An Agency of the European Union
This project is funded by the European Union's Horizon 2020 Programme

Disclaimer

This project is funded by the European Union under the Horizon Europe Programme.

Welcome to this webinar!

This webinar is the final dissemination event of this research project

This project has received funding from the European Union’s Horizon 2020 research and innovation Programme

European Commission

The EC delegated the contractual and technical management of this research action to EASA

INTA

EASA contracted INTA as Consortium lead for the implementation of the research action following a public tender procedure

EASA-managed projects are addressing research needs of aviation authorities and are an important pillar of the EASA R&I portfolio

The agenda

Time	Title and Speaker
14:00 – 14:05	**Welcome to the webinar** Willy Sigl (EASA)
14:05 – 14:15	**Research scope and objectives** Werner Hoermann (EASA), Lisa Ernle (EASA), Theo Rindlisbacher (BAZL)
14:15 – 15:15	**Overview of the project implementation and key results** Jesús Sánchez (INTA), Mark Johnson (RR), Eliot Durand (Cardiff), Andrew Crayford (Cardiff), Lukas Durdina (GreenLet)
15:15 – 15:30	**Benefits from the project, planned follow-up actions** Werner Hoermann (EASA), Lisa Ernle (EASA)
15:30 – 15:55	**Questions and answers** Participants, project team
15:55 – 16:00	**Concluding remarks** Willy Sigl (EASA)

Note: this webinar will be recorded and made available at the EASA website after the event.

Question and Answers

→ For sending questions and comments, please use the slido app, which is also accessible through WebEx:

- www.slido.com
- event code: 2640026

Research Scope and Objectives

This project is funded by the European Union's Horizon 2020 Programme

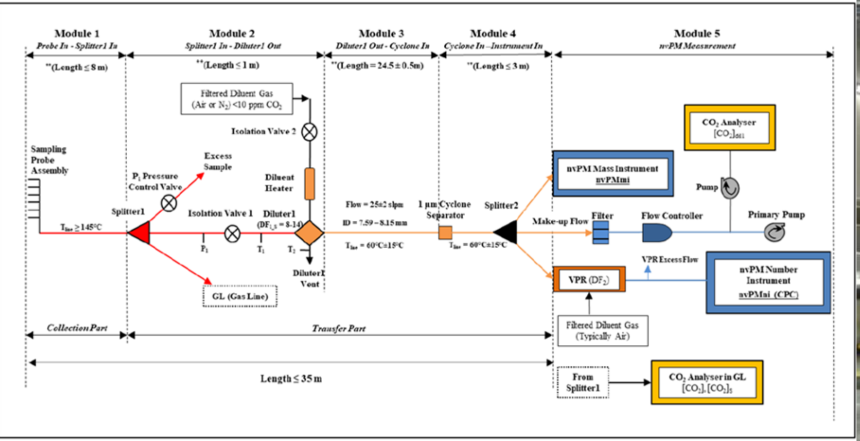
SAMPLE Project History

- What is it about?

- Studying, sAmpling and Measuring of aircraft ParticuLate Emission

- SAMPLE I to III
  - EU funding 2008 – 2016
  - Development of a Sampling & Measurement System for aircraft engine nvPM emissions
  - Development of nvPM measurement procedures and Standards
  - SAE AIR6241/ARP6320, ICAO Annex 16 Volume II CAEP/10 and CAEP/11
  - Improvements still needed to reduce nvPM measurement uncertainty for future regulation

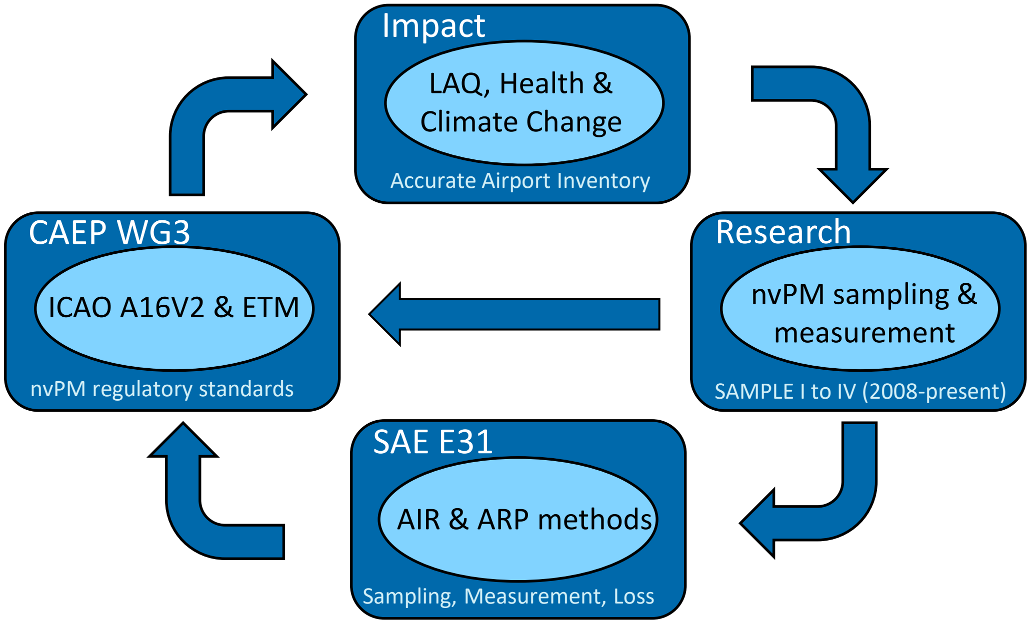
ICAO Annex 16 Vol. II nvPM measurement system



Aircraft engine certification (the first in the world for ultrafine soot particle measurements as small as 1/100’000 mm) required a highly complex sampling and measurement system, including development of instrument calibrations, which can have large uncertainties

Research Scope

- SAMPLE IV: Served to assist both SAE E31 & CAEP in maintaining and potentially improving nvPM sampling & measurement and regulatory practices
- Typically SAE E31 recommended practices are considered by CAEP WG3 for addition to regulatory standard (A16V2) & ETM



EASA

Project Overview

SAMPLE IV

Aim 1

Assessment of non-regulated engine emissions

Task 4

Impact on operations and emissions at European airports

Aim 3

Expanding the aircraft engine emissions database

Task 5

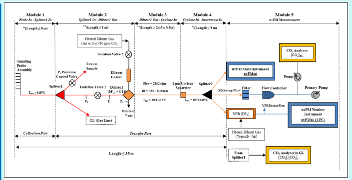
Emission measurement for small and non-regulated engines

Aim 2

Advancement of sampling, measurement and correction techniques

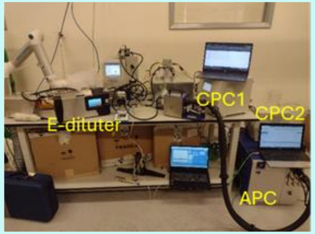
Tasks 1 & 2

State of the art of aircraft engine ICAO Annex 16 Vol II and potential improvements



Task 3

- Improve methodologies for size-dependent loss of nvPM
- Assess technical advancements to improve sampling and measurement system



Task 6

Improve correlations between SN and nvPM

Task 7

Assessing the validity of current fuel correction methodologies

EASA
European Union Aviation Safety Agency

Overview of the project implementation and key results

This project is funded by the European Union's Horizon 2020 Programme

Project Overview

Work programme:
FUNDED BY EASA
Horizon 2020 Research and Innovation Program Societal Challenge 4 “Smart Green and Integrated Transport”

Budget:
SC01; 200,000 €
SC02; 700,000 €

SCO1; START: March 2021 II END: 2023

SC02; START: February 2023 II END: 2025

Coordinated by **INTA**
Spain

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Consortium

Instituto Nacional de Técnica Aeroespacial

MANCHESTER 1824 The University of Manchester

GTRC GAS TURBINE RESEARCH CENTRE

POLITÉCNICA

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https://www.easa.europa.eu/en/research-projects/environmental-research-engine-emissions-sample-iv

SAMPLE IV - Project | LinkedIn

Project Overview

SAMPLE IV

actualidad aeroespacial

Proyecto SAMPLE IV

Por Rocío Gallardo Martínez y Jesús Sánchez Valdepeñas, investigadores en el Proyecto SAMPLE IV

El transporte aéreo se ha consolidado como uno de los medios más veloces y eficaces de transporte en la actualidad, convirtiéndose en una herramienta esencial para el comercio y la economía global. No obstante, este medio de transporte tiene asociados una serie de incon-

PARA INTENTAR REDUCIR LOS EFECTOS NOCIVOS QUE CAUSAN LAS EMISIONES CONTAMINANTES PROCEDENTES DE LA AVIACIÓN, LA UNIÓN EUROPEA DICTA UNA SERIE DE NORMATIVAS EN MATERIA DE CONTAMINACIÓN

de investigación e innovación Horizonte 2020 Societal Challenge 4 'Smart Green and Integrated Transport'.

Este proyecto busca evaluar las características de las emisiones de motores de aviación no regulados (con un empuje inferior a 26.7 kN)

Aerospace TESTING INTERNATIONAL

SAMPLE IV PROJECT MEASURES ENGINE EMISSIONS

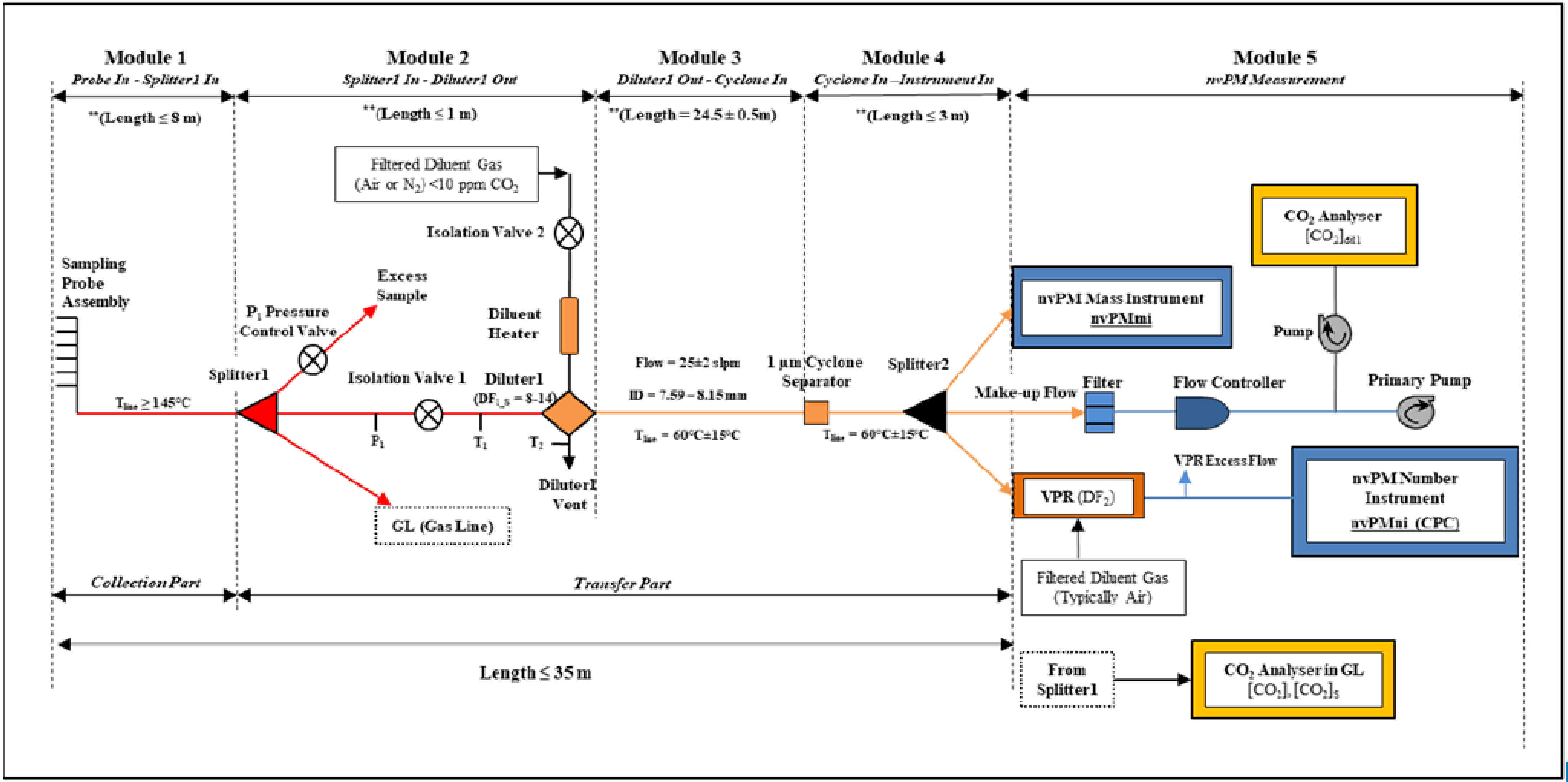
A European project to measure the particulate matter emitted by non-regulated aero engines is informing the creation of environmental emissions regulations

Links:

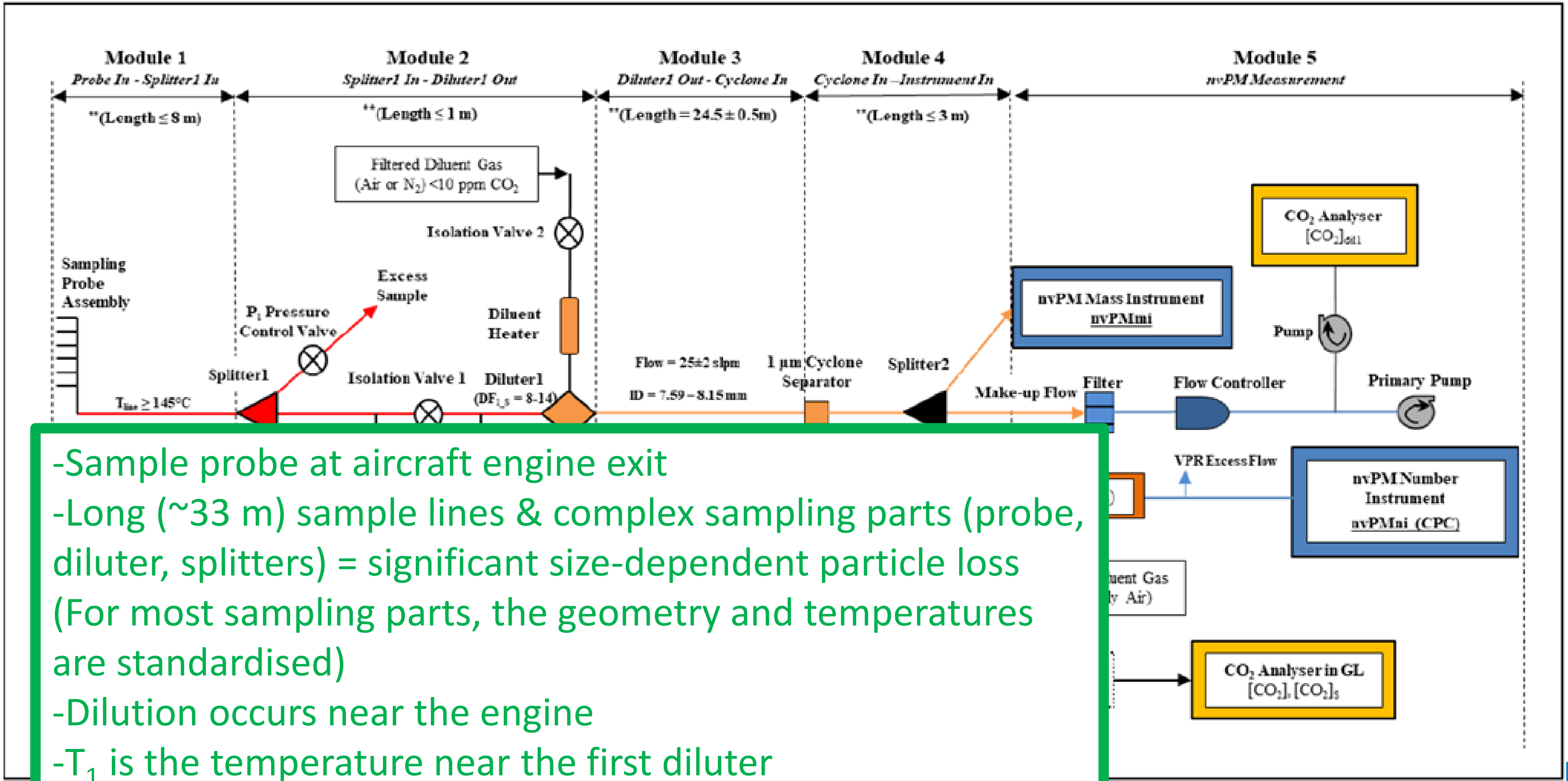
Actualidad Aeroespacial
https://actualidadaeroespacial.com/revista-2024/ (November)

Aerospace Testing International
https://www.aerospacetestinginternational.com/online-magazines/in-this-issue-december-january-2025.html

Regulated aircraft engine non-volatile Particulate Matter emissions sampling and measurement system [ICAO A16V2]



Regulated aircraft engine non-volatile Particulate Matter emissions sampling and measurement system [ICAO A16V2]



-Sample probe at aircraft engine exit
-Long (~33 m) sample lines & complex sampling parts (probe, diluter, splitters) = significant size-dependent particle loss (For most sampling parts, the geometry and temperatures are standardised)
-Dilution occurs near the engine
-T_1 is the temperature near the first diluter

Regulated aircraft engine non-volatile Particulate Matter emissions sampling and measurement system [ICAO A16V2]

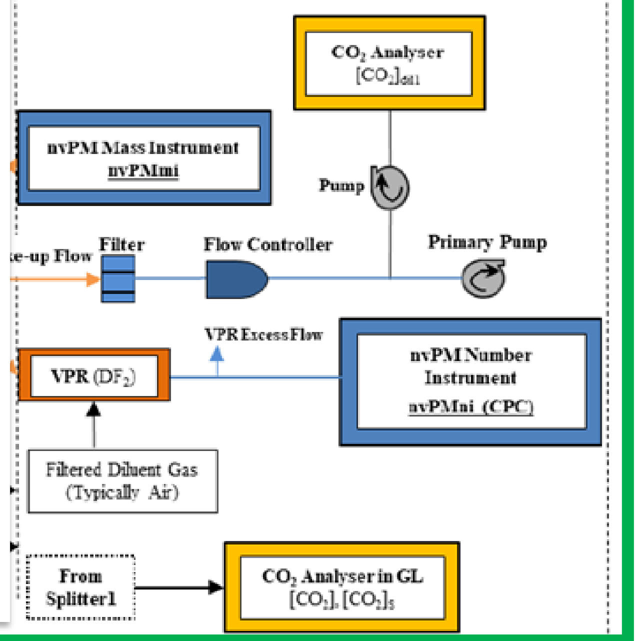
-nvPM mass instrument responds to nvPM only

- Indirect mass measurement
- Transfer calibration standard (not gravimetric)

-CO_2 measured to verify sample dilution

-Careful controlled sample flow rate to fix the sample flow in most of the sampling system

-nvPM number instrument requires an upstream volatile particle remover



1: Solutions for ICAO regulatory aviation nvPM mass and number measurements

(https://www.easa.europa.eu/en/downloads/140627/en)

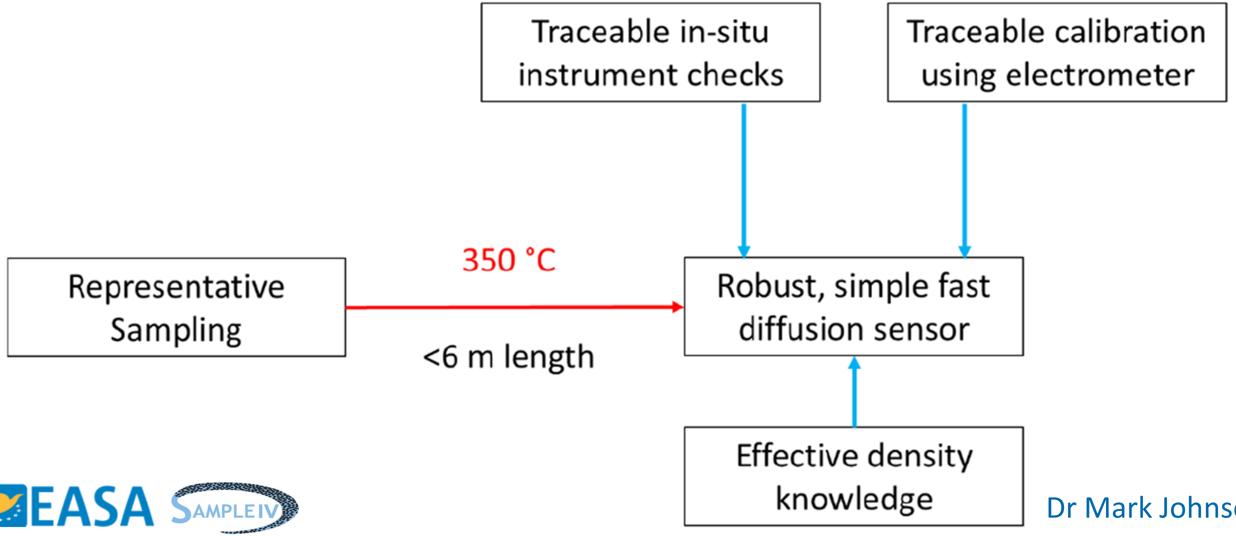
Aims

- → Understand the historical approaches adopted to establishing the ICAO regulatory nvPM baseline sampling & measurement system (from 2005 onwards)
- → Reduce uncertainty in reported aircraft engine nvPM emissions, establish potential improvements to the ICAO regulatory nvPM sampling and measurement system
  - As more information has become available, optimisation of methodology is possible
- → Understand potential benefits of new sampling and measurement approaches
  - Well over a decade after the development of the initial nvPM measurement approach, scientific and operability knowledge has improved, and new/improved instrumentation is commercially available

Optimised nvPM measurement system concepts – measurement location dependent

1. Instruments still (as per current system) located 33 m from engine exhaust probe tip (in benign, carefully controlled environmental conditions)
2. Instrument located to minimise particle sampling loss (short sampling line length):
   a) close to engine <8 m sampling from sample probe tip (more adverse environmental conditions)
   b) Testbed stack sampling <8 m of sampling system length (relatively benign environmental conditions)

Simplest Scientific Optimum Solution:



2: Potential Improvements to Current ICAO nvPM Sampling & Measurement System

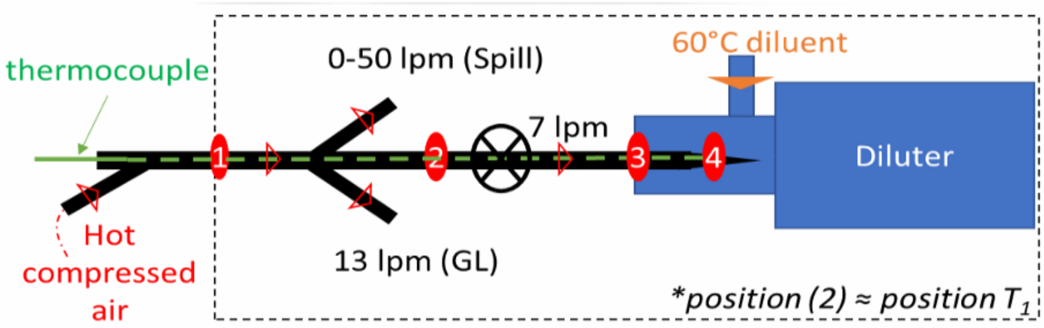
(https://www.easa.europa.eu/en/downloads/140629/en)

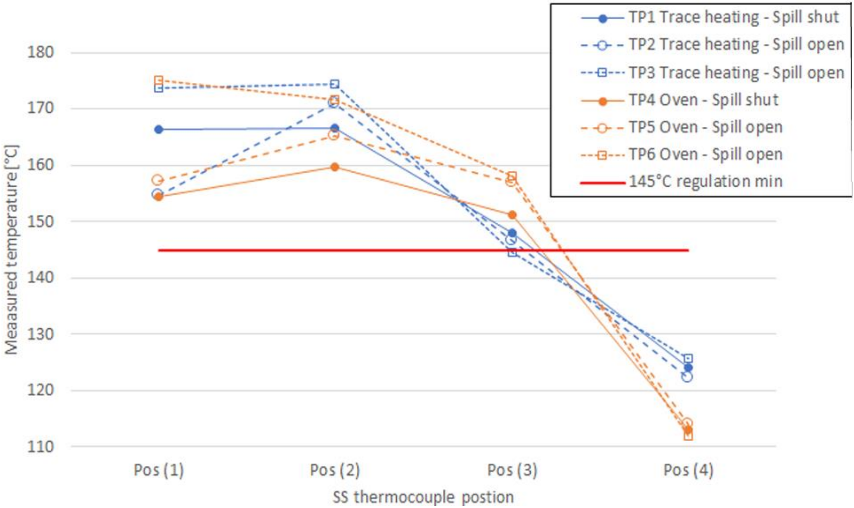
Aim

- → Perform experiments to help SAE E31 and ICAO understand potential improvements that could be made to the current ICAO nvPM sampling and measurement standards and system loss correction reporting

Experiments conducted

- → Assess and understand potential thermophoretic loss uncertainty resulting from adverse temperature gradients near inlet of diluter
  - Different heating and control strategies and Splitter 1 designs results in variations in temperature at Diluter 1 inlet





Additional experiments conducted

- Impact of cyclone cleanliness on uncertainty and operability of nvPM measurements, especially at low nvPM mass emission conditions
- Understanding the charge potential of gas turbine combustion aerosols and their impact on particle size measurement
- Characterisation of particle loss in Splitter1, given the known issue to maintaining uniform flow split velocity across different power conditions

Conclusions of current state-of the-art and future scientific optimal concept

Existing system

- → History of nvPM regulatory measurement system development documented
- → Precise T_1 location definition & need for interim particle loss correction term at diluter inlet
- → Increasing the frequency of cyclone cleaning improves nvPM system operability
- → Particle charge may have an impact on particle loss and particle size measurement
  - further work needed
- → Further work needed to assess Splitter1 particle loss bias under realistic flow conditions
- → High priority improvement items for nvPM sampling and measurement, perceived to have the biggest impact in reducing uncertainties, should be pursued

Future best possible/optimum system

- → Using 'Outside-the-box' consideration, based on 'what we now know', without having to comply with existing system boundary constraints:

  Novel measurement solutions are feasible

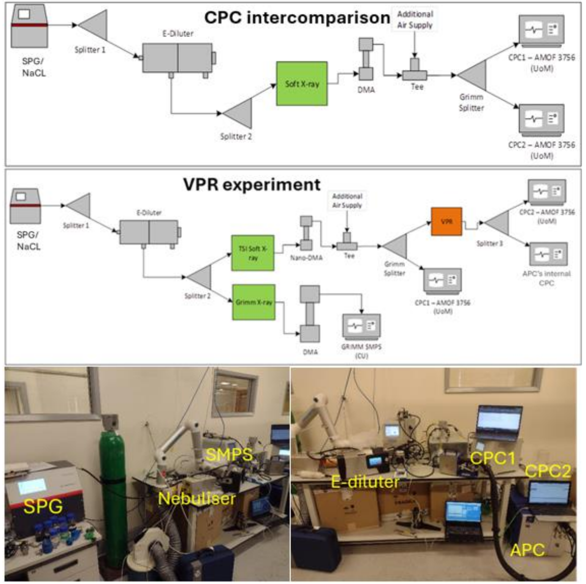
3: Improving nvPM sampling and measurement system uncertainties

(https://www.easa.europa.eu/en/downloads/141733/en)

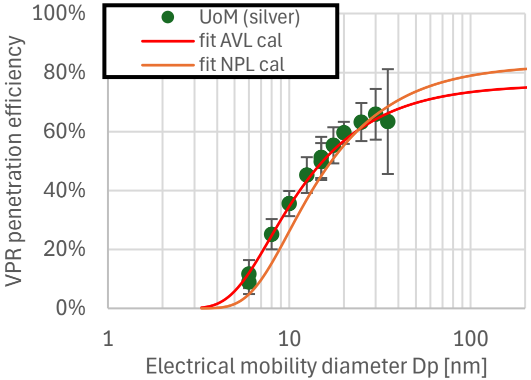
Aims, Experiments conducted and Outcomes

a. Quantify uncertainty and understand potential improvements that could be made to regulatory nvPM number measurement

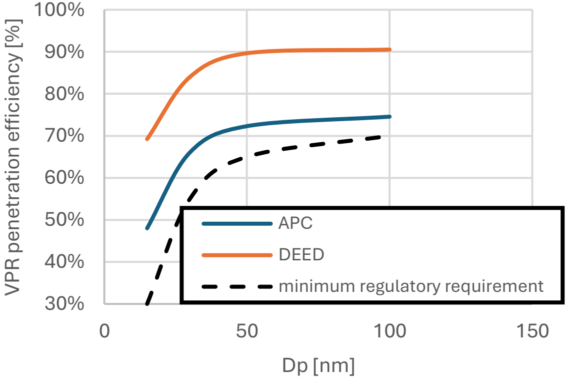
- ➤ CPC uncertainty, VPR uncertainty, Regulatory nvPM number calibration protocols, Drift



Diagrams and pictures of the UoM CPC intercomparison and EUR APC VPR penetration experiments



EUR VPR measured and fitted penetration efficiencies between 5 and 200 nm from different calibration laboratories



Average VPR penetration efficiency for the AVL APC and the Dekati DEED

→ Found significant variability in VPR penetration efficiency across different calibration and research laboratories system (particle type, conditioning, setup, etc)

→ Different VPR technologies can have significantly different penetration efficiencies

→ No measurable drift within 12-month calibration period

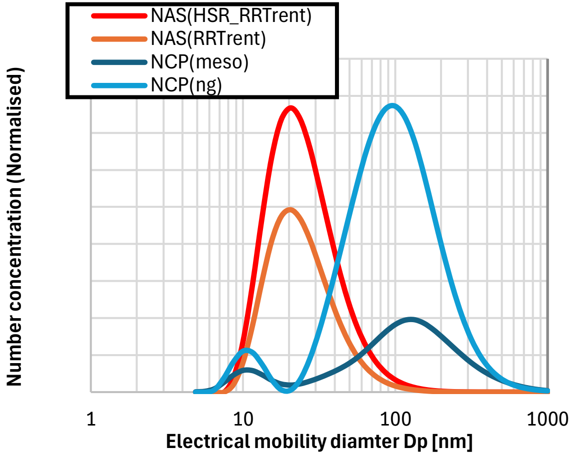
3: Improving nvPM sampling and measurement system uncertainties

(https://www.easa.europa.eu/en/downloads/141733/en)

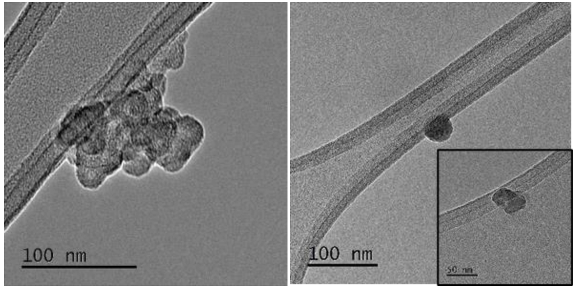
b. Assess the potential of nebulised aqueous colloids composed of either fresh aircraft soot or a proxy carbon nanopowder as novel nvPM mass calibration and for in-field nvPM instrument checks

- Colloids development, Nebulised colloid output, Nebulised colloid properties

Pictures of the different carbonaceous powders & nebuliser tested



Normalised DMS500 particle size distributions of nebulised colloids



TEM images of nebulised carbon powder (left) and nebulised aircraft soot (right)

→ Generated colloids can output ranges of number, mass and size relevant to aircraft nvPM

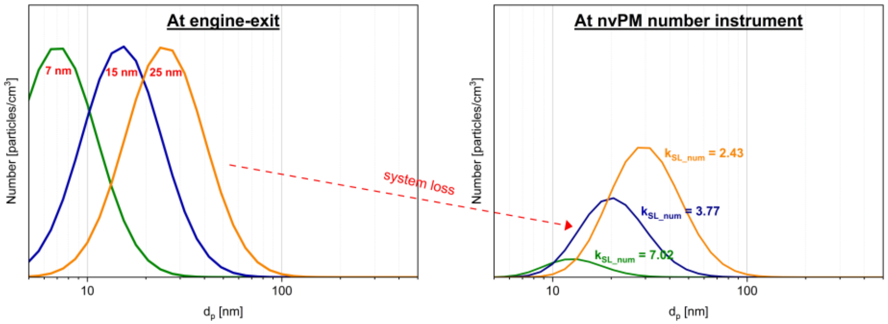
→ Concept proven for simultaneous in-field check of nvPM mass, number and size instruments prior to a test

3: Improving nvPM sampling and measurement system uncertainties

(https://www.easa.europa.eu/en/downloads/141733/en)

c. Further assess the advancement of using particle size measurement for size-dependent system loss correction compared to the currently prescribed method (N/M)

- Uncertainty in not correcting for size-dependent loss, Impact of Particle Size Distribution (PSD) variability on system loss correction uncertainty



Example engine-exit (left) and at instrument (right) aircraft exhaust nvPM size distributions (number-weighted)

→ Quantified the importance of size-dependent loss correction

→ Compared different commercially available particle size instruments

→ Novel data/analysis on uncertainty improvement in system loss correction using measured PSD methods

	Particle type (GMD range)	Instrument used	k_{SL_num} variability				k_{SL_mass} variability				Additional info
			Avg (1)	*Avg (2)*	Max (1)	*Max (2)*	Avg (1)	*Avg (2)*	Max (1)	*Max (2)*	
Durand et al. [20] (PSD_{L2})	RQL combustor exhaust (24 – 42 nm)	2x DMS500 (M44&125) 1x TSI SMPS 1x TSI EEPS	10%	*5%*	19%	*10%*	2%	*1%*	8%	*5%*	Multiple sampling locations
Novel engine data	ALF 502 & 507 (14 – 43 nm)	1x DMS500 (M44) 1X Grimm SMPS	7%	*3%*	15%	*6%*	2%	*1%*	15%	*7%*	Near regulatory nvPM instruments
Novel laboratory data with multiple inversions	Gold, Graphite, salt, carbon colloid (8 – 71 nm)	1x DMS500 (M44) 2x TSI SMPSs 1x Dekati ELPI+HR	10%	*7%*	21%	*10%*	6%	*4%*	23%	*16%*	Different inversion matrices tested

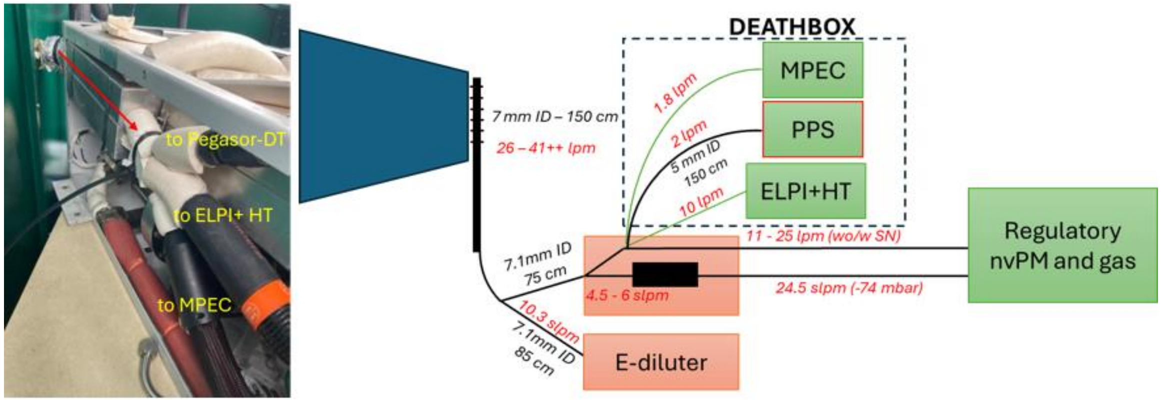
Uncertainty summary for k_{SL_num} and k_{SL_mass} when using different PSD measurements with method PSD_{L2} (PSD input between 10 – 240 nm)

3: Improving nvPM sampling and measurement system uncertainties

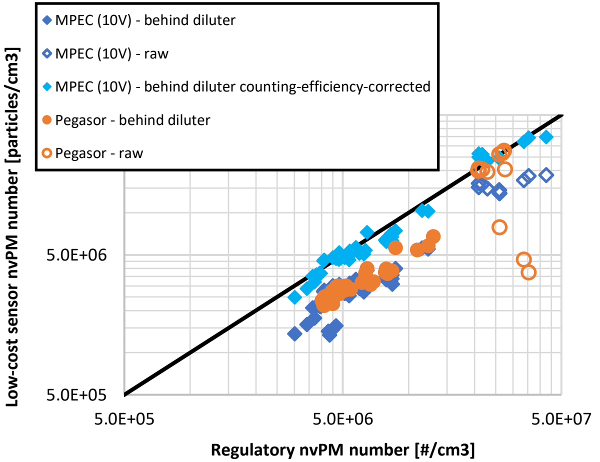
(https://www.easa.europa.eu/en/downloads/141733/en)

d. Assess novel advanced measurement techniques for nvPM number and mass emissions

- ➢ Evaluation of novel measurement techniques in small engine testing and on rich burn combustor rig exhaust, Estimating nvPM number and mass from PSD measurements



Picture and diagram of the novel experimental setup used during some of the LF507/ALF502 tests



Regulatory nvPM number (corrected to low-cost sensor location) Vs low-cost sensor nvPM number

→ Proof of concept for:

- ○ Various portable sensors and diffusion-based counters for measuring nvPM number and mass
- ○ Near probe measurements (including PSD measurements)
- ○ Other novel measurements: Particle charge, LII-300 fluence sweeps

EASA SAMPLE IV

Conclusions: Uncertainties and improvements of nvPM sampling & measurements

- Regulatory nvPM number uncertainty can be reduced by:
  - Standardising VPR calibration measurement approach
  - Mandating the application and reducing allowance of the CPC linearity factor (k-factor)
  - Accounting for size-dependent VPR particle loss and CPC counting efficiency

- Measured-PSD-based methods reduce uncertainty compared to N/M method for system loss correction (k_{SL}), particularly at low measured nvPM mass
  - Guided the development of SEA E31 AIR6504A "*Procedure for the Calculation of non-volatile Particulate Matter Sampling and Measurement System Penetration Functions and System Loss Correction Factors*" and AIR7382 "*Procedures for the Sampling and Measurement of Particle Size Distributions from Aircraft Turbine Engines*"(WIP)

- Carbonaceous colloids show potential for 'in-field' checks & future calibration standards
  - Proof of concept ('low-cost' simultaneous checks of nvPM number, mass and size)
  - Better understanding of the impact of particle morphology on different nvPM mass instruments

- 'novel' sampling & measurement techniques offer potential to reduce sampling and measurement uncertainty, complexity and cost
  - Example - Diffusion-based charger and e-diluter successfully deployed at the probe exit during engine testing

4: Impact assessment of nvPM emissions from non-regulated engines

(https://www.easa.europa.eu/en/downloads/138846/en)

Aims

- → Evaluate the relevance of non-regulated engines, in terms of nvPM, at EU civil airports
  - ○ Non-regulated: Turbofan <26.7 kN, Turboprops, Piston Engines, Helicopter turboshaft & APU
- → Specify a set of candidate representative engines – to consider for emissions measurement

Approach

- → Representative Air traffic Week selected - 2019 – given the impact of COVID in following years
- → Selected 12 representative Airports covering 3 sizes of airport
  - ○ Large (typically large carrier hub: >15 million passengers)
  - ○ Medium (Low-cost carriers have significant presence: 6 – 15 million passengers)
  - ○ Small (Local or touristic travel: <6 million passengers)
- → EUROCONTROL flight database consulted for Instrumental Flight Regime data (IFR)
  - ○ Visual Flight Regime (VFR) also checked to ensure they didn't significantly contribute to flight movements
  - ○ Piston flights also checked to ensure they didn't significantly contribute to flight movements
- → nvPM data assessed for different engine technologies using available or assumed data
  - ○ FOCA database consulted
  - ○ If no data available, data for same engine family or technology type scaled
  - ○ Total LTO cycle nvPM data calculated for mass and number
- → Most 'representative' non-regulated engines proposed for measurement
  - ○ 'total movement' & 'total LTO nvPM' considered

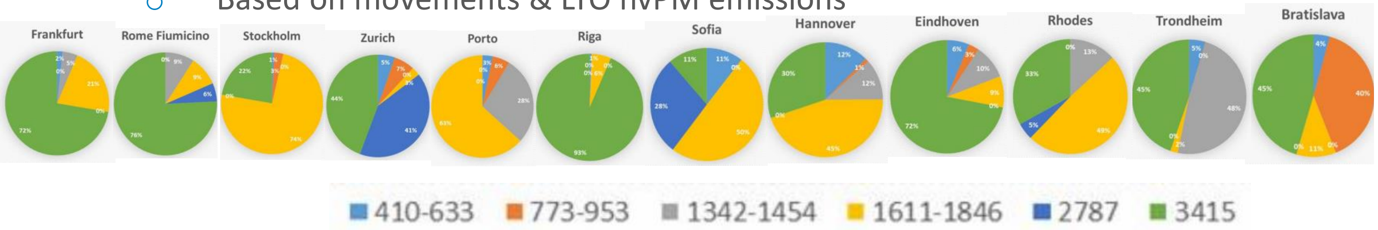
4: Impact assessment of nvPM emissions from non-regulated engines

(https://www.easa.europa.eu/en/downloads/138846/en)

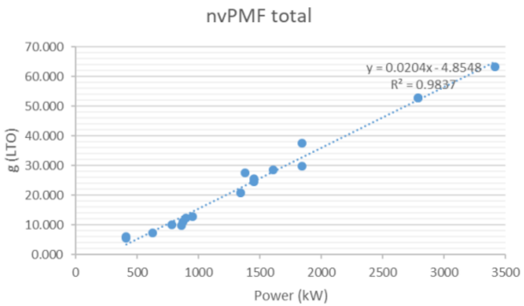
Findings

- → Intermediate week June 2019: representative of annual air traffic
- → Turboprops found to be most prevalent non-regulated propulsion engine
  - ○ Particularly airports with high domestic/local travel (e.g., Stockholm, Riga, Trondheim)
- → Non-regulated turbojets not as prevalent
  - ○ HW TFE731 indicated as most 'representative' non-regulated turbojet
- → APU emissions: difficult to accurately assess the LTO nvPM contribution
  - ○ Uncertainty over specific usage in airports by different carriers
  - ○ Limited APU nvPM data in literature
  - ○ ICAO LAQ design manual 'general approach' used to model
  - ○ P&W APS3200 and HW GTCP 131 indicated as most prevalent APU engines
- → PW100 family turboprop (e.g., PW127 or PW150) indicated as most 'representative' non-regulated propulsion engine to measure
  - ○ Based on movements & LTO nvPM emissions

Airport (ICAO code)	Regulated jets	Non-regulated jets	Turboprops	Piston	APU
Frankfurt (EDDF)	11,479	108	104	1	5,304
Rome (LIRF)	6,618	2	38	0	3,292
Zurich (LSZH)	5,232	330	194	18	2,573
Stockholm (ESSA)	4,558	78	532	0	2,313
Porto (LPPR)	2,000	52	22	0	985
Riga (EVRA)	1,296	32	556	0	874
Sofia (LBSF)	1,132	26	112	3	551
Hannover (EDDV)	1,224	80	86	20	616
Eindhoven (EHEH)	904	12	28	4	208
Rodhes (LGRP)	1,220	16	72	0	606
Trondheim (ENVA)	758	22	360	7	527
Bratislava (LZIB)	428	68	28	4	208
TOTAL	**36,849**	**826**	**2,132**	**57**	**18,057**



Total nvPM mass percentage per Turboprop engine power range (kW)



5: Small and non-regulated engine emission tests

(https://www.easa.europa.eu/en/downloads/141734/en)

Aims

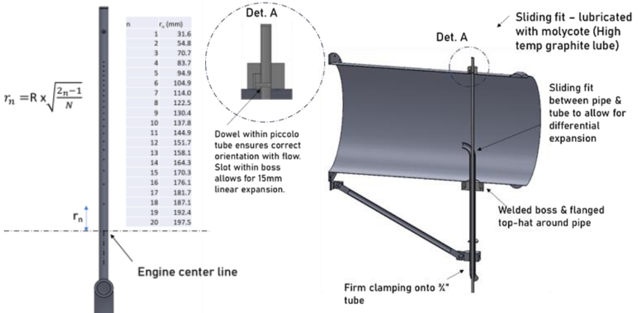
→ Expanding the aircraft engine emissions database for:
- Small ‘legacy’ engines that do not have nvPM data available in the ICAO databank
- A non-regulated turboprop engine (as recommended in D4)

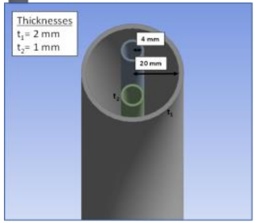
→ Compare small & non-regulated nvPM data with nvPM mass and number regulatory limits.
- ICAO reference LTO cycle (CAEP/11),
- maximum nvPM mass concentration (CAEP/10), as defined for regulated engines

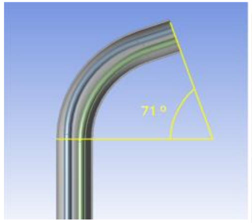
Approach

→ Three engine test campaigns performed:
- Honeywell ALF 502-R5 and 507-1H testing at Hawarden airport (UK) with EUR reference system – September 2023
- Hawarden Test done in conjunction with a NERC (UK) funded campaign – funded extra fuels & additional test hours
- Pratt & Whitney PW127G at INTA with simplified sampling and measurement approach – October 2024

→ Dedicated probe designs for SAMPLEIV engine tests
- Allowing near-field measurements







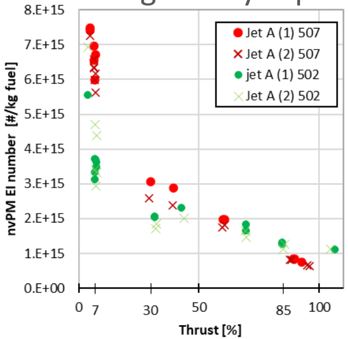
→ Contemporary Swiss non-regulated data also assessed
- Honeywell TFE731-60, FJ44-4 & PW545A

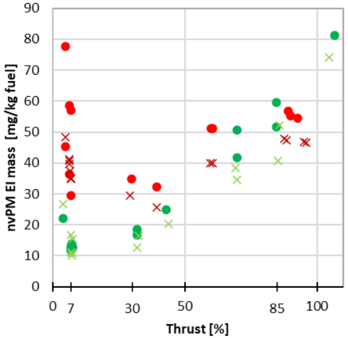
EASA SAMPLE IV

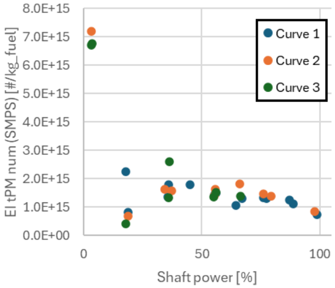
Findings

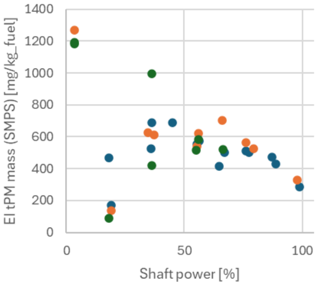
- → ALF502/LF507 (~ 31 kN):
  - ○ Full “regulatory” gaseous (EI HC, EI CO, EI NOx, CO_2), smoke and nvPM emissions for 2 jet A fuels
  - ○ Additional PSD, ‘novel’ and SAF measurements (D3 & D7)
- → PW127G (2130 SHP ~ 13 kN?) :
  - ○ nvPM, tPM, PSD and CO_2
  - ○ regulatory-equivalent PM EIs derived from CPC & SMPS’s

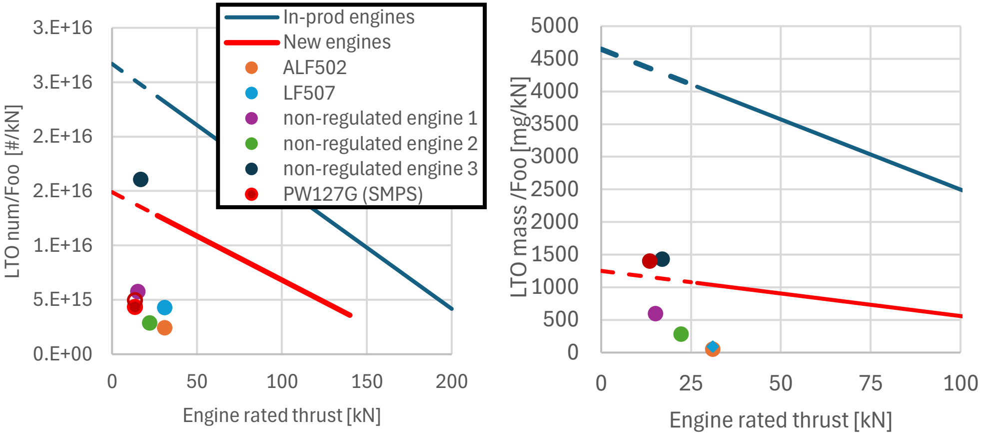
Picture of theLF507/ALF502 test stand (left) and PW127G (Airbus C-295) test probe











nvPM number (left) and mass (right) emitted during the reference LTO for various small and unregulated engines

Conclusions: non-regulated and small engine emissions

- → Non-regulated propulsion engines prevalent at airports serving regional flights
- → Regulated engines dominate all airports in terms of movements and nvPM
- → Non-regulated engines at airports in this study mostly Turboprop
  - PW100 family appearing to have most contribution to movements
  - PW127 and PW150 suggested as most ‘representative’ for measurement
- → No standardised equivalent LTO points for Turboprop, Turboshafts or APU
  - Direct comparison of non-regulated engines to regulatory nvPM limits needs use of assumptions
- → APU hard to assess overall nvPM impact
  - Further emissions data from APU likely useful (P&W APS3200 and HW GTCP 131)
- → Small & non-regulated engines measured exhibit:
  - nvPM EIs within ICAO in-production limits
  - Large variation in nvPM concentrations and sizes (useful for understanding impact of loss correction)
  - Engine tests provided cost effective data to inform D3 & D7

EASA SAMPLE IV

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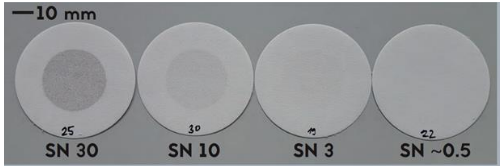
6: Refining Methodologies for Estimating nvPM from Smoke Number

(https://www.easa.europa.eu/en/downloads/140470/en)



Aims

- → Refine methods for estimating non-volatile PM (nvPM) mass and number from legacy Smoke Number (SN) data
- → Evaluate and improve current standard approaches (FOA4, SCOPE11) so that small/non-regulated engines (<26.7 kN thrust) continue to have accurate nvPM estimates
- → Investigate direct correlations between SN and both nvPM mass and number

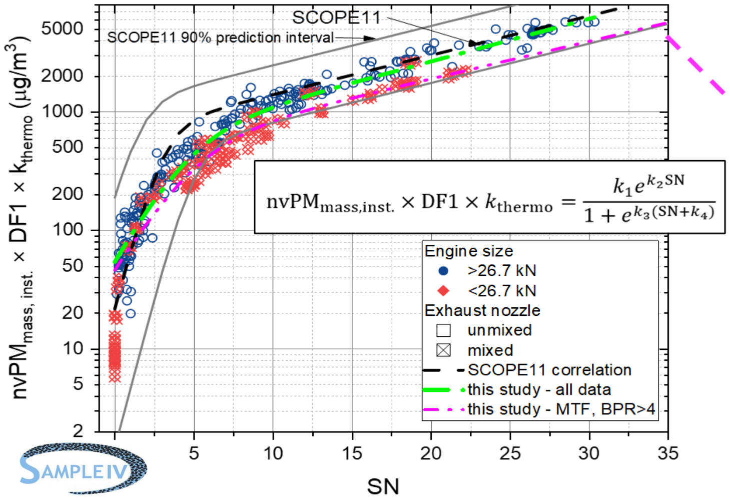
Approach

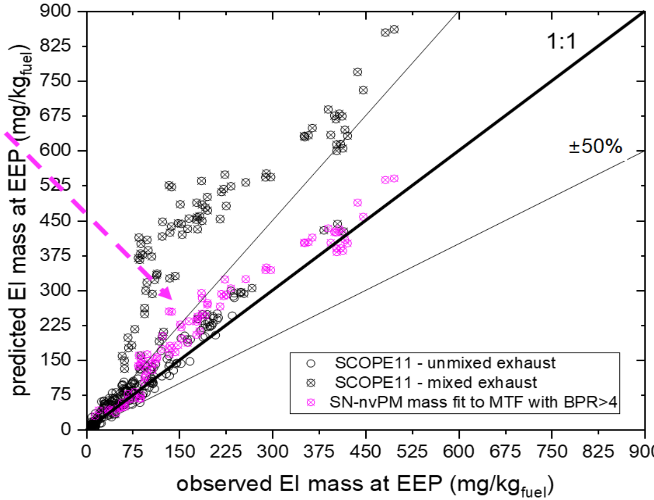
- → Gathered 380 SN–nvPM data pairs from 12 turbofan engine types, including 3 non-regulated (<26.7 kN)
- → Used standardised Swiss (CH) and European (EUR) nvPM measurement systems
- → Compared SCOPE11 and FOA4 correlation methods; proposed updated fits for nvPM mass (especially for mixed-flow turbofans)
- → Examined particle size distributions to refine mass → number conversion

6: Refining Methodologies for Estimating nvPM from Smoke Number

Findings

- → **SN–nvPM Mass Link:** SN correlates strongly with nvPM mass, but high-bypass mixed-flow engines exhibited a distinctly lower mass for a given SN (effect of PSD on filtration efficiency for SN measurement)
- → **Good Mass Estimates:** Adjusted SCOPE11 parameters capture nvPM mass emission indices accurately (mostly within ±50%) once engine type (mixed Vs. unmixed nozzle) is accounted for
- → **Number Uncertainty:** Converting nvPM mass to number remains more uncertain; neither standard method (FOA4 nor SCOPE11) consistently captures wide variations in particle size distributions
- → **Non-regulated Engines:** Interpolating standard ICAO AFRs at different power settings works well even for small engines (<26.7 kN); However, applying unmodified SCOPE11 can overestimate nvPM mass for high-bypass, mixed-flow engines
- → **Potential Improvement:** Direct SN–EI mass correlations (for mixed Vs. unmixed) can simplify mass prediction; For EI number, incorporating updated particle-size data (e.g., variable GMD, lower effective density) improves, but does not fully resolve, the high variability.





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EASA SAMPLE IV

7: Report on ICAO fuel specifications and corrections – nvPM emissions

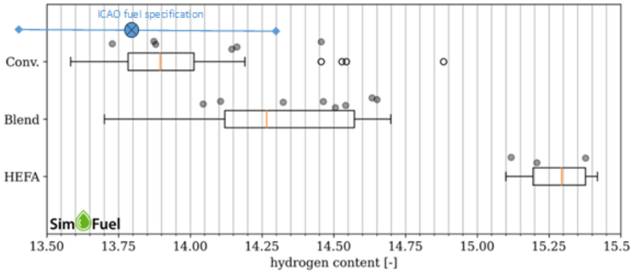
(https://www.easa.europa.eu/en/downloads/141735/en)

Aims

- → Assess the effects of different blending ratios of Jet A-1 with SBC (synthetic blending component) on emission levels
- → Assessment of current ICAO fuel correction method and potential limitations or improvements
  - ○ Understand uncertainty in Fuel Hydrogen Content (FHC) analysis methods
  - ○ Aligned with D5: Collect new data concerning the impact of fuel composition on regulated nvPM for small engines

Approach

- → Literature review of ASTM & ICAO fuel specifications
  - ○ ICAO cert. fuel FHC specified as 13-4 -14.3 (% mass), 13.8% 'standard' FHC for correction
  - ○ Conventional 'fossil' Jet A-1 fuels typical FHC 13.6 – 14.2 (% mass)
- → Review of nvPM fuel correction methods proposed in the literature
- → Data analysis of FHC methods for 23 fossil and SAF fuel blends
  - ○ Inter and intra laboratory FHC comparisons undertaken
  - ○ Many FHC methods considered (GCxGC, ASTM D3343, ASTM D5291 & ASTM D7171)
- → Empirical nvPM reductions for range of engines burning SAF & Jet-A1 blends compared to ICAO predicted reductions
  - ○ New data for LF507 & ALF 502 (31kN)
  - ○ Analysis of preexisting data (PW545A (17kN), CFM56-7B26 (117kN) Trent 500 (249kN))



Modified from Gierens et al (2024) Concawe report e-space

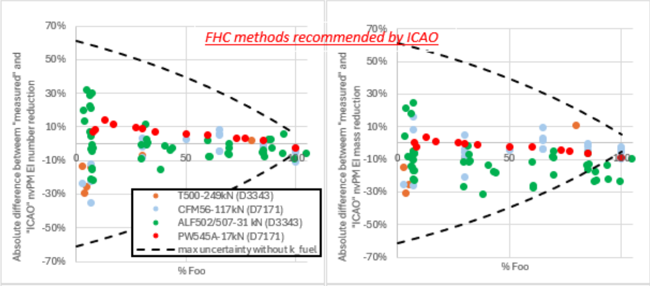
ID	Fuel blend	GCxGC MS	ASTM D3343	ASTM D5291 (not recommended by ICAO)	ASTM D7171	Data confidence info
1	100% Jet A-1	13.97	13.64	13.21		same lab, same sample
2	100% Jet A-1	14.17	13.88			same lab, same sample
3	100% Jet A-1	14.11	13.78			same lab, same sample
4	100% Jet A-1	14.3	14.03			same lab, same sample
5	50% SBC 50% Jet A-1	14.72	14.54			same lab, same sample
6	30% SBC 70% Jet A-1	14.48	14.27			same lab, same sample
7	100% SBC	15.17	15.27	14.92		same lab, same sample
8	100% Jet A-1	14.06		13.99	14.02	different labs, same sample
9	100% Jet A-1			12.69	13.68	different labs, same sample
10	100% Jet A-1			13.72	12.86	different labs, same sample
11	100% Jet A-1	13.72	13.61	13.01	13.65	different labs, same sample
12	100% Jet A-1	14.17	13.95	12.91	14.08	different labs, same sample
13	100% Jet A-1	14.10	13.98	14.60	14.04	different labs, same sample
14	100% Jet A-1			14.06	14.43	different labs, same sample
15	100% Jet A-1		13.75	13.8		different labs, same sample
16	30% SBC 70% Jet A-1	13.53			13.60	different labs, same sample
17	30% SBC 70% Jet A-1	14.54	14.47	14.23	14.51	different labs, same sample
18	30% SBC 70% Jet A-1	14.71		14.58		different labs, same sample
19	49% SBC 51% Jet A-1	14.45	14.46	13.82	14.40	different labs, same sample
20	50% SBC 50% Jet A-1		14.53	14.5		different labs, same sample
21	100% SBC	15.24		15.36	15.31	different labs, same sample
22	100% SBC	15.47		15.5		different labs, same sample
23	100% SBC	15.36	15.41			same lab, D3343 fuel tank sample, GCGC engine sample

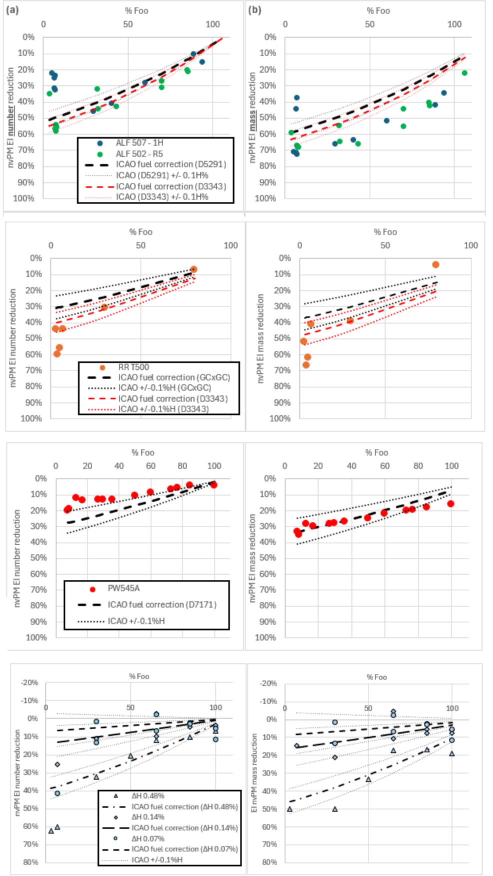
7: Report on ICAO fuel specifications and corrections – nvPM emissions

(https://www.easa.europa.eu/en/downloads/141735/en)

Findings

- → FHC correlates strongly with nvPM emissions
- → Difficult to reach a high degree of confidence
  - ○ Large variation observed in FHC methods
  - ○ Variation in measured nvPM emission indices
  - ○ Hard to match engine conditions, particularly at low power where correction is highest
- → ICAO fuel nvPM correction performed relatively well across engines tested (17 - 249 kN) with FHC's up to 14.5%
  - ○ predicted nvPM EI reduction agreement ±20% of measured (>7% thrust)
  - ○ predicted nvPM EI reduction agreement ±40% (≤7% thrust)
  - ○ overall average around the 1:1 line





Conclusions: nvPM SN correlations & fuel corrections

SCOPE11 SN to nvPM mass (essential for legacy and non-regulated engines environment impact)

- → Unmixed engine exhaust – SCOPE 11 provides accurate prediction
- → Mixed engine exhaust – SCOPE 11 tends to overestimate emissions
  - → Critical for non-regulated engines that tend to be mixed engine exhaust
- → Proposed improvements may reduce prediction uncertainty
  - Engine-specific adjustments for Mixed engines with high bypass ratios
  - Alternative approaches: direct SN-EI correlations and updated particle size distribution parameters
- → ICAO fuel composition (hydrogen) nvPM correction performs reasonably well for 17–249 kN engines, with nvPM EI reductions predicted within:
  - ±20% >7% thrust
  - ±40% at ≤7% thrust
- → Uncertainties due to FHC & nvPM measurement, engine power repeatability at low thrust and potentially engine type
- → Proposed improvements to fuel correction to reduce uncertainty:
  - → Move ICAO FHC limits to better align with current and future fuels and ensures practical certification fuel supply
  - → Reducing uncertainty in FHC determination
    - Develop standardised methods for high-reproducibility fuel analysis, such as GCxGC or high-resolution NMR

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Benefits from the project, planned follow-up activities

This project is funded by the European Union's Horizon 2020 Programme

Benefits – SAE E31

SAE documents:

- Experimental data presented to SAE E31 helped to revise SAE ARP6320B for T_1 definition, heating strategies and cyclone cleaning recommendations
- Led revision of SAE AIR6504A to include methodology to use PSD measurements for particle loss factor estimation - to try and reduce uncertainty in particle loss correction (currently used for airport emissions inventory calculations Doc 9889)
  - AIR specifically references new Journal paper (42 engines) https://doi.org/10.1016/j.jaerosci.2023.106140
- Led drafting of new SAE AIR7382 referencing SAMPLEIV experimental data reports

Knowledge development:

- Historical nvPM system approaches captured - may be referenced in a revised SAE AIR6241
- Optimised concept solutions - Novel White Paper (to CAEP WG3)?
- Investigation of laboratory nvPM sources
  - more robust in-field checks/ calibration protocols
- Improved VPR & CPC Calibration protocols
  - Linearity factor compulsory usage and reduced change allowance
  - Further standardise calibration protocols (e.g. aerosol type & conditioning, measurement strategy, etc)

Benefits – ICAO CAEP

CAEP/13

- Informed revision of A16V2 (agreed in CAEP/13, now in editorial period)
  - T_1 definition
  - Cyclone cleaning recommendations
- Multiple presentations to WG3 (CAEP/13)

CAEP/14

- Fuel tasks now added for consideration in CAEP/14
  - Findings of D7 to be presented to WG3
- nvPM measurement tasks (to reduce uncertainty) now added for consideration in CAEP/14
  - Use of PSD measurements for nvPM loss correction
  - Potential uncertainty improvements of existing measurement system/calibration
- Doc9889 – airport air quality manual SN correlations to nvPM
  - Airport drive to zero emissions – APU data required

Future Work

- Additional nvPM emissions data
  - Non-regulated engines (e.g. APUs)
  - Contemporary technologies (lean burn, advanced rich burn, etc)
- Change in ICAO certification fuel specs
  - Highly reproducible FHC determination is important
  - Improved fuel nvPM correction methods
- Loss-corrected nvPM EI regulatory standards
  - Better control of real-world emissions
  - More accurate comparison of technologies and power conditions, with less FHC impact
- Consideration of total PM (tPM) emission measurements
  - Volatile engine exhaust emissions
  - Oil breather contribution

Validation needs

- Existing nvPM sampling, measurement and calibration
  - Further uncertainty reduction
    - Calibration methods, PSD measurements
    - Particle loss in probes, Splitter1, Diluter1
    - sample representativeness
- ‘novel’ nvPM sampling, measurement and calibration
  - Potential regulatory nvPM replacement
  - SN replacement for non-regulated (<26.7 kN) turbofans
- Combustor rig nvPM sampling

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Questions and answers

Question and Answers

→ For sending questions and comments, please use the slido app, which is also accessible through WebEx:

- www.slido.com
- event code: 2640026

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Concluding Remarks

This project is funded by the European Union's Horizon 2020 Programme

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Thank you for joining this webinar!

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