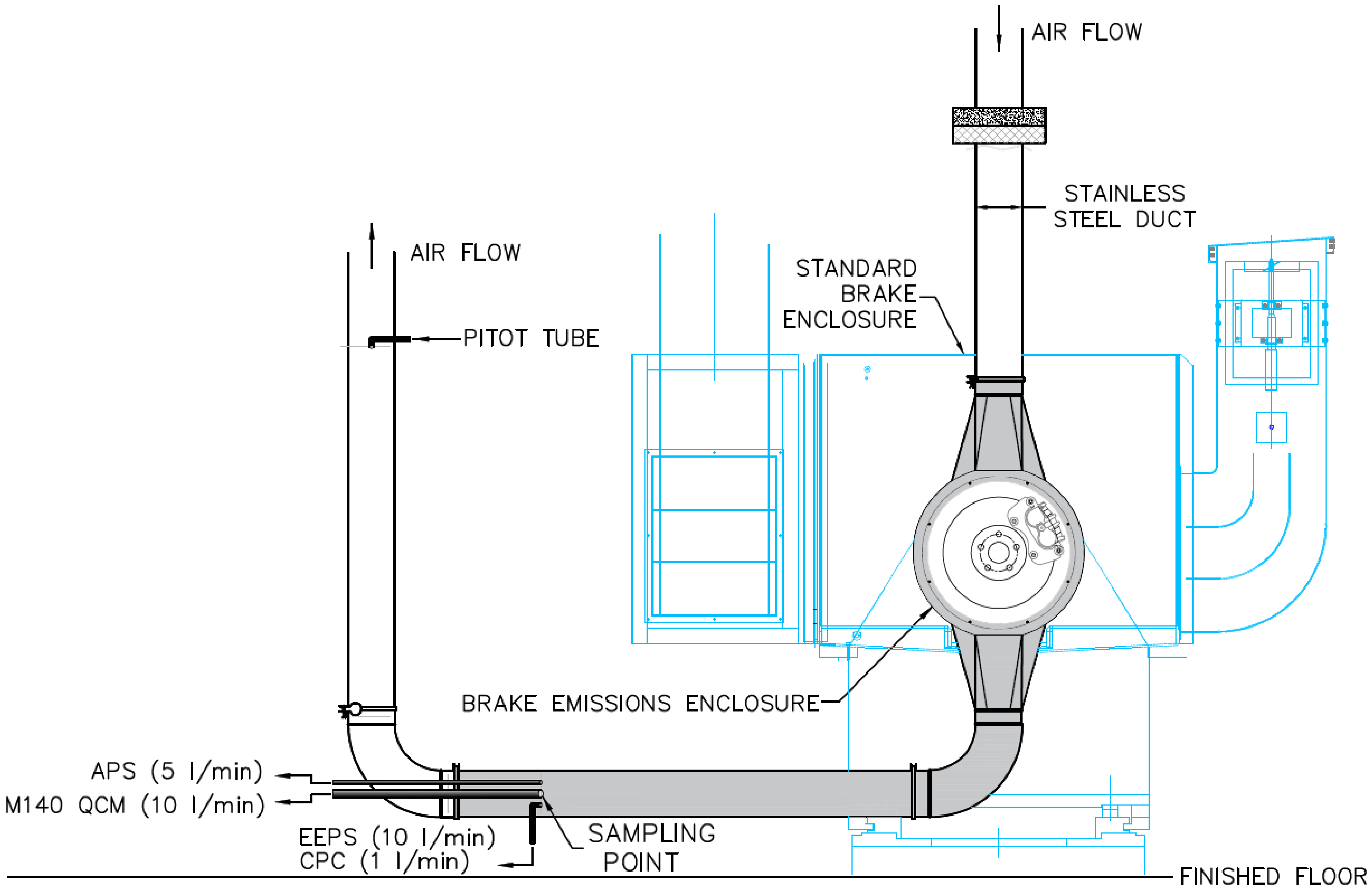
ducting layout - A (150-mm duct)



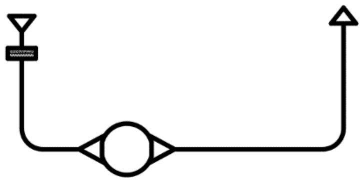
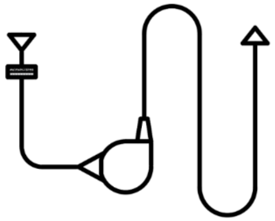
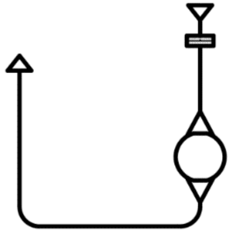
ducting layout - B (150-mm duct)



ducting layout - C (150-mm duct)



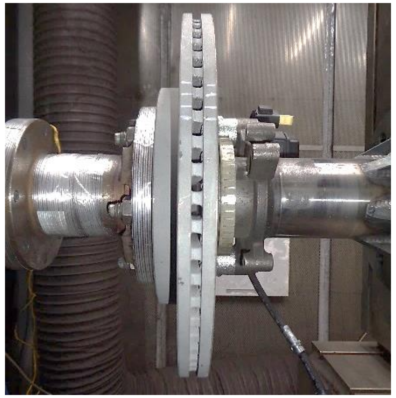
side-by-side

feature	A 	B 	C 
8d/2d, isokinetics, electropolish	+++	+++	+++
floorspace	+	+++	++
instrument layout for isokinetics	++	+++	+
simplicity and installation	+++	++	++
duct transport efficiency	+++	+	++
ruggedness to airflow/duct size	+++	+	++
low leaks and ease of cleaning	+++	+	++
short distance to Pitot tube	+++	+	++

brake fixtures

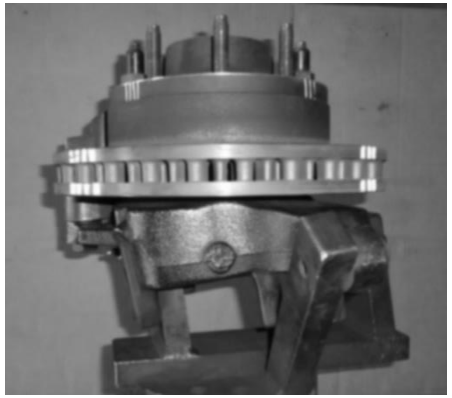
DO

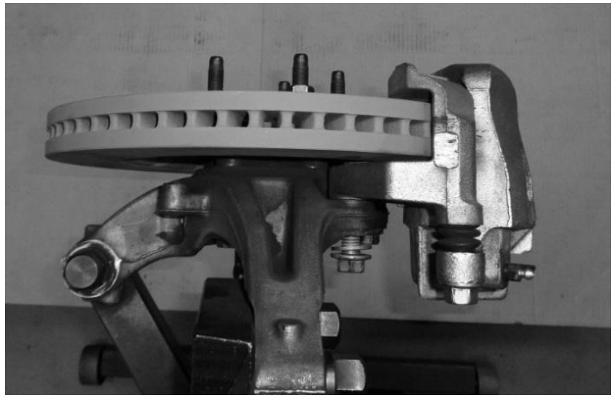
post or universal



DON'T

knuckle or L1





minimal interruption to airflow

allows smaller (round) brake enclosure

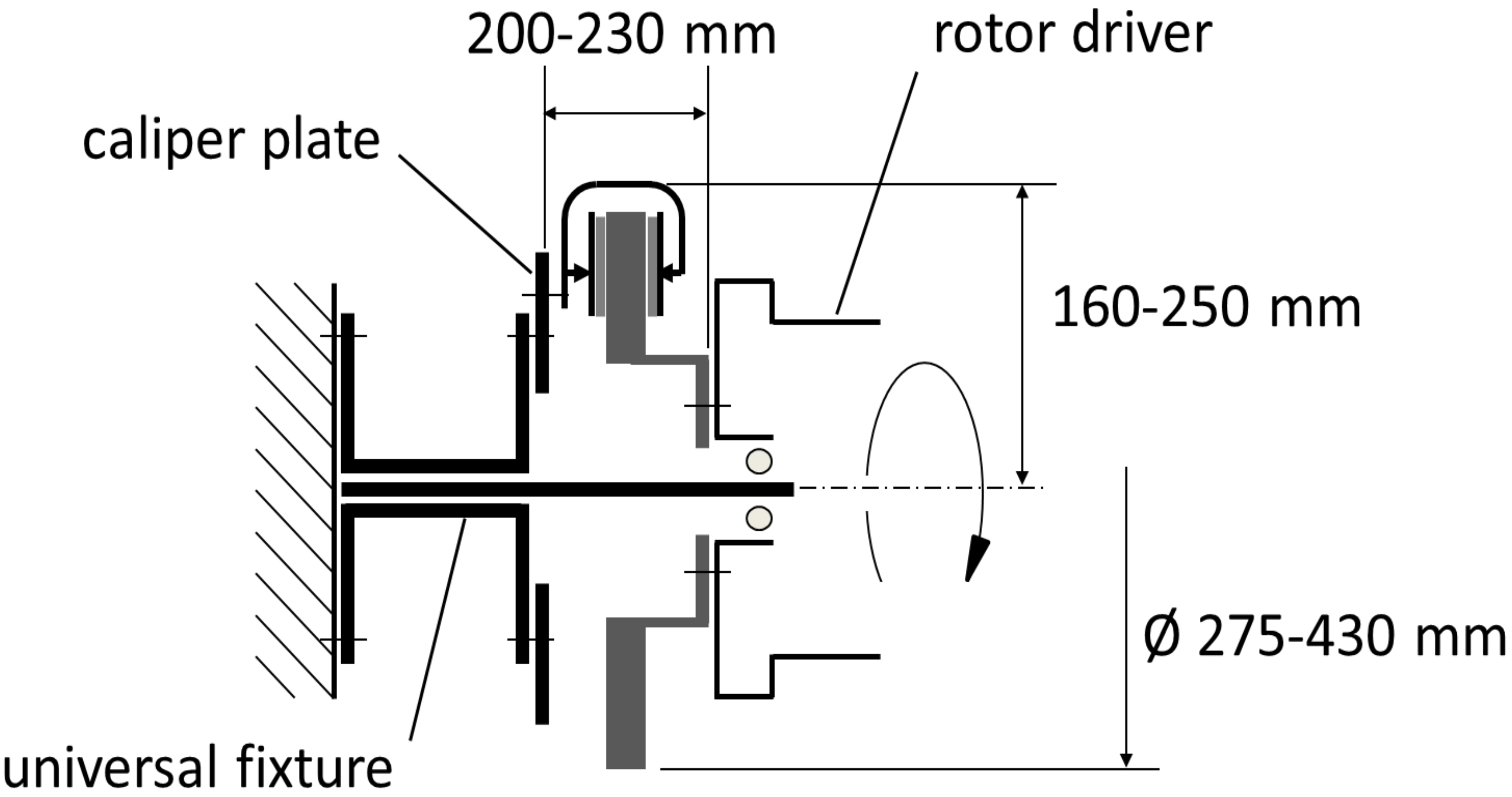
predictable interface with seals

unpredictable turbulence around the brake

large variability in knuckle size and geometry

significant variation at seal interface

envelope dimensions for disc brake fixtures ~ ECE M1/N1



ISO 3:1973 - R5 series for agnostic sizes and airflows

sampling line flow, l/min

1.0 1.5 2.5 4.0 6.0 10 15 25 40 60 100 150 250 400 600 1000 1500 2500

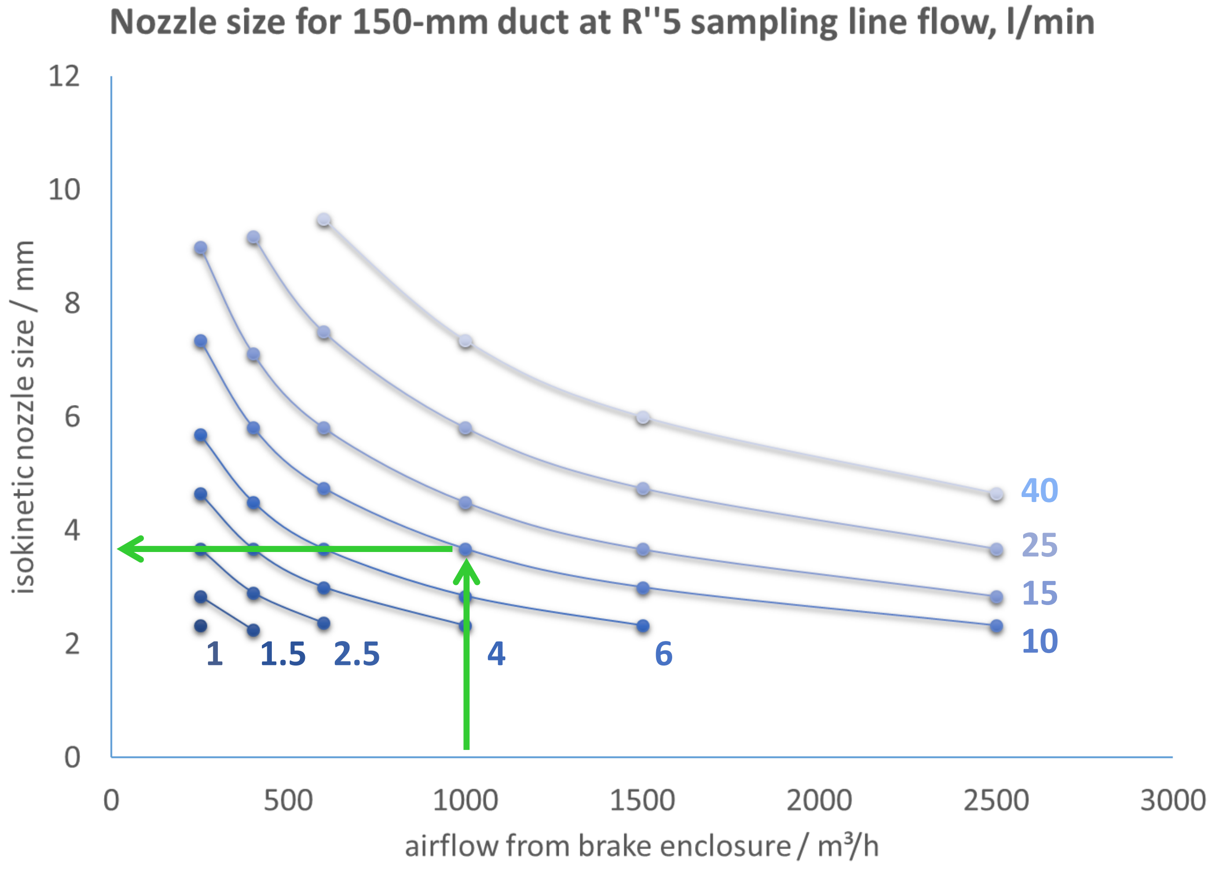
duct diameter, mm

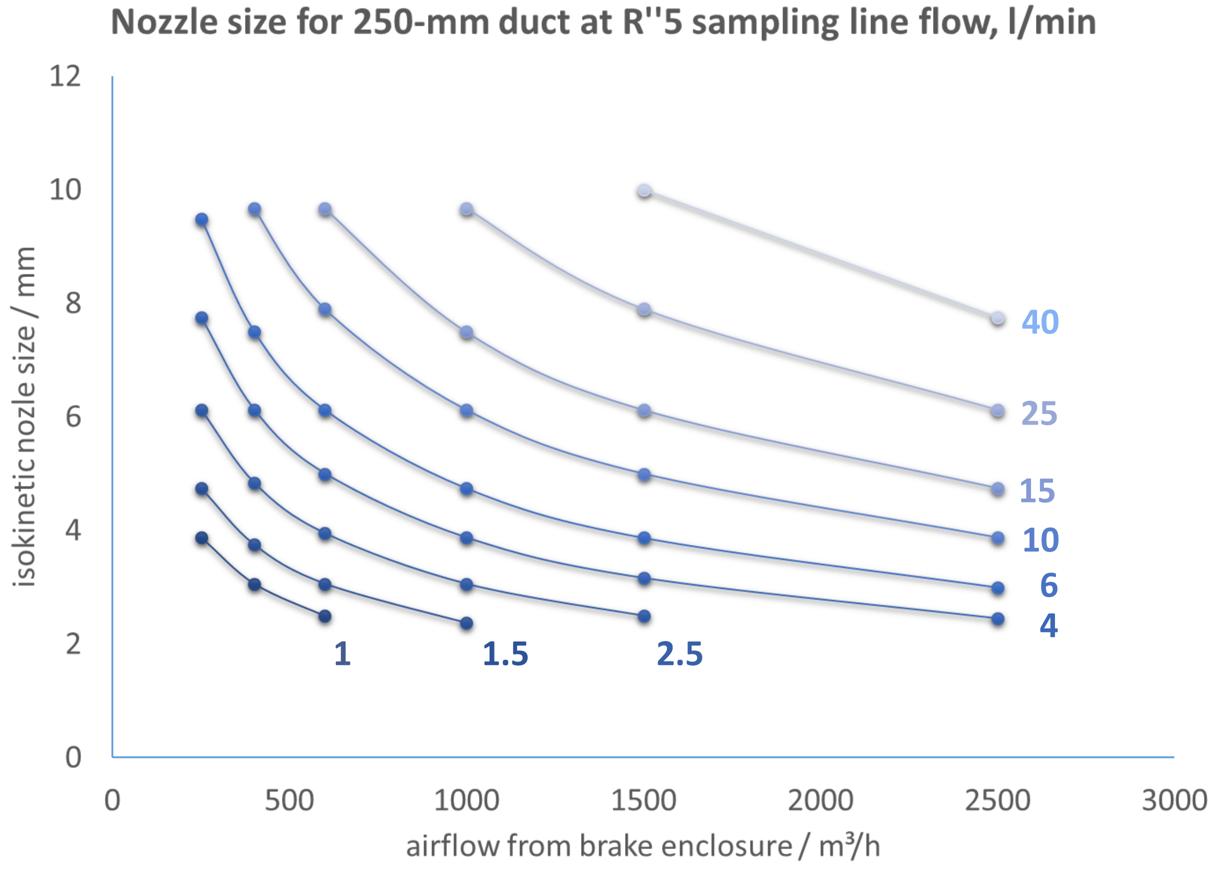
1.0 1.5 2.5 4.0 6.0 10 15 25 40 60 100 150 250 400 600 1000 1500 2500

airflow from brake enclosure, m^3/h

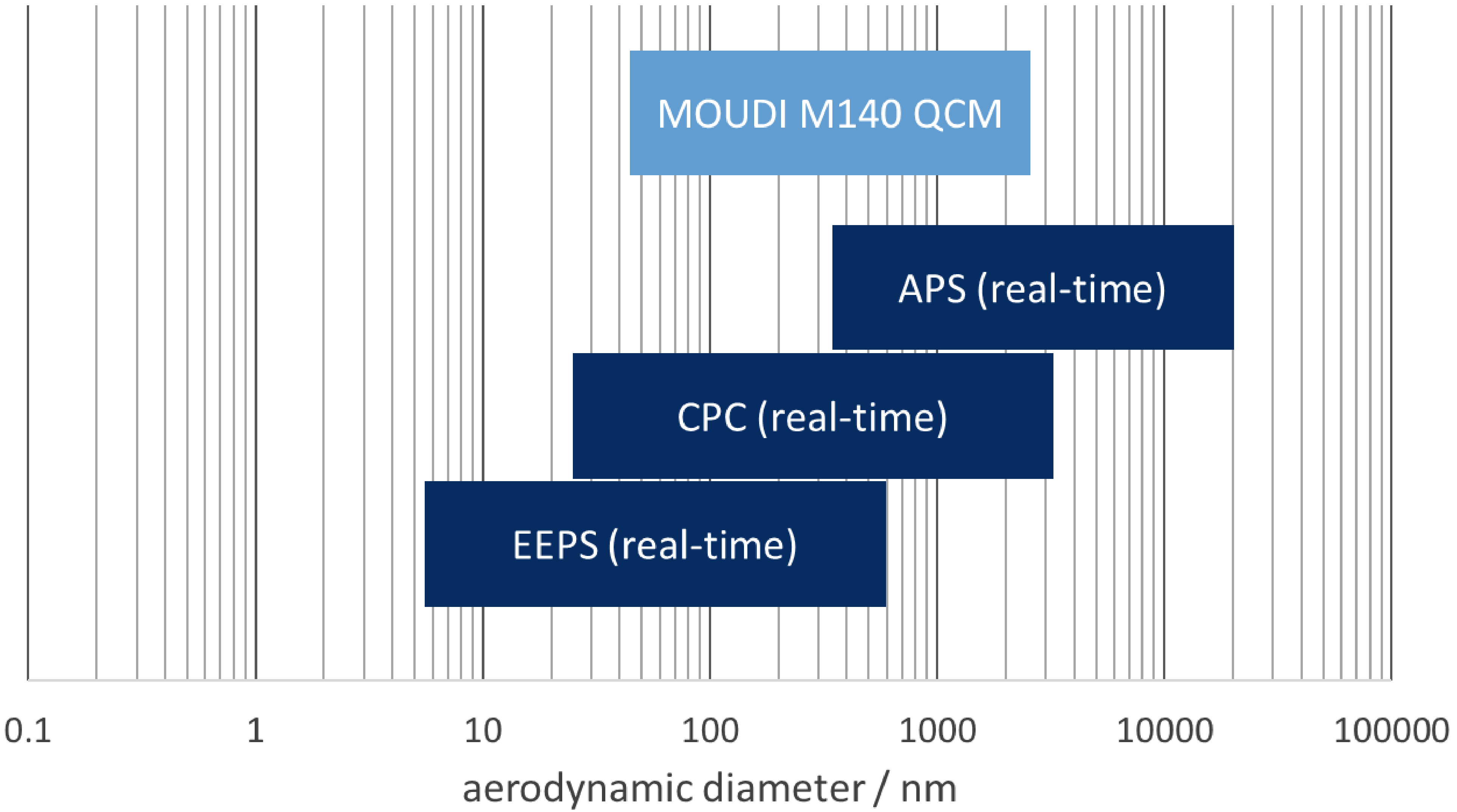
1.0 1.5 2.5 4.0 6.0 10 15 25 40 60 100 150 250 400 600 1000 1500 2500

isokinetic nozzle size = *f* (gas airflow, sampling line flow)





PMS instrument fusion – LINK comprehensive configuration



Particle Measurement System – PMS

5.6-560 nm

1-to-10,000 #/cm³

0.045-2.5 µm

0.37-20 µm

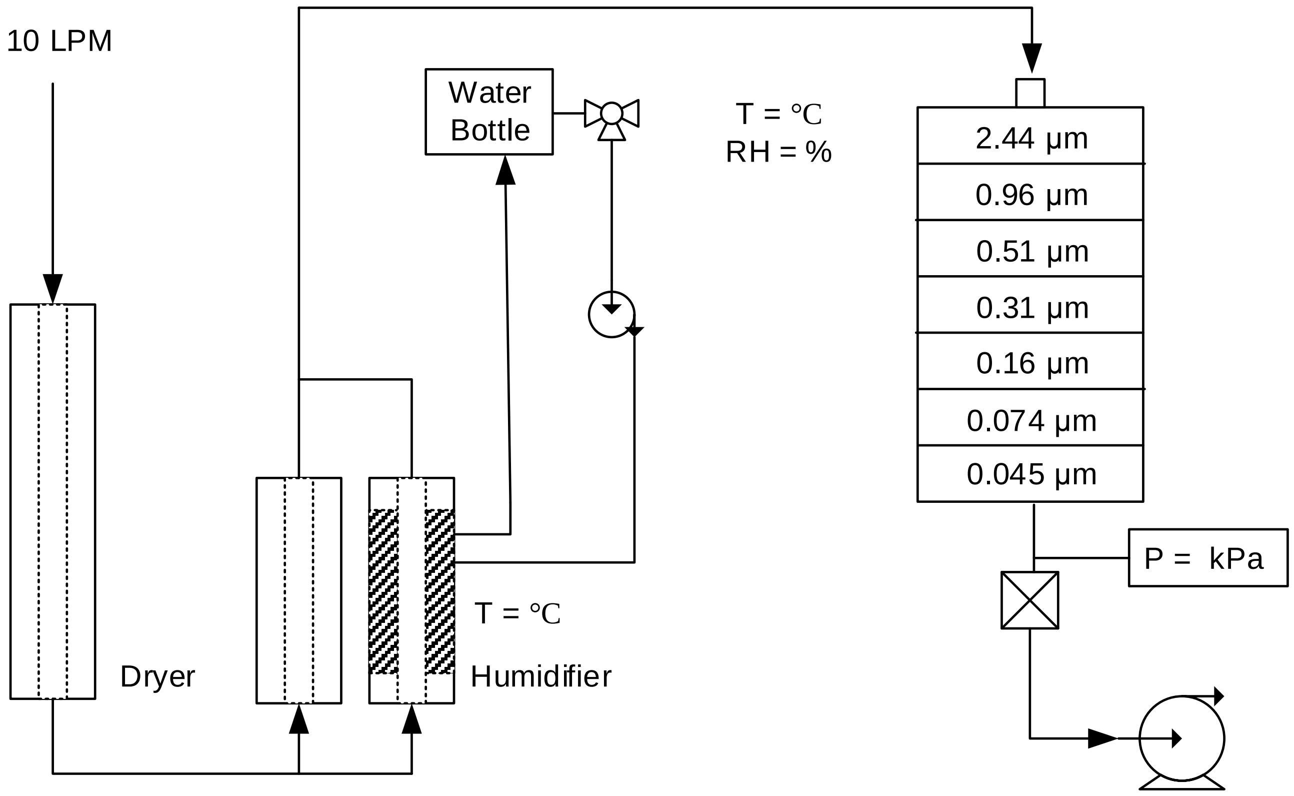
EEPS & CPC, 11 l/min

QCM M140
10 l/min

APS
6 l/min

Isokinetic sampling

low-pressure impactor - Quartz Crystal Microbalance M140



RH conditioner and 6-stage QCM impactor

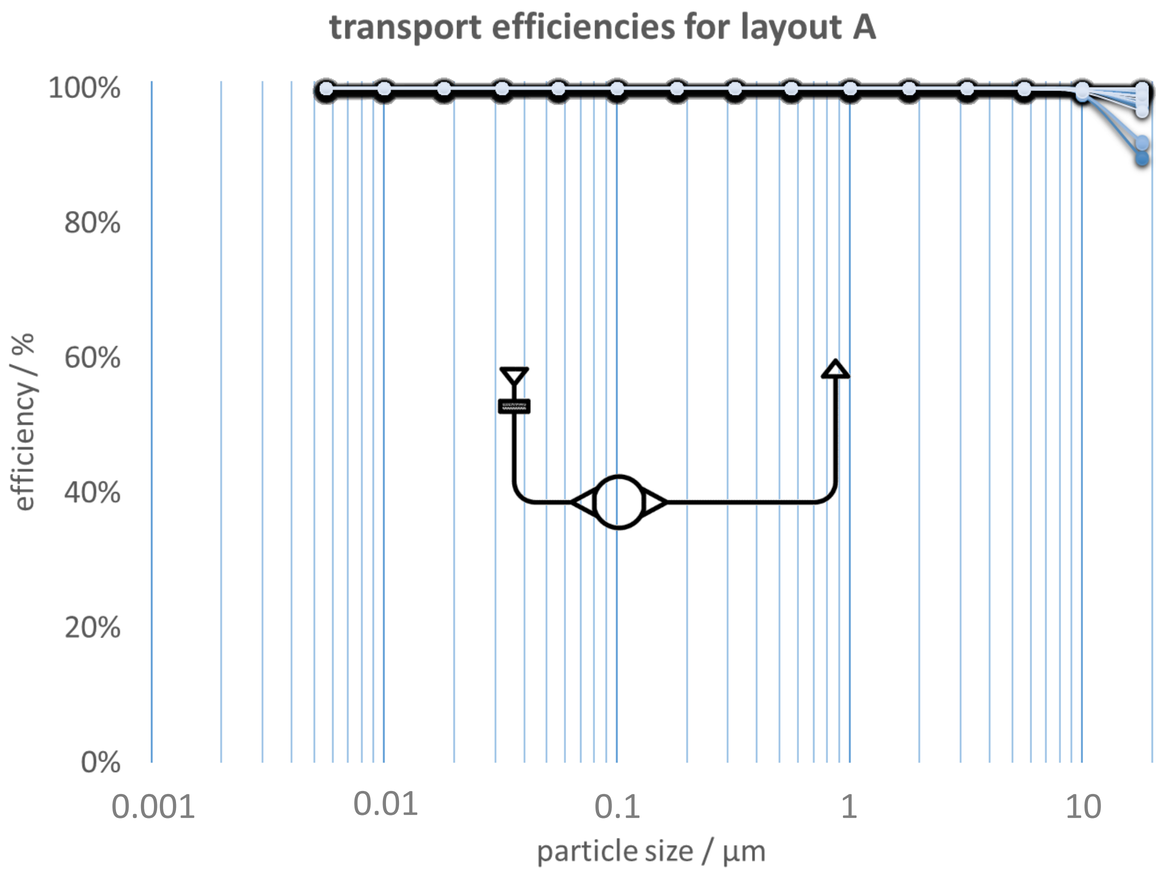
RH conditioner ensures collection at medium RH range (~60-65 %)

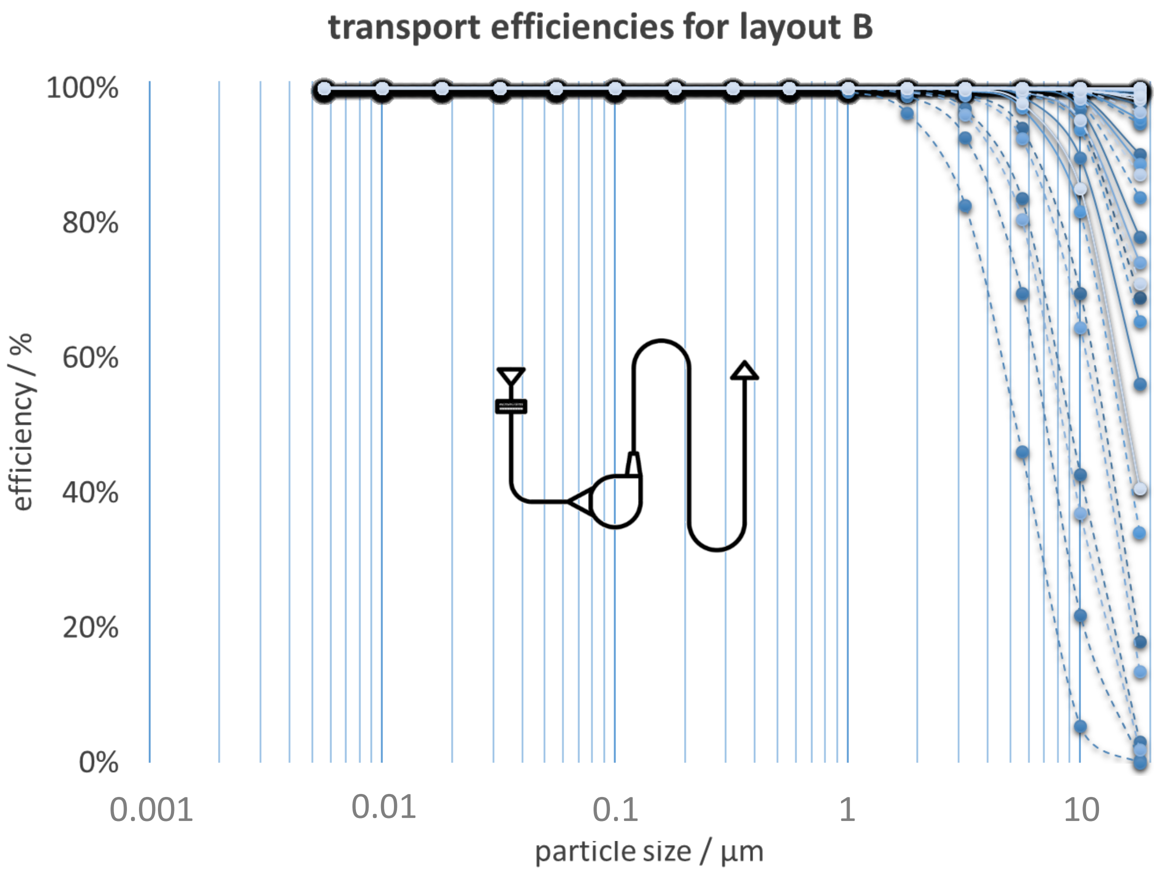
vacuum pump with precise orifice to control the flow rate

transport losses and sampling line efficiency

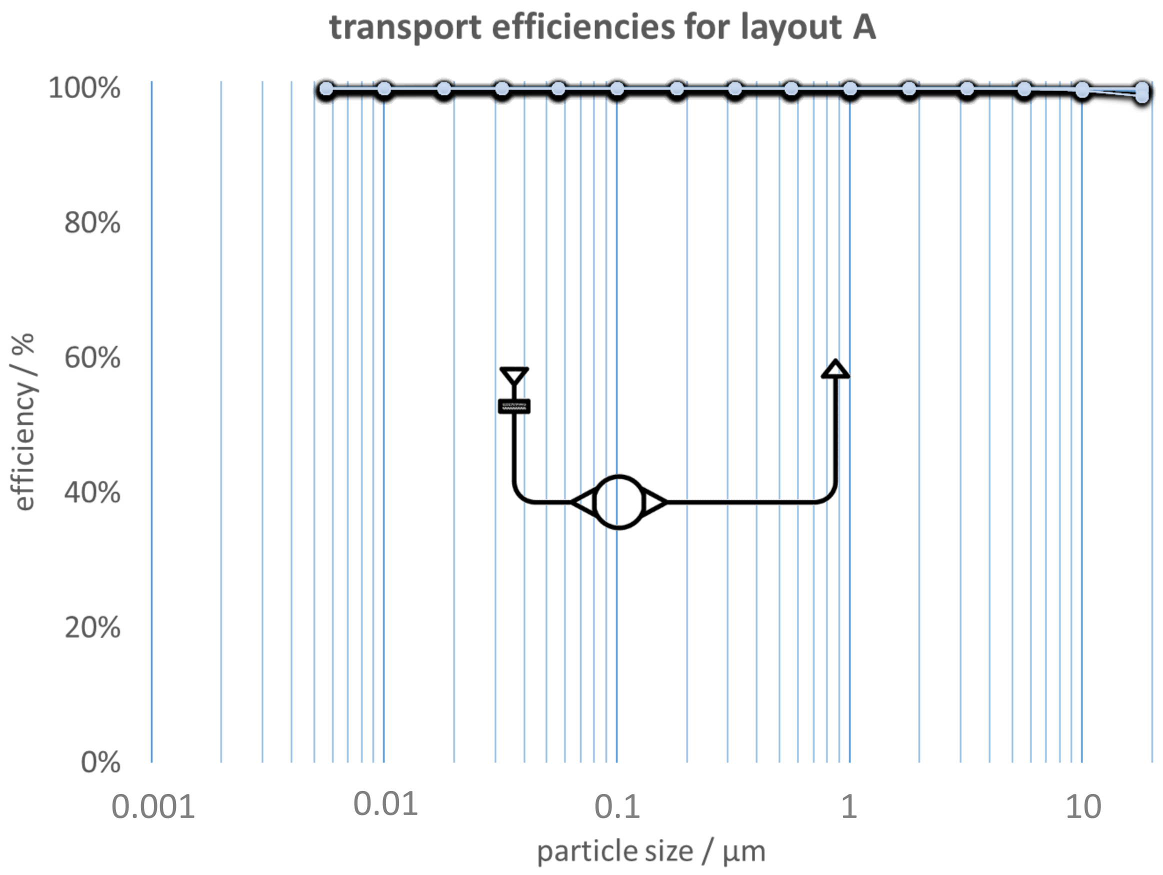
design	approval	testing
STP conditions	STP conditions	actual T, RH, Q
Q (min, max)	(T, RH) ± limits	actual sampling train
isokinetics	Q (min, max)	actual background
	coagulations	coagulation per test
	reference brakes	periodic spot-checks

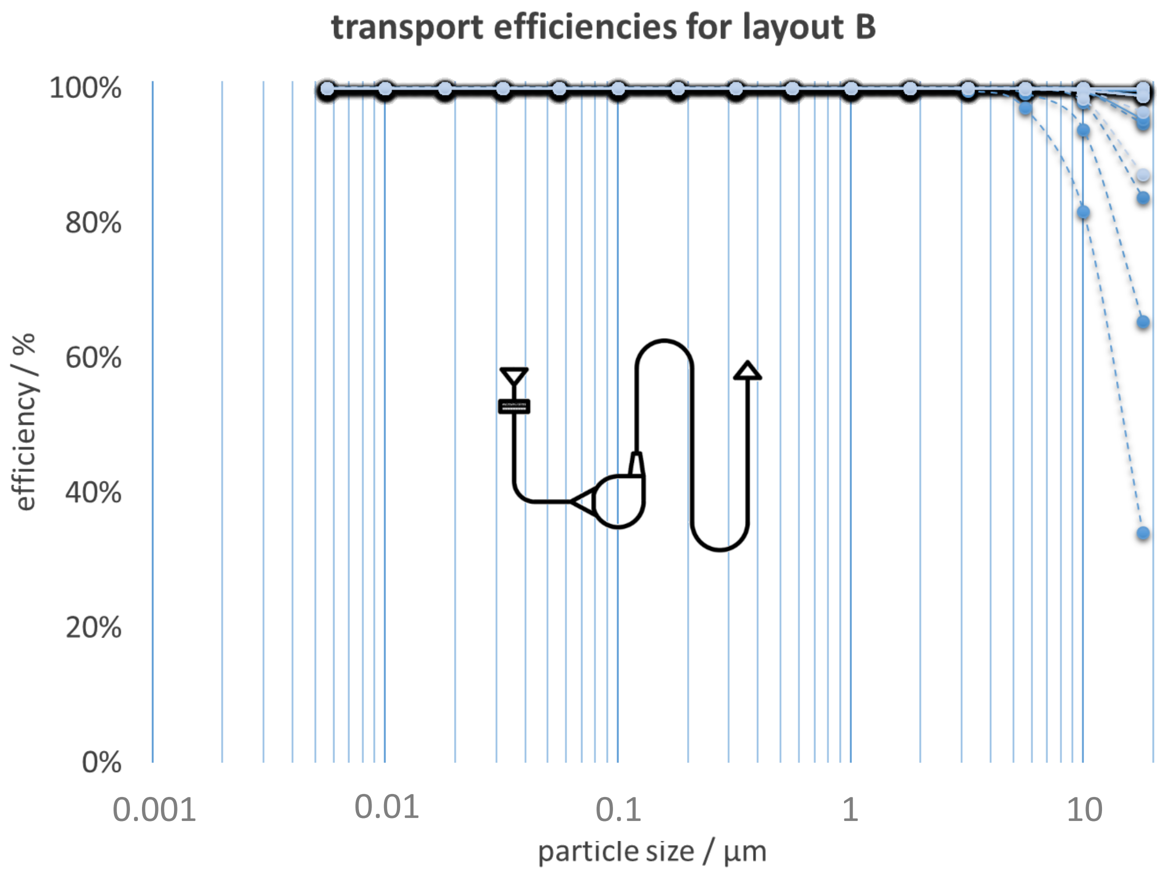
transport efficiencies - (100-250 mm duct, 250-2500 m³/h)



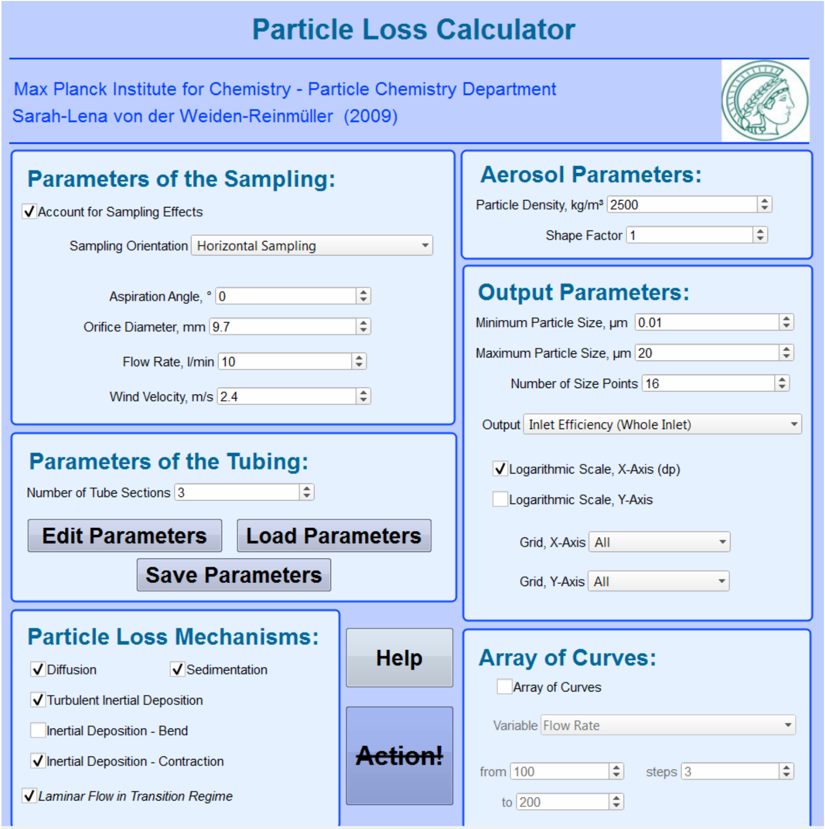


transport efficiencies - (150-250 mm duct, 250-1000 m³/h)



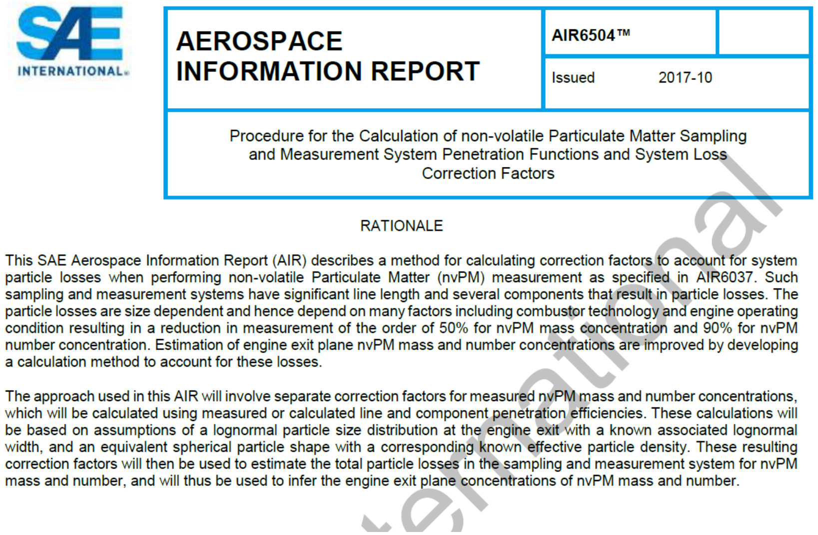


peer-reviewed transport loss and sampling line efficiency



PLC

Max Planck Institute for Chemistry



SAE INTERNATIONAL

AEROSPACE INFORMATION REPORT | AIR6504™ | Issued 2017-10

Procedure for the Calculation of non-volatile Particulate Matter Sampling and Measurement System Penetration Functions and System Loss Correction Factors

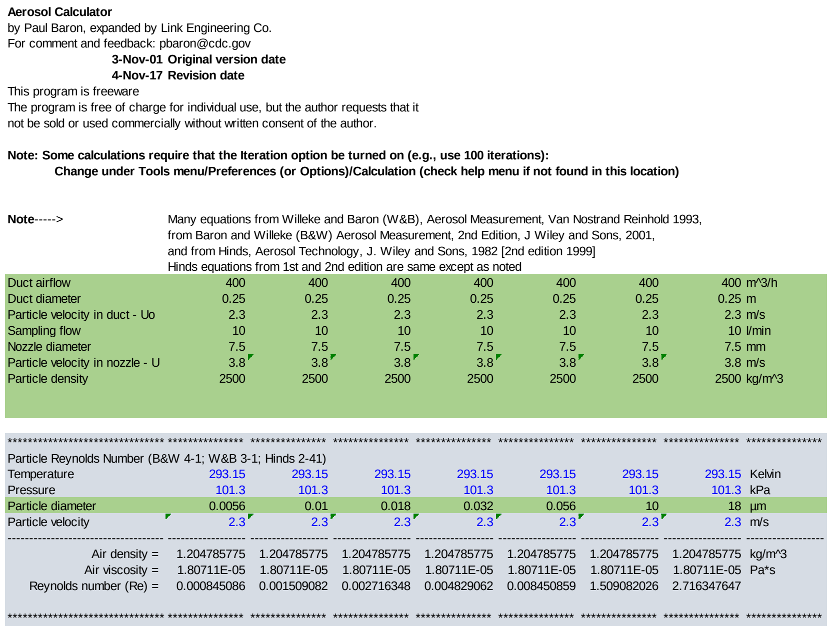
RATIONALE

This SAE Aerospace Information Report (AIR) describes a method for calculating correction factors to account for system particle losses when performing non-volatile Particulate Matter (nvPM) measurement as specified in AIR6037. Such sampling and measurement systems have significant line length and several components that result in particle losses. The particle losses are size dependent and hence depend on many factors including combustor technology and engine operating condition resulting in a reduction in measurement of the order of 50% for nvPM mass concentration and 90% for nvPM number concentration. Estimation of engine exit plane nvPM mass and number concentrations are improved by developing a calculation method to account for these losses.

The approach used in this AIR will involve separate correction factors for measured nvPM mass and number concentrations, which will be calculated using measured or calculated line and component penetration efficiencies. These calculations will be based on assumptions of a lognormal particle size distribution at the engine exit with a known associated lognormal width, and an equivalent spherical particle shape with a corresponding known effective particle density. These resulting correction factors will then be used to estimate the total particle losses in the sampling and measurement system for nvPM mass and number, and will thus be used to infer the engine exit plane concentrations of nvPM mass and number.

AIR6504

SAE E31 Aircraft Engine Emissions



Aerosol Calculator
by Paul Baron, expanded by Link Engineering Co.
For comment and feedback: pbaron@cdc.gov
3-Nov-01 Original version date
4-Nov-17 Revision date

This program is freeware
The program is free of charge for individual use, but the author requests that it not be sold or used commercially without written consent of the author.

Note: Some calculations require that the Iteration option be turned on (e.g., use 100 iterations):
Change under Tools menu/Preferences (or Options)/Calculation (check help menu if not found in this location)

Note-----> Many equations from Willeke and Baron (W&B), Aerosol Measurement, Van Nostrand Reinhold 1993, from Baron and Willeke (B&W) Aerosol Measurement, 2nd Edition, J Wiley and Sons, 2001, and from Hinds, Aerosol Technology, J. Wiley and Sons, 1982 [2nd edition 1999]
Hinds equations from 1st and 2nd edition are same except as noted

Duct airflow	400	400	400	400	400	400	400	m^3/h
Duct diameter	0.25	0.25	0.25	0.25	0.25	0.25	0.25	m
Particle velocity in duct - Uo	2.3	2.3	2.3	2.3	2.3	2.3	2.3	m/s
Sampling flow	10	10	10	10	10	10	10	l/min
Nozzle diameter	7.5	7.5	7.5	7.5	7.5	7.5	7.5	mm
Particle velocity in nozzle - U	3.8	3.8	3.8	3.8	3.8	3.8	3.8	m/s
Particle density	2500	2500	2500	2500	2500	2500	2500	kg/m^3

Particle Reynolds Number (B&W 4-1; W&B 3-1; Hinds 2-41)

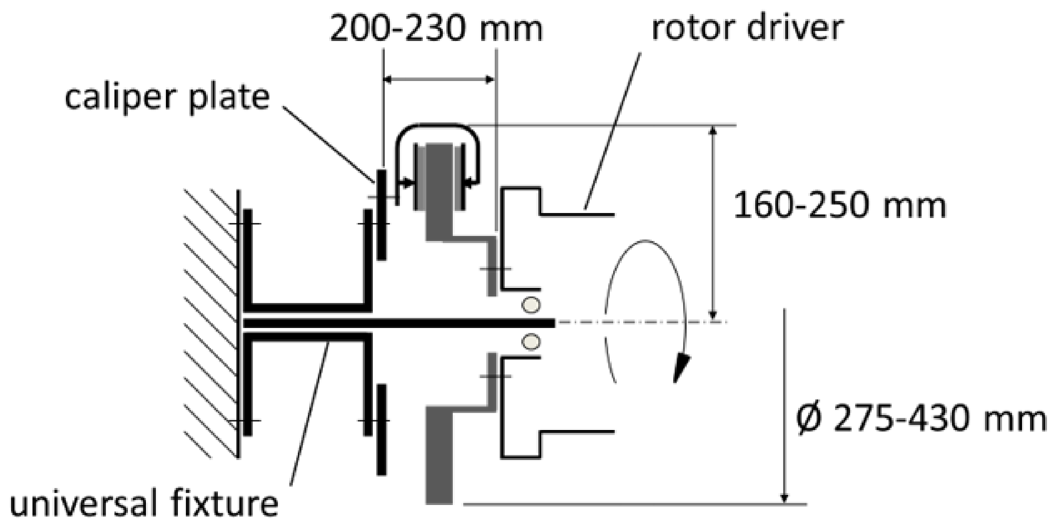
Temperature	293.15	293.15	293.15	293.15	293.15	293.15	293.15	Kelvin
Pressure	101.3	101.3	101.3	101.3	101.3	101.3	101.3	kPa
Particle diameter	0.0056	0.01	0.018	0.032	0.056	10	18	µm
Particle velocity	2.3	2.3	2.3	2.3	2.3	2.3	2.3	m/s
Air density =	1.204785775	1.204785775	1.204785775	1.204785775	1.204785775	1.204785775	1.204785775	kg/m^3
Air viscosity =	1.80711E-05	1.80711E-05	1.80711E-05	1.80711E-05	1.80711E-05	1.80711E-05	1.80711E-05	Pa*s
Reynolds number (Re) =	0.000845086	0.001509082	0.002716348	0.004829062	0.008450859	1.509082026	2.716347647	

AeroCalc

U.S. CDC – expanded

minimum system specs – starting point/reference/example

Item	Description	Value / parameter **(R):** required; **(D):** desired	Comments
1.	**Dynamometer operating parameters and controls**		
1.1.	Data export	(R): 10 Hz in-stop, 1 Hz off-brake	This will allow the proper sync with the TSI data
1.2.	Data exchange	(R): compatible	With different protocols from brake emissions measurement systems and vendors: TBD
1.3.	Cycle controls for speed profiles (WLTP)	(R): TrackSim	Required to follow the speed line of the cycle. Ensure data export
2.	**Sampling, isokinetics, brake enclosure, and air handling**		
2.1.	Airflow measurement	(R): provide total airflow per ISO stds regarding position and average	Per ISO 9096 and related stds. Define with Lab points for manual measurement of air speeds
2.2.	Air supply	(R): ability to connect to the main air handling system of the dyno	
2.3.	Ability to handle and measure total airflow	(R): (250 to 600) m^3/h (D): (250 to 1500) m^3/h	fixed during test; adjustable between tests
2.4.	Incoming air filter	(R): HEPA 13 (D): HEPA 14 or > ULPA 15	Assess need to have a stack of multiple filters on incoming and outlet air
2.5.	Activated carbon filters	Included on filtering stacks	
2.6.	Background (blank) emissions	(R): 5 times below test collection	ISO 9096
2.7.	Vacuum sealing inside sampling train	(R): The flow rate < 2% of the normal flow rate at the max vacuum	Applies to sampling train under vacuum with all nozzles sealed/blocked
2.8.	Environmental conditioning	(R): room air with basic temp control (D): (20 ± 5)°C, (50 ± 10)%RH	
2.9.	Straight length before the aerosol sampling position from last (nearest) upstream duct disturbance	(R): 8 diameters (D): 10 diameters	Per EPA Method 1 & 1a. also applies to air speed
2.10.	Straight length after aerosol sampling position from next (nearest) downstream duct disturbance	(R): > 2 diameters	Per EPA Method 1 & 1a. also applies to air speed

Item	Description	Value / parameter **(R):** required; **(D):** desired	Comments
2.11.	Duct size and geometry	R): keep the same	Applies to wet area after the brake enclosure
2.12.	Duct bends	(R): Ro 4-to-6	Ro = Curvature ratio = bend radius/duct radius. Applies on wet area and sampling train
2.13.	Transition angles in wet areas	(R): < 30° enclosed angle	Applicable to enclosure outlet constriction
2.14.	Isokinetic sampling	(R): within 10% of the theoretical isokinetics flowrate	See ISO 9096
2.15.	Wet area ducting and sampling train material	(R): stainless steel (D): stainless steel with electropolish	Ensure smooth and ease of cleaning if needed
2.16.	enclosure design and shape	(R): round to accommodate M1/N1 brake sizes indicated in Figure 2	Fixture with rotor near the center on the enclosure opening in the axial direction
2.17.	Figure 2: brake fixture envelope dimensions		
3.	**Real-time emission measurement system**		
3.1.	Dynamic range for real-time measurement	(R): 23 nm to 10 µm (D): 6 nm to 20 µm	Gravimetric sampling highly desirable
3.2.	Data format	(R): Ability to export analog data via standard protocol	Specify protocol and connectors See AK Protocol
3.3.	Data exchange	(R): Data sync for basic controls, alarms, and status messages	Coordinate details with PMS vendor
4.	**System validation**		
4.1.	results compared to reference brakes and friction couples (A, B, C)	(R): within XX °C thermal regime (R): within X % of emissions metrics	Temperature and emission targets will be a function of the reference brake used

special acknowledgments

LINK — Troy Caldwell & Terry StAubin

TSI — Andrea Tiwari & Bob Anderson