U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: AC34-1C FUEL VENTING AND EXHAUST EMISSION REQUIREMENTS FOR TURBINE ENGINE POWERED AIRPLANES

Date: 05/09/2024

Initiated By: AEE-300

AC No: 34-1C

This advisory circular (AC) contains information and provides guidance on the implementation of the fuel venting and exhaust emissions requirements for turbine engine powered airplanes that are required by Title 14 of the Code of Federal Regulations (14 CFR) part 34.

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Subject: 14 CFR Part 34 - FUEL VENTING AND EXHAUST EMISSION REQUIREMENTS FOR TURBINE ENGINE POWERED AIRPLANES

Date: 04/24/2024

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1. Purpose

AC34-1C contains information and guidance concerning the regulations for fuel venting and exhaust emission requirements for turbine engine powered airplanes found in 14 CFR part 34 (hereinafter referred to as part 34). Part 34 is complex in that it reflects the following requirements:

- Sections 231-233 of the Clean Air Act (CAA) Title II, Part B: Aircraft Emission Standards, 42 USC 7571-7573;
- 40 CFR part 1031: Control of Air Pollution from Aircraft Engines;
- 14 CFR part 45: Identification and Registration Marking; and
- International Civil Aviation Organization (ICAO) International Standards and Recommended Practices, Annex 16, Volume II, Aircraft Engine Emissions Fourth Edition, July 2017, including Amendment 10 of January 1, 2021 (hereinafter referred to as A16V2)

This AC provides guidance to individuals and agencies seeking to understand and implement the fuel venting, smoke, gaseous, and non-volatile particulate matter (nvPM) engine exhaust emission requirements for turbine engine powered airplanes as specified by part 34. This AC supersedes AC34-1B, which has been cancelled. AC34-1C provides material on new nvPM requirements adopted in part 34 to include the following:

- 2023 nvPM engine emission standards
  - Applicability of nvPM or smoke
  - Updated test procedures used to demonstrate compliance and determine maximum nvPM emissions throughout the thrust range;
- Required confidence interval calculations for nvPM emissions
- Updates to regulatory smoke number – applicability to engines greater than vs less than 26.7 kN and supersonic transport engines (Class TSS); and
- Updating references to the regulations of the Environmental Protection Agency (EPA) from 40 CFR Part 87 to 40 CFR Part 1031.

In addition, editorial changes have been made to the following:

- Differences between U.S. regulations and ICAO SARPs,
- Exemption process and associated Title 14 Sections,
- Description of the 2012 NOx regulations,
- Description of part 34 applicability to Unmanned Aircraft Systems (UASUASS), and
- Updates to information on test procedures incorporated by reference from A16V2.

1.1. Contents

The information contained in this document sets forth acceptable means, but not the only means, by which compliance may be shown with the requirements of part 34.

TABLE of CONTENTS

1.2. Establishment and Implementation of Aircraft Emissions Regulations

The United States is one of 193 signatory States to ICAO's Convention on International Civil Aviation, also known as the Chicago Convention. Under Article 12 of the Chicago Convention, each contracting State agrees to keep its own regulations uniform, to the greatest extent possible, with those established under the Chicago Convention. Domestically, under 49 U.S.C. § 40105(b)(A), the Secretary of Transportation and Administrator of the FAA are required to act consistently with obligations of the United States Government under an international agreement such as the Chicago Convention,

As part of ICAO's standard setting process regarding aviation emissions, the FAA leads the U.S. delegation with assistance from EPA. FAA, EPA, industry representatives, and foreign certification authorities all participated in a multi-year process that resulted in the nvPM standards adopted by the ICAO, which the EPA thereafter adopted in 40 CFR part 1031.

This rulemaking adopts the procedures necessary for the FAA to implement the regulatory standards and test requirements for nvPM emitted by aircraft engines adopted by the EPA under 42 U.S.C. § 7571 (§ 231 of the Act) (87 FR 72312, November 23, 2022) that were effective December 31, 2022.

Section 7571 of the CAA states the following:

> *(2)(A) The [EPA] Administrator shall, from time to time, issue proposed emission standards applicable to the emission of any air pollutant from any class or classes of aircraft engines which in his judgment causes, or contributes to, air pollution which may reasonably be anticipated to endanger public health or welfare.*
>
> *(B)(i) The [EPA] Administrator shall consult with the Administrator of the Federal Aviation Administration on aircraft engine emission standards.*
>
> *(ii) The [EPA] Administrator shall not change the aircraft engine emission standards if such change would significantly increase noise and adversely affect safety.*

The FAA is statutorily required (*see* 42 U.S.C. § 7572 (§ 232 of the Act)) to incorporate the EPA's nvPM emissions standard into its regulations (14 CFR part 34) and apply the EPA-designated test procedures that allow applicants to demonstrate compliance with the emissions standards at the time of engine airworthiness certification. The FAA has no authority to alter the standards or test requirements adopted by the EPA for engine emissions.

As a signatory to the Chicago Convention, the US must establish standards that have the highest practicable degree of uniformity to the ICAO Standards and Recommended Practices (SARPs) or file a difference. US federal agencies also consider impacts of regulatory actions under a variety of executive orders and other requirements.

To meet its obligations under the Chicago Convention, the U.S. Government considers the standards and recommended practices adopted by ICAO. The EPA, using its authority under the CAA, then adopts the same or similar aircraft engine emissions standards through the U.S. rulemaking process, with public notice and opportunity to comment, prior to their being adopted in 40 CFR part 1031, once final. The FAA then implements the EPA standards by enforcing them at the time of aircraft engine certification under part 34. Consequently, regulated entities and certification staff should be aware that there will be a time lag in the adoption of ICAO's new regulations in the U.S. as the two agencies take their required actions under the CAA. In the event there is a change to 40 CFR part 1031 that has yet to be adopted into part 34 at the time of engine certification, 40 CFR part 1031 is the applicable U.S. regulation.

1.3. Advisory Nature

The language in this document is intended to be permissive and advisory in nature, except when regulatory text is specifically cited. In addition, compliance methods are generally chosen by an applicant within the framework of the regulation as written. Terms such as "must" and "shall" are only used in this AC when directly referring to requirements defined in regulatory text (e.g., 14 CFR part 34). Nothing in the is AC may be interpreted as changing any regulation or its requirements, and does not authorize changes in, or deviations from, any regulatory requirement.

1.4. FAA and EPA Regulatory Citations

This AC uses citations from the FAA regulations in 14 CFR part 34, and a citation for the corresponding EPA regulation in 40 CFR part 1031, with the latter appearing in parenthesis and italics. For example, reference to the fuel venting requirements of 14 CFR 34.11 will appear with reference to the equivalent EPA regulations in 40 CFR part 1031 as "14 CFR 34.11 (*40 CFR 1031.30(b)*)."

1.5. Definitions and Abbreviations

Attachment 1 of this AC includes the definitions found in 14 CFR 341. Attachment 2 of this AC includes all abbreviations found in 14 CFR 34.2 and throughout this AC.

1.6. Incorporation by Reference

The engine emissions measurement and test procedures of ICAO A16V2, Appendices 1-7 have been incorporated by reference in subpart G of part 34. Incorporated material is considered part of U.S. regulatory requirements. Note: EPA has also incorporated, by reference, the measurement and test procedures of ICAO A16V2 into its regulations in 40 CFR 1031.210. The EPA has also incorporated Appendix 8 to Volume 2, which covers procedures for estimating nvPM system loss corrections. System loss correction data is required in EPA's annual production reports as specified in 40 CFR 1031.150(c)(6)(ii), (iii) and (v). Those reporting requirements are specific to EPA regulations; FAA's reporting requirements only pertain to the submission of emissions test reports, discussed in 6.2 of this AC.

1.7. Audience

The intended audience for this AC includes engine specialists and propulsion engineers from the FAA's Aircraft Certification Service (AIR) and aircraft certification branches, aircraft and aircraft engine industry specialists, aircraft certification applicants, Designated Engineering Representatives (DERs), Organization Designation Authorization (ODA) Unit Members (UMs), other certification authorities, airline customers, airport operators, the engineering and scientific communities, and other persons that are interested in the certification of aircraft engines for fuel venting, smoke, gaseous emissions, and nvPM.

1.8. Intent

The intent of this AC is to present the FAA's explanation of selected portions of the aircraft engine emissions regulations and certification requirements contained in part 34. This AC also presents some historical policies, examples, interpretations and further guidance that have been used in the aircraft engine certification process.

1.9. Technical Advancement

Since the introduction of aircraft engine emission regulations in the United States in 1973[1], acceptable means and procedures for emissions measurement, testing, data management, evaluation, and compliance reporting have advanced considerably. In seeking compliance with the certification requirements, applicants may submit (and may receive approval to use) engine-specific alternative and equivalent testing, measurement, and data reduction procedures that reflect these advances. Approval of such alternatives[2] is granted by the FAA's Office of Environment and Energy (AEE), at FAA Headquarters in Washington DC. For further information, see 6.1 of this AC.

1.10. FAA Certification Process

As a part of its certification responsibilities, the FAA reserves the right to observe aircraft engine emission tests[3], or the agency may delegate that responsibility to the engine manufacturer through a designee[4] or Organizational Designation Authorization[5] (ODA). Every applicant for an engine type certificate must comply with the emissions requirements of part 34[6].

More detailed information on the FAA's certification process and procedures may be found in FAA Order 8110.4C[7], Type Certification, and the FAA and Industry Guide to Product Certification, Third edition, May 2017.[8]

The FAA's Office of Environment and Energy (AEE) is responsible for answering any questions or approving any deviation from the requirements of part 34. Once an engine type certificate is issued, an OEM may elect to provide engine emissions certification data to AEE for review followed by submission of the data to ICAO's Aircraft Engine Emission Data Bank (EDB)[9].

2. Cancellation

Advisory Circular 34-1B Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes, dated June 27, 2003, is canceled.

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[1] 38 FR 19088, July 17, 1973

[2] Including variations from test fuel specifications in A16V2, Appendix 4

[3] 14 CFR § 34.3(p)

[4]See 14 CFR part 183, Representatives of the Administrator

[5] FAA Order 8100.15B, Organizational Designation Authorization Procedures

[6] 14 CFR § 33.1(b)

[7] https://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentid/15172

[8] https://www.faa.gov/aircraft/air_cert/design_approvals/media/CPI_guide.pdf

[9] https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank

3. References

(1) 42 USC Part B, §§ 7571-7573 Aircraft Emissions Standards
(2) 14 CFR part 1, §1.1 *General Definitions*
(3) 14 CFR part 21, §21.93 Classification of Changes in Type Design
(4) 14 CFR part 25, § 25.903 *Engines* and § ad its Appendices as follows: 25.951 *General*
(5) 14 CFR part 34, Fuel Venting and Exhaust Emission Requirements For Turbine Engine Powered Airplanes
(6) 14 CFR part 45, Identification and Registration Marking
(7) 40 CFR part 1031, Control of Air Pollution from Aircraft Engines (formerly 40 CFR part 87 prior to adoption of the nvPM regulations)
(8) 40 CFR part 87, Control of Air Pollution from Aircraft and Aircraft Engines (now reorganized under 40 CFR part 1031)
(9) FAA Order 8110.4C, Type Certification
(10) FAA Order 8100.15B, Organizational Designation Authorization (ODA) Procedures
(11) FAA and Industry Guide to Product Certification, Third edition, May 2017
(12) ICAO Aircraft and Emissions Databank (https://www.easa.europa.eu/easa-and-you/environment/icao-aircraft-engine-emissions-databank)
(13) ICAO, International Standards and Recommended Practices, Annex 16, Environmental Protection, Volume II, Aircraft Engine Emissions Fourth Edition, July 2017, and its revisions and appendices as follows: Volume 2 Amendment 10 of January 1, 2021, incorporated by reference in 14 CFR part 34 *(40 CFR part 1031);* Appendices 1, 2, 4 and 6 as applicable to smoke emissions; Appendices 1, 3, 4, and 6 as applicable to gaseous emissions, and Appendices 1, 4, 6, and 7 as applicable to nvPM emissions. Appendix 5 applies to gaseous emissions and smoke for afterburning engines.
(14) ICAO Annex 16 Volume II Environmental Technical Manual – Procedures for Emissions Certification of Aircraft Engines Second Edition, October 2017
(15) SAE--International Aerospace Recommended Practice (ARP() 1179D, Aircraft Gas Turbine Engine Exhaust Smoke Measurement, July 2011
(16) SAE-International ARP1256D , Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines, July 2011
(17) SAE-International ARP1533B, Procedure for the Analysis and Evaluation of Gaseous Emissions from Aircraft Engines, January 2013
(18) SAE-International ARP6320, Procedure for the Continuous Sampling and Measurement of Non-Volatile Particulate Matter Emissions from Aircraft Turbine Engines
(19) SAE-International ARP6481, Procedure for the Calculation of Sampling Line Penetration Functions and Line Loss Correction Factors

4. Differences Between ICAO Annex 16 Volume II and 14 CFR Part 34

4.1. U.S. Regulation of Turboprops for Fuel Venting and Smoke Number

The U.S. fuel venting regulations of 14 CFR 34.11 (*40 CFR 1031.30 (b)(iii)*) apply to all turboprop engines regardless of rated output (rO). That regulation prohibits the venting of liquid fuel after engine shutdown.

The smoke number limits in 34.21(e)(3) (*40 CFR 1031.40(a)*) apply to turboprop engines with a rO equal to or greater than 1,000 kilowatts (kW). The regulations specify a maximum SN limit of $187(rO)^{-0.168}$ across the full engine thrust range.

Annex 16 Volume 11 has no equivalent standards for fuel venting or smoke that apply to turboprop class engines. That Annex only applies to turbofan and turbojet class engines.

5. Sections 34.21, 34.23, 34.25 and 34.60 LTO Emissions and Maximum Emissions Throughout the Thrust Range

Pollutant limits found in part 34 (*40 CFR 1031*) apply to the "characteristic" test values for each pollutant. The characteristic value is calculated by following the requirements of A16V2, Appendix 6, where a factor, which depends on the number of engines tested, is applied to the emissions test results for each pollutant. If complete emissions test data is submitted from more than one engine, the characteristic value of a pollutant decreases with the application of the Appendix 6 factor corresponding to the higher number of test engines from which test data is obtained.

Regulatory limits in part 34 apply to the characteristic pollutant levels based on an LTO weighted test cycle for all gaseous emissions, nvPMmass and nvPMnum. For SN and $nvPM_{MC}$, the regulatory limit is based on the characteristic maximum value throughout the full thrust range. See Section 14 of this AC for further information on $nvPM_{MC}$. Applicability for each pollutant is summarized below:

Applicability of Characteristic LTO or Maximum Throughout the Thrust Range

Pollutant	SN	Gaseous Emissions of CO, HC, NOx	$nvPM_{MC}$	$nvPM_{mass}$	$nvPM_{num}$
Characteristic Emissions	Maximum, throughout the thrust range	LTO	Maximum, throughout the thrust range	LTO	LTO

LTO weighted test cycles for the various classes of engines are defined in 14 CFR 34.60 (f) (*40 CFR 1031.140(e)*) and are based on time in mode (TIM) and thrust settings (% rO) as follows:

LTO Test Cycles and Times in Mode

Mode	Class					
	TP		TF, T3, T8		TSS	
	TIM (min)	% of rO	TIM (min)	% of rO	TIM (min)	% of rO
Taxi/idle	26.0	7	26.0	7	26.0	5.8
Takeoff	0.5	100	0.7	100	1.2	100
Climb out	2.5	90	2.2	85	2.0	65
Descent	NA	NA	NA	NA	1.2	15
Approach	4.5	30	4.0	30	2.3	34

6. Part 34 Emissions Certification Test Plans and Test Reports

6.1. Part 34 Emissions Certification Test Plans

Prior to undertaking an emissions certification test, the applicant is expected to submit an emissions compliance test plan to the FAA that describes the method(s) by which the applicant proposes to show compliance with the emissions requirements. Approval of test plans and test reports may not be delegated to a designated engineering representative (DER) or Organization Delegation Authorization

(ODA) holder; test plans and reports must be approved by FAA certification staff. Approval of any equivalent test procedure must be done in accordance with § 34.60(e) and § 34.71(e)(2) which are discussed in 7.1 and 7.2 of this AC.

Emissions compliance test plans should include the following types of information:

a) *Introduction:* a description of the engine emissions certification basis, i.e., the applicable amendment of part 34.

b) *Engine description:* type, model number and specific details of the basic engine configuration to be certified;

c) *Engine emissions certification methodology:* test concepts, equivalent procedures, and technical procedures. Equivalent procedures may not be delegated and must be approved by FAA staff (see 7.2 of this AC on Special Test Procedures):

d) *Test description:* test methods that comply with the emissions regulations;

e) *Measurement system:* a description of measurement and sampling system components and procedures, including calibration procedures, that are intended to be used to demonstrate compliance with the emissions regulations; and

f) *Data evaluation procedures:* data evaluation and correction procedures to be used in compliance with the provisions of part 34:

6.2. Part 34 Emissions Certification Test Reports

Emissions Certification Test Reports should reflect compliance to engine emissions regulatory limits and other requirements in part 34. In accordance with 14 CFR § 21.20(b), type certification applicants must provide a statement certifying that the applicant has complied with the applicable requirements.

For engine type certification, applicants should include the required compliance statements in its emissions certification test reports and include the characteristic values for all gaseous and nvPM emissions.

Other information in emissions certification test reports that support the compliance statement of § 21.20 (b) may include the following:

Test Procedures

- Acknowledgement that the test procedures were conducted according to the emissions certification test plans and, the applicable requirements of part 34;
- Description of, or reference to, the applicable procedures that were followed, e.g.:
    - Emissions sampling probe, or rake, validation
    - Emissions test set-up and procedures
    - Test fuel specifications
    - Instrumentation
    - Calibration
    - Quality assurance and procedural checklists

Data

- Emissions test data results
- Method of data acquisition
- Required calculations
- Required corrections
- Any other data requested by FAA

Section 34.73(e) identifies the information to be included in an emissions test report, once nvPM emissions certification testing is complete.

Note:EPA has additional reporting requirements as specified in 40 CFR 1031.150, including nvPM loss corrections. This AC does not address those requirements, because the FAA does not collect or use that information.

7. Part 34 Subpart A - General Provisions

7.1. Section 34.3 General Requirements

Section 34.3(a):

In the United States the legal authority to establish and enforce aircraft engine emissions standards is done by two agencies. The CAA authorizes the EPA to establish aviation emission regulations (42 USC 7571) which it publishes in 40 CFR part 1031. Section 7572 of the CAA requires the FAA to enforce the standards adopted by the EPA at the time of aircraft certification, which the FAA publishes in 14 CFR part 3. EPA and FAA are required to consult with each other in the establishment and enforcement of aircraft engine emissions regulations. Within the FAA, the rulemaking to revise part 34, to set policy and to coordinate with the EPA are accomplished by the Office of Environment and Energy (AEE). AEE is assisted in the implementation of these actions by the Aircraft Certification Service (AIR). See 1.2 of this AC, Establishment and Implementation of Aircraft Emissions Regulations, for more discussion of the relationship between the FAA and EPA and the adoption of regulations to conform to ICAO SARPs.

Section 34.3(i) and (j):

Both 14 CFR part 34 and 40 CFR part 1031 provide for alternative (or “special”) test procedures; such procedures must be approved in advance of engine emissions testing. See 7.2 of this AC on § 34.5, Special Test Procedures, for further guidance.

Section 34.3(k):

Wherever 40 CFR part 1031 requires agreement, acceptance, or approval by the Administrator of the EPA, part 34 requires a showing that such agreement or approval has been obtained.

Manufacturers that seek agreement, acceptance, or approval by the Administrator of the EPA are requested to coordinate with AEE, in advance of certification testing, which will coordinate with EPA’s Designated Program Officer. Agreements, acceptance, or approval must be signed off by both EPA’s Designated Program Officer and AEE and should be added to emissions certification test plans and reports. Agreements, acceptance, or approvals apply to specific, individual emissions test programs and are not to be considered applicable to other test programs.

7.2. Section 34.5 Special Test Procedures

A manufacturer or operator of aircraft or aircraft engines may submit a written request to use special (or alternative) test procedures. Any procedures that deviate from the test procedures specified in A16V2 Appendices 1 through 7 for the measurement and calculation of smoke number, gaseous or nvPM emissions (i.e. “special test procedures”) must be approved by the FAA prior to the engine test.

Manufacturers and operators may request approval of special test procedures by submitting their written request, with supporting justification, to the FAA Office of Environment and Energy. The FAA will coordinate with EPA’s Designated Program Officer for approval, as required by statute or regulation.

Sections 34.60(e) and 34.71(e)(2) specify that, for special test procedures to be approved, one of the following conditions must be met:

(1) The engine cannot be tested using the procedures specified in a regulation; or

(2) The proposed alternative procedure is shown to be equivalent to, or more accurate or precise than, the specified procedure.

Examples of special test procedures include those for fuel composition, probe material, probe design or performance, or required calculations:

Applicants are advised to submit requests for special test procedures as early in the process as possible. The review and approval process by the FAA and EPA can be lengthy, and approval as submitted is not guaranteed. Any approval of special test procedures should be documented by the applicant in its certification test plans and test reports.

Procedures that deviate from the regulatory test and measurement procedures that are not approved prior to their use may require that an engine be retested.

Note: The EPA requires the reporting of nvPM data for loss corrections in 40 CFR 1031.150(c)(6)(ii)(f) and (v). The procedures for calculating loss corrections are found in A16V2, Appendix 8, Procedures for estimating non-volatile particulate matter system loss corrections.

7.3. Section 34.7 Exemptions

Petitioners for exemptions from any emissions regulation or test procedure of 14 CFR part 34 are encouraged to contact AEE prior to filing exemption requests. The FAA has the authority to grant exemptions from its regulations when doing so has been determined to be in the public interest. Exemption requests should consider other requirements such as those found in 14 CFR parts 21, 25, 33 45, 91.203(d) where those parts require compliance with part 34. Exemptions are normally time-limited and require the applicant to achieve compliance to the exempted regulation at a future date.

Petitions for exemption from part 34 are subject to the rulemaking procedures of 14 CFR part 11. Information required in a petition for exemption includes that specified in §11.81 and 40 CFR 1031.15 when consultation with the EPA is required. Petitions for exemption may be filed in electronic or hardcopy format following the instructions of §11.63.

For all part 34 exemption requests, denials, or grants, AEE will be the responsible FAA office and will coordinate with EPA's Designated Program Officer and other FAA offices, as needed.

Temporary exemptions based on flights for short durations at infrequent intervals under 14 CFR 34.7(a) (*40 CFR 1031.15(b)*) require only FAA written approval to be effective.

Additional data on exempted engines is required in EPA annual production reports, as specified in 40 CFR 1031.150(d).

7.4. Section 34.9 Exceptions

The regulations for spare engines contain an exception, as specified in §34.1, Definitions, and §34.9, Exceptions (*40 CFR 1031.20, Exceptions*).

Newly manufactured spare engines may only be installed on in-service aircraft to replace an existing engine and must be identical to a sub-model previously certificated for that aircraft. Newly manufactured, spare engines must meet Tier 4 regulations, or cleaner. An excepted spare engine must be certificated as having equal or lower regulated emissions than the engine it replaces. No written approval is needed from FAA to produce spare engines meeting these requirements. Records for excepted spare engines must indicate that the engine was produced as an excepted spare engine.

Excepted spare engines must be labelled as "EXCEPTED SPARE" as specified by 14 CFR 45.13 and manufacturers must provide annual reports to EPA for excepted spare engines for each engine model and engine sub-model, with the information specified in 40 CFR 1031.150(d). As specified in 40 CFR part 1031, "Engine manufacturers must submit an annual production report for each calendar year in which they produce any engines subject to emission standards under [part 1031]." These reports are due to the Designated EPA Program Officer by February 28 of the following calendar year. The information that is required for the report is specified in 40 CFR 1031.150.

Part 34 contains no other exceptions to the emissions regulations. Manufacturers seeking relief from any other emissions regulation must follow the regulations and guidance specified for exemptions.

8. Part 34 Subpart B - Engine Fuel Venting Emissions (New and In-Use Aircraft Gas Turbine Engines)

8.1. Section 34.10 Applicability

The following table provides a summary of engine classes to which the fuel venting regulations apply.

Engine Fuel Venting Emissions

(new and in-use aircraft gas turbine engines)

Engine Class	Effective Date
T3, T8, TSS, TF ≥ 36 kN	All new aircraft gas turbine engines manufactured on or after January 1, 1974
T3, T8, TSS, TF ≥ 36 kN	All in-use aircraft gas turbine engines manufactured after February 1, 1974
TF < 36 kN, TP	All new and in-use aircraft gas turbine engines manufactured on or after January 1, 1975

8.2. Section 34.11 Regulations for Fuel Venting Emissions

Aircraft gas turbine engine fuel systems operate in a pressurized condition, which may be relieved by various fuel system design features after engines are shut down. Raw, liquid fuel that drains uncontained or drips onto hot internal engine parts after shutting down may result in the discharge of fuel vapor into the atmosphere, adding to the local air pollution burden.

14 CFR 34.11(a) states the following:

> *"No liquid fuel venting emissions shall be discharged into the atmosphere from any new or in-use aircraft gas turbine engine subject to this subpart." This paragraph is directed at the elimination of intentional discharge to the atmosphere of fuel drained from fuel nozzle manifolds after engines are shut down and does not apply to normal fuel seepage from shaft seals, joints and fittings."*

40 CFR 1031.30(b)(2) has equivalent, but not identical language:

> *"Engines may not discharge liquid fuel emissions into the atmosphere. This standard is directed at eliminating intentional discharge of liquid fuel drained from fuel nozzle manifolds after engines are shut down and does not apply to normal fuel seepage from shaft seals, joints, and fittings.*

Certification for the fuel venting standard will be based on an inspection of the method designed to eliminate these emissions."

ICAO's Annex 16 Volume II Environmental Technical Manual, hereafter referred to as "ETMV2", Part II, Chapter 2 provides the following explanatory information for engine shutdown:

General:

The process of engine shutdown, following normal flight or ground operations, begins with the cut-off of fuel flow from the fuel control unit, and continues until a time when the design features of the engine and/or aircraft stop this flow. The engine and/or aircraft are required to be designed in such a way that this fuel cannot be discharged into the atmosphere.

Engine Shutdown process:

The process of engine shutdown is described as follows.

"The engine shutdown process begins when fuel cut-off is commanded by the pilot. Once fuel flow to the engine is cut-off, a process begins leading to engine shutdown. The amount of time for this process to take place is dependent upon the design features of the engine. As a generic description, this process involves the simultaneous movement of the liquid fuel that resides within the engine (whether from pressure and/or gravitational forces), into the combustion chamber, and/or settling in areas of the engine of lower potential energy (e.g., to a drain tank). The process may also include valves closing to prevent fuel flow into the combustor from the fuel manifold system, as well as trying to prevent residual fuel from vaporizing after engine shutdown. Any residual fuel that drains into the combustion chamber during engine shutdown is expected to be combusted, as the chamber remains at a high enough temperature to combust the fuel. Once the combustor temperature has cooled, any remaining un-combusted fuel is expected to be held (e.g., fuel delivery system, ecology tank, etc.) and not susceptible to release to the atmosphere after engine shutdown."

14 CFR 34.11(c) states that the manufacturer or operator may show compliance with liquid fuel venting regulations using any engine design feature(s) that prevents the intentional discharge of fuel from fuel nozzle manifolds after engine shutdown. 14 CFR 34.11(c)(1)-(3) describes three acceptable design features that comply with engine fuel venting regulations:

(1) Incorporation of an FAA-approved system that recirculates the fuel back into the fuel system

Explanation: Some engine designs may use case drains or other mechanisms that collect residual fuel. The residual fuel is then directed back into aircraft-mounted tanks and recirculated back into the fuel system during the next engine operation.

(2) Capping or securing the pressurization and drain valve

Explanation: Systems may be designed with multiple valves, sometimes within each fuel injector, to relieve manifold pressure within the system and prevent the manifold from draining residual fuel onto hot combustor surfaces when the engine is shut down.

(3) Manually draining the fuel from a holding tank into a container.

Explanation: Older systems may be designed to purge fuel from the manifolds and into a separate tank by using residual engine air pressure from the combustor, gravity, or a combination of gravity and pressure. The tanks may then be emptied manually on a periodic basis.

Certification to fuel venting regulations at the part 33 engine level does not guarantee engines will pass fuel venting certification requirements at the part 25 aircraft level after engines are installed. For this reason, part 25 requires compliance at the part 33 level. Examples of difficulties with fuel venting requirements that arose at the part 25 certification level, after engines passed fuel venting requirements at the part 33 level, include the following:

Example: Heat Soak Effects

Engines installed on a part 25 certification test aircraft released small quantities of fuel after engine shut down due to fuel expansion in the fuel manifold caused by heat soak effects that would intermittently open a pressure release valve under certain conditions. The released fuel would vaporize on contact with hot surfaces inside the engine. This would result in visible fuel vapors being emitted from either the inlet or the exit plane of the engine for up to 30 minutes after engine shutdown.

Finding: The Clean Air Act mandates that FAA coordinate with EPA on non-compliance emission issues. In this instance, the EPA analyzed the environmental effects of fuel releases of this magnitude and determined that the effects were minimal. However, EPA emphasized that the fuel venting regulation should be interpreted to mean *zero liquid fuel release into the atmosphere*. EPA will not establish a minimum threshold for fuel venting or consider an alternative means of compliance. The FAA issued a time limited exemption to the part 25 certification on the basis that the part 34 certified engine fuel system be redesigned to eliminate the intermittent fuel release. The time limited exemption required the engine manufacturer to redesign the fuel system for both newly built engines and retroactively modify the existing engines within two years. The design of the new fuel system relieves back pressure to the fuel nozzles by allowing fuel expansion to take place within the system and collecting in a chamber and recirculating within the system in compliance with § 34.11(c)(1).

9. Part 34 Subparts C and D - Exhaust Emissions (New and In-Use Aircraft Gas Turbine Engines)

9.1. Sections 34.10, 34.21, 34.23, 34.25, and 34.31 Applicability Dates

The regulations in 14 CFR part 34 and 40 CFR part 1031 may apply to new types for which an application for certification will be made, newly manufactured engines under an existing type certificate, or engines that are currently in-use and include a subsequent compliance date such as “on or before” or “on and after” and, oftentimes, the class and rated output of the engine.

The applicability date for part 34 regulations is the date when the application for a type certificate for the engine is submitted to the FAA. Applications for design changes may also trigger the applicability of regulations which have been adopted subsequent to the original type certificate. For example, the new nvPM regulations may apply to engines for design changes that have not been previously certified to the nvPM regulations found in § 34.25 (see 9.5 of this AC).

9.2. Section 34.21(e) Smoke exhaust emissions

SN regulations in 14 CFR 34.21(a), (b), and (c), (e)(1)-(3); 34.23(a)(1); and 34.31(a) and (b) (*40 CFR 1031.60, 40 CFR 1031.40, and 40 CFR 1031.50*) apply to all engine classes; TF, T3, T8, TP and TSS; and are based on engine class, rated output (rO) and date of manufacture. A summary of the SN regulations is provided in the table below.

Smoke Number (SN) Regulations

Regulation 14 CFR / 40 CFR	Engine Class	rO	Manufacture Date	Characteristic Value NTE
34.21(e)(1)(A) / *40 CFR 1031.50(a)*	TF	< 26.7kN	On or after 08/09/1985	$83.6(rO)^{-0.274}$ or 50 max

			and before 07/18/2012	
34.21(e)(1)(B) / *40 CFR 1031.60*	TF, T3, T8	< 26.7 kN	On or after 07/18/2012 and before 01/01/2023	$83.6(rO)^{-0.274}$ or 50.0, whichever is smaller
34.21(e)(1)(C) / *40 CFR 1031.60*	TF, T3, T8	≤ 26.7 kN	On or after 01/01/2023	$83.6(rO)^{-0.274}$ or 50.0, whichever is smaller
34.21(e)(2) / *40 CFR 1031.60*	T3, T8, TSS, TF	≥ 26.7 kN	On or after 01/01/1984 and before 01/01/2023	$83.6(rO)^{-0.274}$ or 50 max
34.21(e)(3) / *40 CFR 1031.40*	TP	≥ 1,000 kW	On or after 01/01/1984	$187(rO)^{-0.168}$
34.21(e)(4) / *40 CFR 1031.90*	TSS	All	On or after 01/01/2023	$83.6(rO)^{-0.274}$ or 50 max

The United States has a smoke number regulation that applies to turboprop (Class TP) engines, while ICAO has no smoke number or other emission standards that apply to turboprop engines. The FAA has therefore filed a difference with ICAO regarding the U.S. turboprop SN regulation (see 4 of this AC, Differences Between ICAO Annex 16 Volume II and 14 CFR Part 34).

For all turbofan engines with a rO greater than 26.7kN that are manufactured on or after January 1, 2023, the smoke number regulations in 14 CFR 34.21 (*40 CFR 1031.60(a)*) will no longer apply and are being replaced by the non-volatile particulate matter (nvPM) regulation for those aircraft engines. See 9.5 of this AC for additional information on the nvPM standard. As illustrated on the chart above, the smoke number requirements continue to apply to engines not converting to the nvPM standard.

9.3. Section 34.21 and 34.23 Hydrocarbon (HC) and Carbon Monoxide (CO)

The HC and CO regulations in 14 CFR 34.21(d)(1)(i) and (ii) (*40 CFR 1031.60*) apply to TF, T3 and T8 engines with rO greater than 26.7 kN. HC and CO regulations are the following:

HC and CO Regulations for Class TF, T3 and T8 Engines with rO > 26.7 kN

14 CFR / 40 CFR	Pollutant	Manufacture Date	Characteristic Value NTE
34.21(d)(1)(i) / *40 CFR 1031.60*	HC	On or after 01/01/1984	19.6 g/kN rO
34.21(d)(1)(ii) / *40 CFR 1031.60*	CO	On or after 07/07/1997	118 g/kN rO

9.4. Section 34.21 and 34.23 Oxides of Nitrogen (NOx)

The NO_x regulations in 14 CFR 34.23 apply to Class TF, T3 and T8 engines manufactured on or after July 18, 2012. The regulatory limits are based on the date of production of the first individual model (type certification date), rated pressure ratio (rPR) and rated output (rO) of the engine.

“Tier 6” and “Tier 8” in the NO_x regulations corresponds to the ICAO Committee on Aviation Environmental Protection (CAEP) meeting number, CAEP/6 or CAEP/8 respectively, during which the NOx standards were adopted by ICAO.

In-production engines type certificated on or before December 31, 2013 must meet Tier 6 regulations in 14 CFR 34.23(a)(2) (*40 CFR 1031.60(e)(4)*). Tier 6 NO_x regulations are defined in 34.23(a)(2) (*40 CFR1031.60(e)(4)*)*.)*

All engines type certificated after December 31, 2013, must meet Tier 8 NO_x regulations in 14 CFR 34.23(b)(1) (*40 CFR 1031.60(e)(5)*). Tier 8 NOx regulations are defined in 34.23(b)(1) (*40 CFR1031.60(c)(5)i)*.

9.5. Section 34.25 Non-Volatile Particulate Emissions Standards (nvPM)

On or after 1 January 2023, nvPM regulations apply to all TF, T3 and T8 engines with greater than 26.7 kN thrust, replacing the SN regulations for these engines. Any change in type design for engines that do not qualify as derivative engines under § 34.48 must demonstrate compliance with nvPM requirements, as applicable.

The nvPM requirement adopted in § 34.25 are not meant to affect the SN requirements for engines of any class having a rated output of 26.7 kN or less, for turboprop engines (Class TP), or for supersonic engines (Class TSS).

For Class TF, T3, or T8 engines (regulated classes of large turbofan engines) with a rated output greater than 26.7 kN, this rule replaces the SN requirement with a measurement of a maximum nvPM mass concentration ($nvPM_{MC}$) limit in micrograms per cubic meter [$\mu g/m^3$]. This action maintains the standard that aircraft engine exhaust plumes remain invisible, which was the intent of the ICAO standards adopted in the United States by the EPA. When determining $nvPM_{MC}$, values must be obtained from measurements made across the entire thrust range of an engine. The characteristic level of the measured maximum $nvPM_{MC}$ value may not exceed the regulatory limit established using the formula in § 34.25.

The standards for $nvPM_{mass}$ and $nvPM_{num}$ apply to all subsonic turbofan and turbojet engines that have a rated output greater than 26.7 kN. The $nvPM_{mass}$ limit is the mass of emissions of nvPM expressed in milligrams (mg) divided by kN of rated thrust, as determined over the LTO cycle. The $nvPM_{num}$ limit is the number of particles divided by kN of rated thrust, as determined over the LTO cycle.

An engine for which an application for an original type certificate is submitted on or after January 1, 2023 is subject to the $nvPM_{mass}$ and $nvPM_{num}$ emission limits of § 34.25. An engine that was type certificated before January 1, 2023, for which an application for type design modification is submitted on or after January 1, 2023, is also subject to the $nvPM_{mass}$ and $nvPM_{num}$ emission limits of § 34.25. This date is consistent with the effective date of the EPA final rule that adopted these standards.

When nvPM standards are expressed as a formula, § 34.25 requires that $nvPM_{MC}$ be rounded to the nearest 1.0 µg/m3, that $nvPM_{mass}$ be rounded to the nearest 0.1 mg/kN, and that $nvPM_{num}$ be rounded to three significant figures.

The FAA is incorporating by reference into part 34 the nvPM test and measurement procedures of ICAO Annex 16, Volume II, Appendices 4, 6 and 7. The EPA incorporated these appendices and Appendix 8, which is not relevant to FAA regulations.[10] This incorporation by reference continues the FAA use of these procedures in part 34 to conform to accepted international standards.

9.6. Section 34.48 Emissions Test Requirements for Derivative Engines

14 CFR 34.48 specifies regulations to determine if design changes or cumulative design changes to derivative engines require retesting to determine new emissions characteristic levels. A derivative engine is defined in part 34 in terms of emissions certification and applies to modifications of already certificated engine types. Changes to a certificated engine which are considered major from an airworthiness perspective require an amendment or supplement to the Type Certificate. However, these same modifications may have no or very little effect on the emissions characteristics of that engine. Part 34 defines the limits to enable a determination of whether a modification can be classified as a "no emissions change" or if it would affect the emissions levels to such an extent that the modification to the engine type would need to be re-certificated to Annex 16, Volume II requirements. Of course, manufacturers may voluntarily apply for re-certification to the latest requirements at any time.

Section 34.48(a) states that a type certificate holder may request that the FAA determine if an engine configuration is considered a derivative engine for emissions certification purposes.

A derivative engine that has been derived from an original engine that was certificated to the requirements of part 33 does not have to be retested for emissions characteristics if it complies with one of the three criteria listed in § 34.48(a).

14 CFR 34.48(b)(2) requires that an applicant for a design change to an original certificated engine model (or any sub-models within the emission type certificate family tested for certification), must be retested to determine compliance with regulatory limits if any pollutant is at or above 95% of the applicable regulatory limit before modification to the derived model. If the characteristic levels of the original certificated engine model (and all other sub-models within the emission type certificate family tested for certification) are below 95% of the applicable limit for each pollutant, the applicant may use engineering analysis, consistent with good engineering judgment[11], to demonstrate that the derivative engine will not exceed applicable emissions limits for each pollutant. Applicants should submit substantiation of engineering analysis to AEE for approval if it is to be used in lieu of retesting.

The engineering analysis must address all modifications to the original engine including those approved for previous derivative engines. Analysis may consider areas such as cycle changes, combustor and fuel nozzle design, or large changes in combustor inlet velocity profile or turbine cooling flows. ETMV2, Part III, Chapter 2, 2.1.1. Paragraph 5 may be consulted for specific examples of design changes, including assessing design changes from an engineering analysis perspective such as for changes to engine cycles, combustor and fuel nozzles, and boundary conditions.

[10] Control of Air Pollution From Aircraft Engines: Emission Standards and Test Procedures quotes "The EPA is incorporating by reference Appendix 8 of Annex 16, Volume II, which outlines procedures used to estimate measurement system losses, which are a required element of the reporting provisions." page 72333 in FR Vol 87 No 225, November 23, 2022.

[11] Good engineering judgement means judgement that is consistent with generally accepted scientific and engineering principles and all available relevant information.

10. Sections 34.10 and 34.21 Supersonic Aircraft Engine Emissions Regulations

The fuel venting and gaseous emissions regulations are applicable to all engines intended for use on aircraft that operate at supersonic speeds, turbo supersonic class (TSS).

Regulations applicable to TSS class engines are the following:

TSS Emissions Regulations

14 CFR / 40 CFR	Pollutant	Manufacture Date	Characteristic Value NTE
34.10(a) / *1031.30(b)*	Fuel Venting	After 1/1/1975	No fuel venting after engine shutdown
34.21(d)(2) / *1031.90(c)*	HC	On or after 1/1/1984	$140(0.92)^{rPR}$ g/kN
34.21(e)(2) / *1031.90(a)*	SN	On or after 1/1/1984	$83.6(rO)^{-0.274}$ not to exceed 50
34.23(a)(4) / *1031.90(e)*	NOx	On or after 7/18/2012	36 + 2.42(rPR) g/kN
34.23(a)(4) / *1031.90(d)*	CO	On or after 7/18/2012	$4{,}550(rPR)^{-1.03}$ g/kN

11. Engine Emissions Regulations for Unmanned Aircraft Systems (UAS) / Advanced Air Mobility (AAM)

Engines for UAS/AAM that are defined as civil aircraft pursuant to 14 CFR 1.1 are subject to the same regulations as civil, manned aircraft under 14 CFR part 34. Therefore, if the civil UAS has a turbofan or turboprop engine, it is subject to the fuel venting requirements of 14 CFR 34.11 (*40 CFR 1031.30*). If the UAS has a turbofan engine with rated output greater than 26.7 kN, it is also subject to the SN, gaseous and nvPM emissions standards of 14 CFR 34.31 (*40 CFR 1031.30*), 14 CFR 34.21 (*40 CFR 1031.50*) and 14 CFR 34.23 (*40 CFR 1031.60*). If the UAS has a turboprop engine with thrust equal to or greater than 1,000 kW, it is subject to the smoke number requirements of 34.21(e)(3) (*40 CFR 1031.40*). None of the part 34 emissions requirements apply if the UAS/AAM has an electric or internal combustion engine.

12. Commercial Space Vehicle Emissions

Part 34 applies to turbofan and turboprop engines for aircraft. There are no emission regulations applicable to commercial space vehicles or the engines that power these vehicles at the time of this publication.

13. Part 34 Subpart G - Test Procedures for Engine Exhaust Gaseous Emissions (Aircraft and Aircraft Gas Turbine Engines)

13.1. Test Procedures Incorporated by Reference

The system and procedure for sampling and measurement of gaseous and SN emissions are specified in Appendices 2, 3, 4, 5 and 6 to the International Civil Aviation Organization (ICAO) Annex 16, Environmental Protection, Volume II, Aircraft Engine Emissions, Third Edition, July 2008.

13.2. Section 34.60 Introduction

14 CFR part 34 and 40 CFR part 1031.1 require that the systems and procedure for sampling and measurement of gaseous emissions are specified by the various appendices of A16V2. 14 CFR 34.60(g) and 40 CFR 1031.30(a)(3) both state that engines comply with an applicable standard if the engine family's characteristic level does not exceed the numerical level of that standard, as described in the applicable appendix of A16V2.

A16V2, Appendix 6, Compliance Procedure for Gaseous Emissions, Smoke and Particulate Matter Emissions, explains how to calculate characteristic emissions values (see 13.2.1 of this AC) to which the regulatory emissions limits apply.

13.2.1 of this AC further describes the calculation of characteristic engine emissions from measured data based on the number of actual engines tested and required curve fitting methods for determining maximum characteristic values for SN and nvPM.

13.2.1. Section 34.60(g) Calculation of Characteristic Emissions

14 CFR 34.60(g) states that, "engines comply with an applicable standard if the testing results show that the engine type certificate family's characteristic level does not exceed the numerical level of that standard…" This statement is written regarding the applicable emissions standard and the characteristic emissions for an engine that are calculated following the procedures of A16V2, Appendix 6.

The characteristic level is calculated by dividing the measured and corrected mean emissions levels for CO, HC, NOx, SN and nvPM values by the coefficients listed in A16V2, Appendix 6, Table A6-1, which is provided as Attachment 3 to this AC. The coefficients are determined by the actual number of engines tested (i), with a minimum of three data sets averaged for each pollutant.

For example, a single engine test (i = 1) may be used to certify an engine based on a minimum of three data sets for each pollutant. The measured and corrected mean emissions levels from three or more data sets for each pollutant are then divided by the coefficients from A16V2 Appendix 6, Table A6-1 (Attachment 3) for i = 1 to determine the characteristic emissions for the engine. The coefficients for i = 1 are 0.8147 for CO, 0.6493 for HC, 0.8627 for NOx, 0.7769 for SN, and 0.7769 for $nvPM_{MC}$ and 0.7194 for both $nvPM_{mass}$ and $nvPM_{num}$.

If three engines are tested (i = 3) with data from a minimum of one test for each pollutant from each engine, the measured and corrected mean emissions levels for each pollutant from ICAO A16V2 Appendix 6, Table A6-1 (Attachment 3) for i = 3 are divided by 0.9246 for CO, 0.8572 for HC, 0.9441 for NOx, 0.9091 for SN, 0.9091 for $nvPM_{mc}$,, and 0.8858 for both $nvPM_{mass}$ and $nvPM_{num}$.

Increasing the number of engines tested (i) reduces the reportable characteristic values for each pollutant by improving confidence in the averaged test data. The use of cycle deck data in lieu of an actual engine test to increase the value of engines tested (i) for calculating characteristic emissions is not permissible.

14. Part 34 Subpart H - Test Procedures and Compliance Demonstration for Non-Volatile Particulate Matter Emissions

Section 34.71 identifies the $nvPM_{MC}$, $nvPM_{mass}$ and $nvPM_{num}$ emissions test requirements applicable to Class TF, T3, or T8 engines manufactured on or after January 1, 2023, with rated output greater than 26.7 kN. The test procedures include the minimum number of emissions test runs required, the number of engines of the same type design that may be used to gather test data, and the operational conditions required for emissions certification (§§ 34.71 (b), (c), and (g)).

Section 34.71 also includes test fuel specifications (§ 37.71 (d)), a description of the LTO cycle (§ 34.71(h)), and how to prepare and operate an engine for emissions certification (§ 34.71 (f)). Section 34.71(i) states how characteristic values, in conjunction with Table A6-1 of Annex 16 Vol II, Appendix 6, are to be calculated.

Section 34.71(e)(1) includes an incorporation by reference of ICAO Annex 16, Volume II, Appendices 1, 4, 6 and 7 requiring that the tests and procedures in the applicable Appendices be used when measuring and collecting nvPM emissions data.

Section 34.71(e)(2) provides instructions to the applicant interested in requesting an alternative to any of the test procedures of subpart H. In advance of conducting engine emissions certification tests, the FAA expects that any such written request would be pertaining to a procedure that was included in the approved test plan but was discovered to be unworkable. Any proposed alternative test procedure must be equivalent to, or more accurate than, the procedures specified in Subpart H. The proposed alternative procedure must be approved by the FAA before any emissions test is conducted. The FAA will consult with the EPA prior to making a written determination on any requested alternative procedure.

14.1. Determining Maximum $nvPM_{MC}$ Values

The regulatory emissions levels for $nvPM_{MC}$ apply to the maximum values of $nvPM_{MC}$ throughout the entire thrust range of an engine, rather than the four LTO thrust settings as with gaseous emissions of HC, NOx, CO and $nvPM_{mass}$ and $nvPM_{num}$ (see 5 of this AC for a discussion of maximum vs LTO values). In either case, A16V2, Appendix 6 requires a minimum of three engine tests to be conducted, which may be on more than one engine, and the results averaged as explained below.

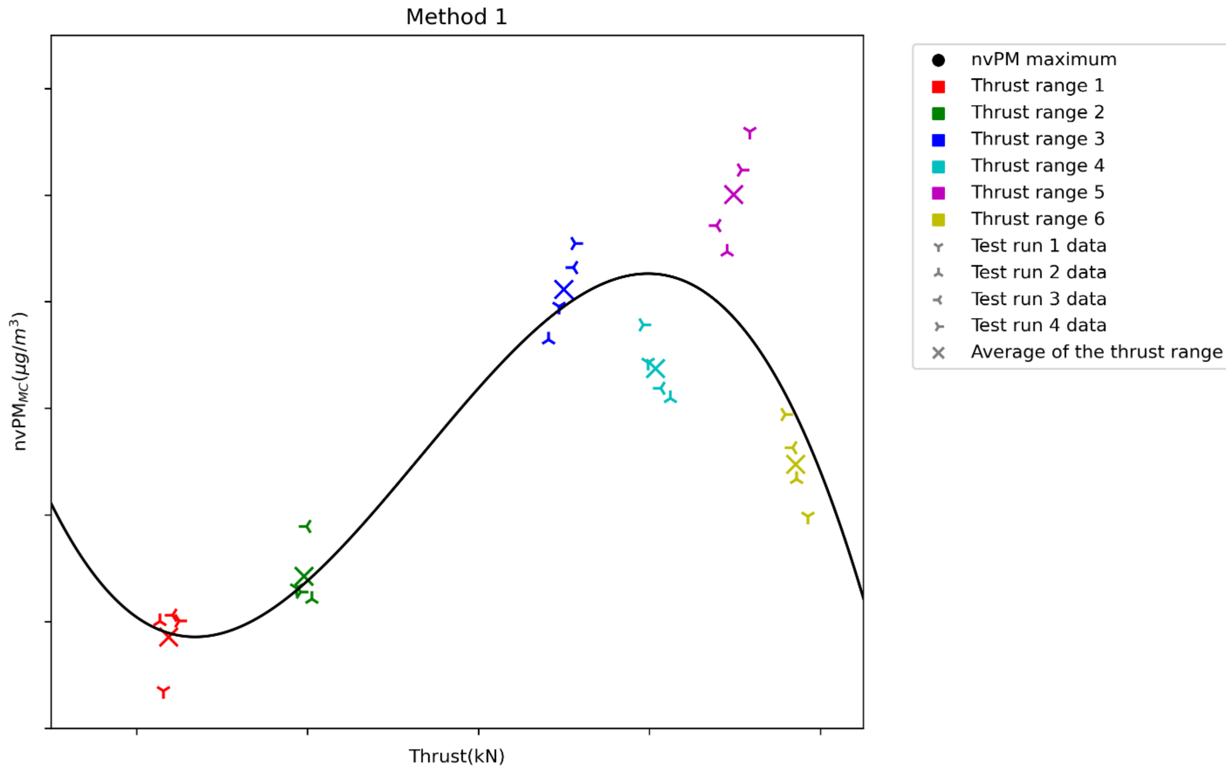
In determining the maximum nvPM mass concentration, an applicant is required to obtain measurements *"at sufficient thrust settings, in such a way that the emissions maximum can be determined"* (§ 34.71 (c)(1)). While there is no restriction on the number of thrust settings measured, a consistent set of measurement points and thrust settings should be chosen for each engine tested, typically encompassing low idle (less than 7% rated thrust) to thrusts greater than 100% rated thrust at ISA sea level conditions. The resulting dataset should consist of nvPM mass concentration measurements made at each thrust setting across the thrust range chosen by the applicant for each engine.

The maximum $nvPM_{MC}$ standard is applicable to all engines with a rated thrust greater than 26.7kN produced on or after 1 January 2023. This includes derivative versions or modified engine models which are certified to the smoke number standard. These engines are no longer required to comply with the smoke number standard on or after 1 January 2023. Instead, they must comply with the maximum $nvPM_{MC}$ standard. Thus, beginning 1 January 2023, any modifications and changes to engines with rated thrust greater than 26.7 kN will not be assessed with the no change criteria for the smoke number standard, instead they will be assessed with the no emissions change criteria for nvPM as required by § 34.48 and described in 9.6 of this AC.

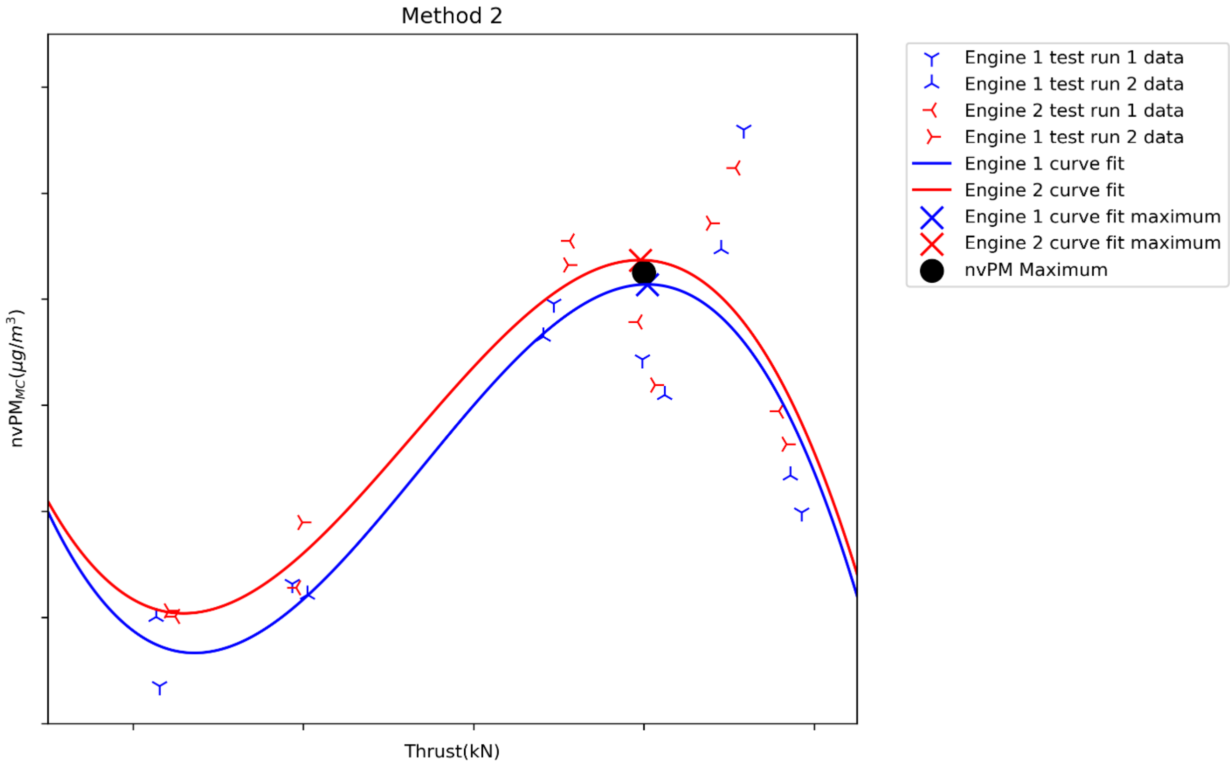
Because the requirements rely on data from multiple tests, and the $nvPM_{MC}$ regulations apply to maximums throughout the thrust range of an engine, there are various mathematical curve fitting and averaging approaches that may be applied to yield different maximum values for $nvPM_{MC}$.

Therefore, the FAA requires that one of the three individual methods, specified in § 34.73.(c)(1), and described below, be used for curve fitting and averaging to determine the maximum values for $nvPM_{MC}$. Engine manufacturers should report which of the methods was used in their test reports.

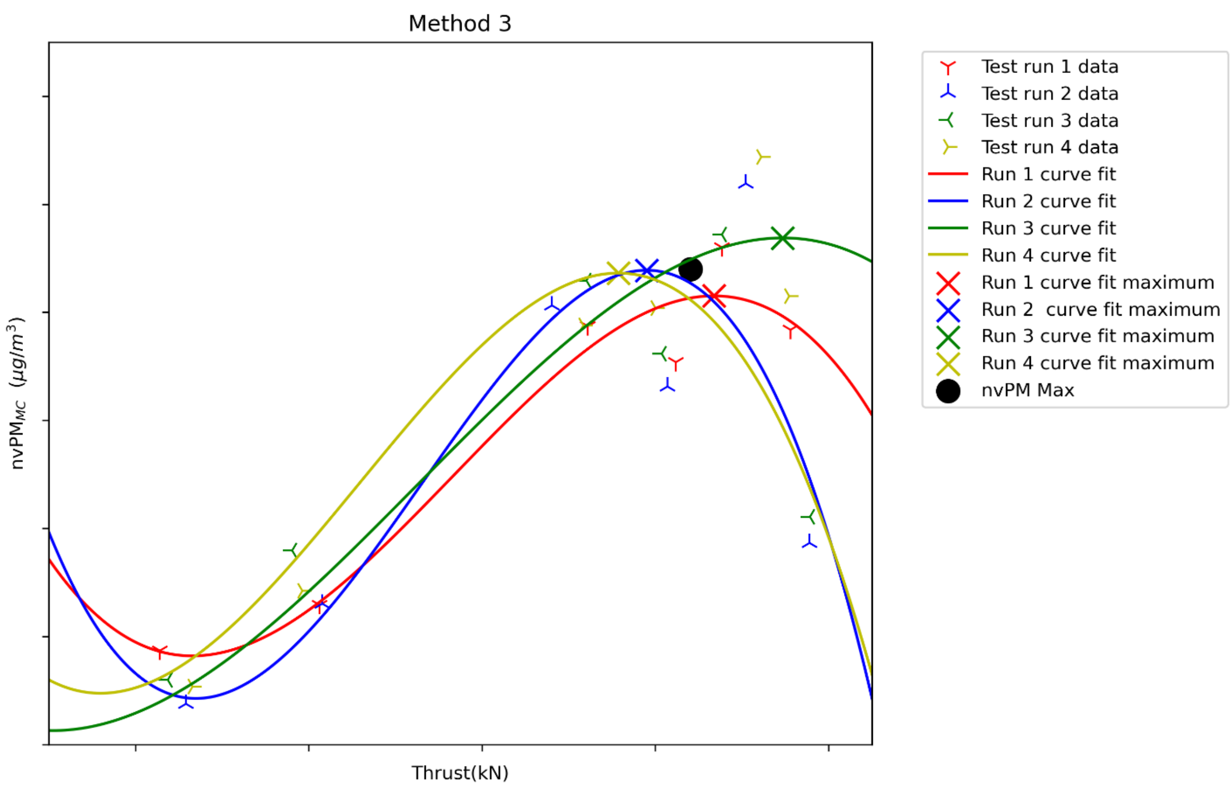
Method 1. The $nvPM_{MC}$ for individual data points is averaged to form an engine data point at a specific thrust setting then engine data points are averaged at common thrust settings in order to arrive at a single dataset which can then be curve fit from which the maximum may be determined to find the overall average maximum concentration. This approach requires common thrust settings. (Data points falling within ±6° F of the combustor inlet temperatures may be considered the same thrust settings for averaging purposes, consistent with the "no emission change" criteria as described in § 34.48 and 9.6 of this AC). Method 1 is graphically illustrated, below.



Method 2. Develop curve fits of $nvPM_{MC}$ vs thrust range for all datasets combined for each engine and find the maximum for each engine. Then average all maximum engine values to find the overall average, maximum value for $nvPM_{MC}$. Method 2 is graphically illustrated, below.



Method 3. Develop curve fits of $nvPM_{MC}$ vs thrust range for each individual dataset and find the maximum for each individual curve fit. Average the individual curve fit maximums to get a maximum value for each engine. Average all of these maximum engine values to find the overall average, maximum value for $nvPM_{MC}$. Method 3 is graphically illustrated, below.



In all cases, the maximum value of $nvPM_{MC}$ is then divided by the coefficients listed in A16V2, Appendix 6, Table A6-1 (provided as Attachment 3 to this AC), as described in 13.2.1 of this AC.

OEMs may request approval from FAA for variations to this approach for curve fitting and averaging, with supporting justification.

14.2. Section 34.73 nvPM Demonstration of Compliance

Section 34.73 (*14 CFR 1031.140*) requires that the equipment and procedures specified in Appendix 6 of A16V2 be used to determine whether an engine meets the applicable nvPM limit specified in § 34.25. A demonstration of compliance includes calculations to determine the characteristic nvPM emissions levels for maximum $nvPM_{MC}$, $nvPM_{mass}$, and $nvPM_{num}$ by using the measurements collected in accordance with § 34.71. The applicant's compliance demonstration must be conducted within 90% confidence intervals (§ 34.73(d)), use the required rounding in calculations (§ 34.73(a)(3)), and correct for standard temperature and pressure as prescribed in the Annex 16, Volume II, Appendix 1 for the measurement of reference pressure ratio.

Section 34.73(c)(1) directs the applicant to conduct the minimum number of measurements at the thrust settings given in § 34.71(h). This section also provides an applicant with the flexibility to make as many additional measurements as it chooses across the entire thrust range of an engine when measuring nvPM. Additional measurements conducted across the thrust range of an engine result in a more precise understanding of any trending nvPM behavior.

Section 34.73(c)(1) allows an applicant to use one of the three equivalent evaluation methods listed in that section when calculating $nvPM_{MC}$. Once nvPM emissions certification testing is complete, § 34.73(e) identifies the required information to be reported to the FAA in the emissions test report.

The nvPM rule is written based on corrected thrust as the correlating parameter. However, the FAA recognizes that for each thrust setting there is one unique combustor inlet temperature (T_3). Therefore, thrust and T_3 may be used interchangeably as a correlating parameter in demonstrating nvPM compliance.

Note: EPA has separate reporting requirements in 40 CFR 1031 that are different than those required under part 34.

14.3. Corrections to Reference Atmospheric Conditions

The reference atmospheric conditions to which the gaseous emissions (HC, CO and NO_x) are to be corrected are the reference day conditions, as follows: temperature = 15°C, humidity = 0.00634 kg H_2O/kg of dry air, pressure = 101.325 kPa.

The requirements and procedures to correct gaseous emissions indices to reference day conditions are provided in A16V2, Appendix 3, 7.1 – 7.3. These procedures require defining a constant through curve fitting techniques of the measured emissions data, and applying the constant to the measured gaseous emissions indices for CO, HC, and NO_x.

Corrections to reference atmospheric conditions for nvPM emissions is done automatically by the nvPM mass and number instrumentation that is calibrated and operated pursuant to A16V2, Appendix 7., 5.1., and further discussed in 15.6 of this AC.

15. Guidance on ICAO A16V2, Appendix 7, Instrumentation and Measurement Techniques for nvPM Emissions

Note: As defined in Attachment 2 of this AC, the FAA nomenclature used for nvPM is: $nvPM_{MC}$, $nvPM_{mass}$, and $nvPM_{num}$, while the ICAO nomenclature used for these terms is $nvPM_{mass}$, EI_{mass}, and EI_{num}, respectively. ICAO nomenclature is used throughout 15 of this AC.

15.1. Appendix 7, 3.1: Data Required – nvPM Emissions

The non-volatile particulate matter (nvPM) sampling and measurement system is standardized to measure nvPM mass and number engine emissions. In addition, it uses the measurement of the full gaseous emissions as specified in A16V2, Appendix 3. The measurement of the full gaseous emissions allows a more precise calculation of nvPM mass concentration and nvPM mass and number emission indices (EIs), based on wet gaseous concentrations. In this case, the matrix solution described in Attachment A of A16V2 for the calculation of emissions parameters is typically used to perform necessary corrections to determine gaseous concentrations on a wet basis. For that reason, the CO, HC and NO_x concentrations are listed as data required.

15.9 of this AC (ETMV2, Appendix 7, 6.1.2) provides an equivalent procedure for the calculation of EI_{mass} and EI_{num} ($nvPM_{mass}$ and $nvPM_{num}$ in this AC) using only nvPM and dry or wet CO_2 measurements. Since the combustion efficiencies of modern turbine engines are greater than 95 per cent, it is reasonable to assume that all of the fuel carbon is converted to CO_2. Thus, CO_2-only (undiluted and diluted) measurements could be used to determine nvPM emission factors. In this case, measurements of [HC], [CO] and [NOx] are not required.

15.2. Appendix 7, 4 General Arrangement of the nvPM Sampling and Measurement System

The nvPM sampling and measurement system specified in A16V2, Appendix 7 addresses the collection, transport and quantification of mass and number of particles emitted from the engine. The measurement environment behind a gas turbine engine places significant constraints on the sampling system used to collect the exhaust sample. The high temperature, high velocity exhaust requires a robust probe at the engine exit and transports the sample to the measurement instruments. The system requirements are compounded by the need to minimize the influence of the sampling system on the exhaust sample. Thus, a sophisticated system is specified. The transfer part of the system has been physically standardized to minimize variability between test facilities and operators, including the sampling lines. The exhaust sample is diluted and maintained at prescribed temperatures and flow rates to prevent condensation, minimize coagulation of particles to be measured and minimize particle transport loss prior to measurement. Once the sampling system has transported the exhaust sample to the measurement instruments, nvPM mass and number concentrations are measured.

The nvPM sampling and measurement methodology is established upon SAE International Aerospace Information Report (AIR) 6241 — *Procedure for the Continuous Sampling and Measurement of Non-Volatile Particle Emissions from Aircraft Turbine Engines* and documented in SAE International Aerospace Recommended Practice (ARP) 6320A – *Procedure for the Continuous Sampling and Measurement of Non-Volatile Particulate Matter Emissions from Aircraft Turbine Engines*.

15.3. Appendix 7, 4.1 nvPM Sampling and Measurement System (connections)

An example of an acceptable sample line connection for use in Modules 2 to 4 is shown in Figure 2-7.

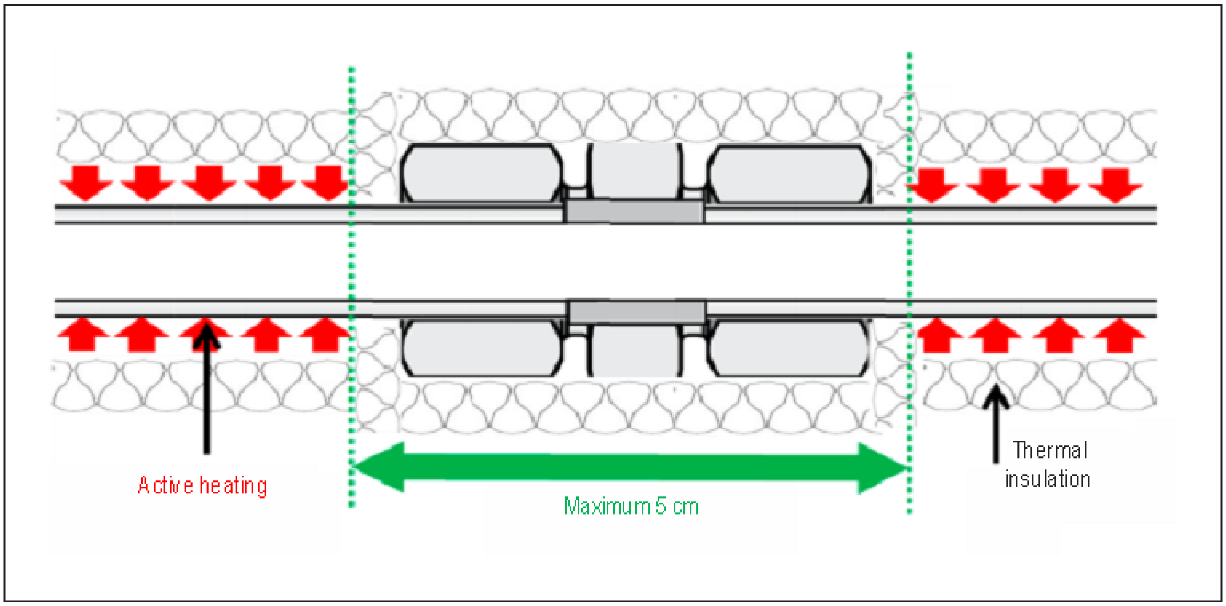
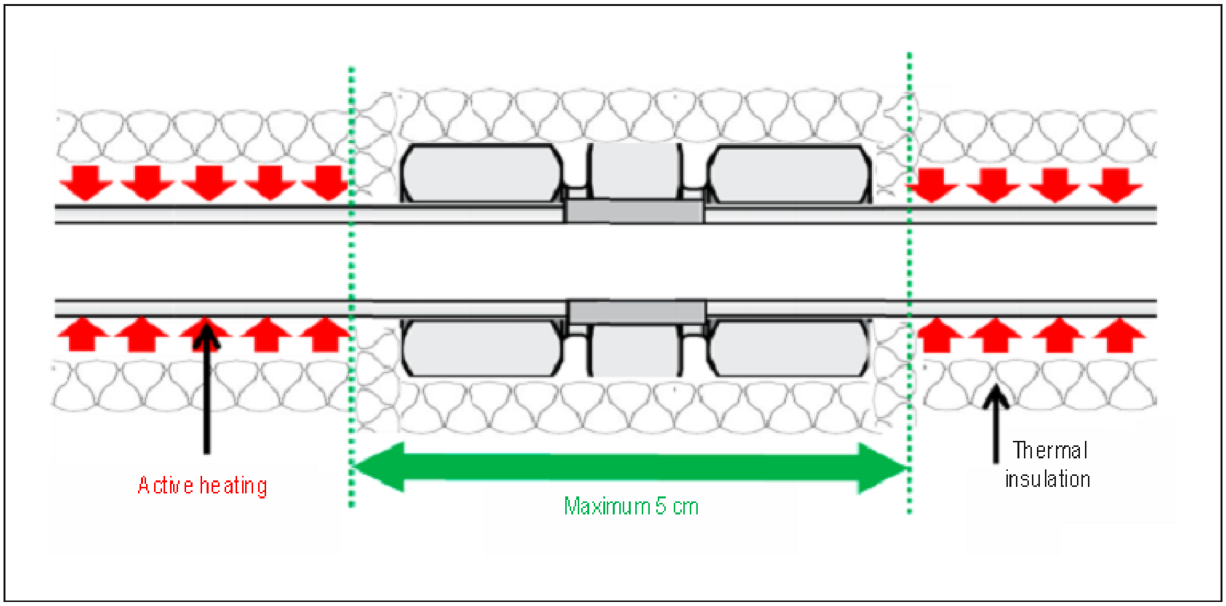


Figure 2-7. Example of a sampling line connection heating

An example of an acceptable bulkhead connection for use in Modules 2 to 4 is shown in Figure 2-8.



Appendix 7, 4.2: Collection Part (traverse measurements)

For existing certified engines:

Where detailed traverse measurements for gaseous and smoke emissions testing have been conducted prior to the applicability of Amendment 9 to A16V2, and have been agreed to by FAA, the probe configurations already established may be acceptable for nvPM certification measurements.

For new engine types or modifications that invalidate the previous probe configuration for emissions certification:

Where traverse measurements are required to demonstrate representative sampling, all emissions certification species should be taken into account for the evaluation of representativeness.

15.4. Appendix 7, 4.4.1: nvPM Mass Measurement (instrument conformity)

A16V2, Appendix 7 requires the nvPM mass instrument (nvPMmi) to have a certificate showing the instrument has demonstrated conformity to the performance specifications listed in Appendix 7, 8.1.

Each instrument is delivered with a user manual to provide operating instructions and instrument specific calibration procedures. As standard practice, this manual includes the performance specifications of the instrument. The performance specifications which must be met to demonstrate conformity should normally be contained in this manual.

If the manual provides sufficient information to demonstrate conformity, the manual can serve as the instrument's certificate. If this information is not contained in the manual, then an appendix to the manual or another separate document should be provided.

The data that could be expected is:

- Instrument make, model, sub-model/version number
- Versions of instrument software and hardware
- The values of the performance specifications with the indication of the determination methods used (e.g. test protocol, numerical results)
- The aerosol source recommended for annual calibration

The instrument certificates are documents required by Appendix 7 and should be provided to the FAA during the aircraft engine certification process. If FAA determines the instrument certificates are not sufficiently detailed, further details may be requested.

As stated in Appendix 7, *"each make and model of the nvPMmi shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that the make and model of the nvPMmi meets the performance specifications".* It is assumed that the instrument manufacturer has at least the same level of expertise as a competent laboratory, as defined in Appendix 7.

15.5. Appendix 7, 4.4.2 nvPM Number Measurement (instrument conformity)

Annex 16, Volume II, Appendix 7 requires the nvPM number instrument (nvPMni) to have certificates showing the VPR and CPC have demonstrated conformity to the performance specifications listed in Appendix 7, 9.1.

Each instrument is delivered with a user manual to provide operating instructions and instrument specific calibration procedures. As standard practice, this manual includes the performance specifications of the instrument. The performance specifications which must be met to demonstrate conformity should normally be contained in this manual.

In the case the manual provides sufficient information to demonstrate conformity, the manual can serve as the instrument's certificate. If this information is not contained in the manual, then an appendix to the manual or another separate document should be provided.

The data that could be expected is:

- Instrument make, model, sub-model/version number
- Versions of instrument software and hardware

- The values of the performance specifications with the indication of the determination methods used (e.g. test protocol, numerical results)

The instrument certificates are documents that may be required by the certificating authority during the aircraft engine certification process.

As stated in Appendix 7, 9.1.3.1, *"each make and model of the CPC shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that it meets the performance specifications listed"*. It is assumed that the instrument manufacturer has at least the same level of expertise as a competent laboratory, as defined in Appendix 7.

15.6. Appendix 7, 5.1: Calibration and Maintenance

Once an nvPMmi or nvPMni has been demonstrated to comply with the performance specifications (Table A7-5 of A16V2, Appendix 7, 8.1 for nvPMmi, Appendix 7, 9.1.3 for nvPMni), its configuration, both in hardware and software affecting data acquisition and signal processing must be maintained. For example, an nvPMmi may relate optical or other physical properties of the engine particles to the particle used in the calibration method performed in a laboratory using signal processing methods. Changes or improvements to hardware and such processing software or firmware of the nvPMmi or nvPMni, which affect the fundamental processing and the measurement of reported quantities, will require a new demonstration of conformity to the requirements in 8.1 for the instrument for use in engine certification. This requirement does not include the routine or annual calibration of the instrument. The calibration of the instrument may lead to entering a different calibration factor into the instrument software but does not change the way measured physical properties are processed.

Any changes to the nvPMmi should be documented to allow the FAA to determine if changes affecting data acquisition and processing have been made.

To determine if changes affect data acquisition and processing, an independently calibrated and approved nvPMmi and an independently calibrated nvPMmi with hardware and software changes should be configured in parallel with the thermal optical transmittance (TOT) instrument behind the engine source, as specified in Annex 16, Volume II, Appendix 7, 8.3.3.

In addition to the four filters acquired to meet the verification requirement (Appendix 7, 8.3.3.2), data points should be obtained with the two nvPMmi (filters not required) at a minimum of 10 mass concentrations, at relatively uniform intervals, up to the maximum mass concentration measured for the verification (as specified in Table 2-2). A minimum of three or six (at respective relative mass

Once an nvPMmi or nvPMni has been demonstrated to comply with the performance specifications (Table A7-5 of A16V2, Appendix 7, 8.1 for nvPMmi, Appendix 7, 9.1.3 for nvPMni), its configuration, both in hardware and software affecting data acquisition and signal processing must be maintained. For example, an nvPMmi may relate optical or other physical properties of the engine particles to the particle used in the calibration method performed in a laboratory using signal processing methods. Changes or improvements to hardware and such processing software or firmware of the nvPMmi or nvPMni, which affect the fundamental processing and the measurement of reported quantities, will require a new demonstration of conformity to the requirements in 8.1 for the instrument for use in engine certification. This requirement does not include the routine or annual calibration of the instrument. The calibration of the instrument may lead to entering a different calibration factor into the instrument software but does not change the way measured physical properties are processed.

Table 2-2. Elemental carbon (EC) mass loading parameters for demonstration of conformity for a nvPMmi after a hardware or software (HW/SW) change

Verification (Appendix 7, 8.3.3) **(Reference mass from TOT EC filters)**		**Repeatability, Linearity, and Accuracy** **(Reference mass from approved nvPMmi)**	
Target Concentration *(Relative to Maximum Verification Concentration — μg/m³)*	*No. of Tests*	*Target Concentration* *(Relative to Maximum Verification Concentration — μg/m³)*	*No. of Tests*
minimum ≤ 0.67 × middle concentration (< 120 μg/m3)	1 or 2	0.0	6
		0.10 ± 0.05 × maximum	6
		0.20 ± 0.05 × maximum	6
		0.30 ± 0.05 × maximum	3
		0.40 ± 0.05 × maximum	3
middle ≤ 0.67 × maximum	1 or 2	0.50 ± 0.05 × maximum	3
		0.60 ± 0.05 × maximum	3
		0.70 ± 0.05 × maximum	3
maximum (> 120 μg/m3)	1 or 2	0.80 ± 0.05 × maximum	3
		0.90 ± 0.05 × maximum	3
		maximum	6
Total:	4	Total:	45

For verification, a minimum of four filters are required, as stated in Appendix 7,8.3.3.

15.7. Appendix 7, 5.3: Carbon balance check for nvPM using air/fuel ratio (AFR)

Since it is possible to perform the full gaseous emissions measurement with the nvPM sampling and measurement system, the carbon balance check for nvPM measurements should be achieved using the air/fuel ratio (AFR) formula given in Annex16, Volume II, Appendix 3, 7.1.2:

$$Air/fuel\,ratio = \left(\frac{P_0}{m}\right)\left(\frac{M_{Air}}{M_c + \left(\frac{n}{m}\right)M_H}\right)$$

where P_0 includes all gaseous emissions concentrations.

Since the combustion efficiencies of modern turbine engines are greater than 95 per cent, it is reasonable to assume that all of the fuel carbon is converted to CO_2. Thus, CO_2-only measurements could be used for determination of the AFR and the equation could be simplified using a simplified P_0.

$$\frac{P_0}{m} = \frac{1}{[CO_2]_S} + \frac{n}{4m}$$

$[CO_2]_b$ Gas concentration of CO_2 in dry air, by volume = 0.0003

$[CO_2]_S$ Mean gas concentration of CO_2 vol/vol in undiluted exhaust as sampled, wet, semi-dry or dry

M_{AIR} Molecular mass of dry air = 28.966 g or, where appropriate,

= (32 $[O_2]_b$ + 28.156 4 $[N_2]_b$ + 44.011 $[CO_2]_b$) g

M_C atomic mass of carbon = 12.011 g

M_H atomic mass of hydrogen = 1.008 g

$[N_2]_b$ Gas concentration of N_2 + rare gases in dry air, by volume = 0.790 2

$[O_2]_b$ Gas concentration of O_2 in dry air, by volume = 0.209 5

m number of C atoms in characteristic fuel molecule

n number of H atoms in characteristic fuel molecule

The AFR estimated from the CO_2 measured concentration should agree with the estimated engine AFR with an accuracy of ±15 per cent for the taxi/ground idle mode and with an accuracy of ±10 per cent for all other operating modes.

For modern engines, the simplified AFR estimation always predicts a slightly higher AFR than the full gaseous estimation. The estimated bias is:

a) less than 1 per cent for high power settings due to the high combustion efficiency; and

b) less than 3 per cent for idle conditions.

This impacts the carbon balance accuracy comparison to the estimated engine AFR. It is possible that the simplified carbon balance method could exceed the requirement. Thus, care should be taken to take account of the bias.

15.8. Appendix 7, 6.1.1: nvPM mass concentration correction for first stage dilution factor (DF_1)

The nvPM mass concentration has to be corrected for the first stage dilution factor (DF_1). DF_1 is determined using the following equation:

$$DF_1 = \frac{[CO_2]}{[CO_2]_{dil1}}$$

where $[CO_2]$ is calculated using the full gaseous emissions concentrations, as specified in Annex 16, Volume II, Attachment A for the wet correction.

Since the combustion efficiencies of modern turbine engines are greater than 95 per cent, it is reasonable to assume that all of the fuel carbon is converted to CO_2, and CO_2-only measurements could be used for determination of nvPM emissions. In this case, the CO_2 concentration cannot be wet-corrected and the first stage dilution factor is calculated using directly the sampled $[CO_2]_S$:

$$DF_{1\_S} = \frac{[CO_2]_S}{[CO_2]_{dil1}}$$

Thus, the nvPM mass concentration could be calculated using the following equation:

$$nvPM_{mass} = DF_{1\_S} \times nvPM_{mass\_STP} \times k_{thermo}$$

For modern engines, the uncertainties introduced by using the simplified equation result in an increase of $nvPM_{mass}$ by up to 5 per cent for high power settings. This number decreases towards low power settings.

15.9. Appendix 7, 6.1.2: nvPM mass and nvPM number and CO2 only measurements for determination of EI_{mass} and EI_{num}

Since the combustion efficiencies of modern turbine engines are greater than 95 per cent, it is reasonable to assume that all of the fuel carbon is converted to CO_2. nvPM and CO_2-only measurements could be used for determination of EI_{mass} and EI_{num} using the following simplified equations:

$$EI_{mass} = \frac{22.4 \times nvPM_{mass\_STP} \times 10^{-3}}{\left([CO_2]_{dil1} - \frac{1}{DF_{1\_S}}([CO_2]_b)\right)(M_C + \alpha M_H)} \times k_{thermo} \times k_{fuel\_M}$$

$$EI_{num} = \frac{22.4 \times DF_2 \times nvPM_{num\_STP} \times 10^{6}}{\left([CO_2]_{dil1} - \frac{1}{DF_{1\_S}}([CO_2]_b)\right)(M_C + \alpha M_H)} \times k_{thermo} \times k_{fuel\_N}$$

where DF_{1_S} is the first stage dilution factor calculated using directly sampled $[CO_2]_S$:

$$DF_{1\_S} = \frac{[CO_2]_S}{[CO_2]_{dil1}}$$

For modern engines, the uncertainties introduced by using the simplified equations result in an increase of the EI_{mass} and EI_{num} by less than 0.1 per cent for high power settings due to the high combustion efficiency, and by less than 5 per cent for idle conditions.

15.10. Appendix 7, 6.1.2: Examples of nvPM mass and nvPM number calculations using full gaseous emissions concentrations and simplified method

Examples of nvPM mass and number calculations, using the full gaseous emissions concentrations to obtain more precise EIs and using the simplified method.

In these examples, the engine operates at an idle power condition and Jet A1 fuel is used. The engine exhaust plane temperature is 405°C (T_{EGT}) and Diluter 1 inlet temperature is 163°C (T_1).

Given parameters:

$[CO_2]_{dry}$	26051 ppm = 0.026051
$[CO]_{dry}$	1012 ppm = 0.001012
$[H_2O]$	0.0244
[HC]	0.000117
$[CO_2]_b$	0.0003
$nvPM_{mass\_STP}$	19 [μg/m^3]
$nvPM_{num\_STP}$	2.18×10^3 [number/cm^3]
$[CO_2]_{dil1}$	2591 ppm/1000000 = 0.002591
DF_2	100
α	1.92 (typical Jet A1)

1. *Full gaseous method nvPM mass and number emission indices and nvPM mass concentration calculation examples*

$$k_{thermo} = \left(\frac{T_1 + 273.15}{T_{EGT} + 273.15}\right)^{-0.38}$$

k_{thermo} = 1/(((163+273.15)/(405+273.15))$^{0.38}$) = 1.18

Convert $[CO_2]$ dry to wet basis, $[CO_2] = [CO_2]_{dry}$ (1 - 0.0244) = 0.025415

$DF_1 = [CO_2]/[CO_{2\_dil1}]$ = 0.025415/0.002591 = 9.809

Convert $[CO_2]$ dry to wet basis, $[CO_2] = [CO_2]_{dry}$ (1 - 0.0244) = 0.025415

- **nvPM primary mass concentration**

$nvPM_{mass} = DF_1 \times nvPM_{mass\_STP} \times k_{thermo}$

$nvPM_{mass}$ = 9.809 × 19 × 1.18

$nvPM_{mass}$ = 220 μg/m^3

- **nvPM mass emission index**

$$EI_{mass} = \frac{22.4 \times nvPM_{mass\_STP} \times 10^{-3}}{\left([CO_2]_{dil1} - \frac{1}{DF_1}([CO] - [CO_2]_b + [HC])\right)(M_C + \alpha M_H)} \times K_{themo}$$

$$EI_{mass} = \frac{22.4 \times 19 \times 10^{-3}}{\left(0.002591 + \frac{1}{9.81}(0.0009873 - 0.0003 + 0.000117)\right)(12.011 + 1.92 \times 1.008)} \times 1.18$$

$$EI_{mass} = 13.5 \left[\frac{mg}{kg\ fuel}\right]$$

- **nvPM number emission index**

$$EI_{num} = \frac{22.4 \times DF_2 \times nvPM_{num\_STP} \times 10^{6}}{\left([CO_2]_{dil1} + \frac{1}{DF_1}([CO] - [CO_2]_b + [HC])\right)(M_C + \alpha M_H)} \times k_{themo}$$

$$EI_{num} = \frac{22.4 \times 100 \times 2.18 \times 10^{3} \times 10^{6}}{\left(0.002591 + \frac{1}{9.81}(0.0009873 - 0.0003 + 0.000117)\right)(12.011 + 1.92 \times 1.008)} \times 1.18$$

$$EI_{num} = 1.55 \times 10^{14} \left[\frac{number}{kg\ fuel}\right]$$

2. *Simplified nvPM mass and number emission indices and nvPM mass concentration calculation examples*

k_{thermo}= 1/(((163+273.15)/(405+273.15))0.38) = 1.18

DF_{1_S} = $[CO_2]_S/[CO_2]_{dil1}$ = 0.026051/0.002591 = 10.05

- **nvPM primary mass concentration**

DF_{1_S} = $[CO_2]_S/[CO_{2\_dil1}]$ = 0.026051/0.002591 = 10.05

$nvPM_{mass}$ = 10.05 × 19 × 1.18

$nvPM_{mass}$ = 225 µg/m³ (full gaseous method value calculated above: 220 µg/m³)

- **nvPM mass emission index**

$$EI_{mass} = \frac{22.4 \times nvPM_{mass\_STP} \times 10^{-3}}{\left([CO_2]_{dil1} - \frac{1}{DF_{1\_S}}([CO_2]_b)\right)(M_C + \alpha M_H)} \times k_{themo}$$

$$EI_{mass} = \frac{22.4 \times 19 \times 10^{-3}}{\left(0.002591 - \frac{0.0003}{10.05}\right)(12.011 + 1.92 \times 1.008)} \times 1.18$$

$EI_{mass} = 14.1 \left[\frac{mg}{kg\ fuel}\right]$ (full gaseous method value calculated above: 13.5 mg/kg fuel)

- **nvPM number emission index**

$$EI_{num} = \frac{22.4 \times DF_2 \times nvPM_{num\_STP} \times 10^{6}}{\left([CO_2]_{dil1} - \frac{1}{DF_{1\_S}}([CO_2]_b)\right)(M_C + \alpha M_H)} \times k_{themo}$$

$$EI_{num} = \frac{22.4 \times 100 \times 2.18 \times 10^{3} \times 10^{6}}{\left(0.002591 - \frac{0.0003}{10.05}\right)(12.011 + 1.92 \times 1.008)} \times 1.18$$

$EI_{num} = 1.61 \times 10^{14} \left[\frac{number}{kg\ fuel}\right]$ (full gaseous method value calculated above: 1.55×10^{14} number/kg fuel)

15.11. Appendix 7, 6.2.2: Correction for fuel composition using legacy, EEDB hydrogen to carbon ratio

Legacy data in the Engine Emissions Databank may contain only the hydrogen to carbon ratio. Assuming the Jet-A fuel is comprised only of hydrogen and carbon, it is recommended to use the equation below to calculate %H (mass) from H/C ratio:

$$\%H(mass) = \frac{100 \ \times H/C}{11.916 + H/C}$$

This equation can be inverted to calculate H/C ratio from %H (mass):

$$H/C = \frac{11.916 \ \times \%H\ (mass)}{100 - \%H\ (mass)}$$

15.12. Appendix 7, 7.2: Examples of splitter geometries and assemblies

Figures 2-9 and 2-10 show examples of splitter geometries and assemblies that meet the requirements and are acceptable for use. Note that there are many other possible geometries and assemblies that could meet the requirements and could be acceptable for use.

The number of Splitter 1 flow paths depends on the number of undiluted sample measurement lines and/or the need to relieve large excess sample pressure. Additional emission diagnostic instrumentation may be placed in the make-up flow path downstream of Splitter 2.

Splitter design is not based upon hydraulic flow considerations but on the desire for standardization between sampling systems. Consideration of splitter design may not be necessary for the measurement of turbine engine nvPM emissions, since theoretically there is no impact on small particles (less than 300 nm diameter).

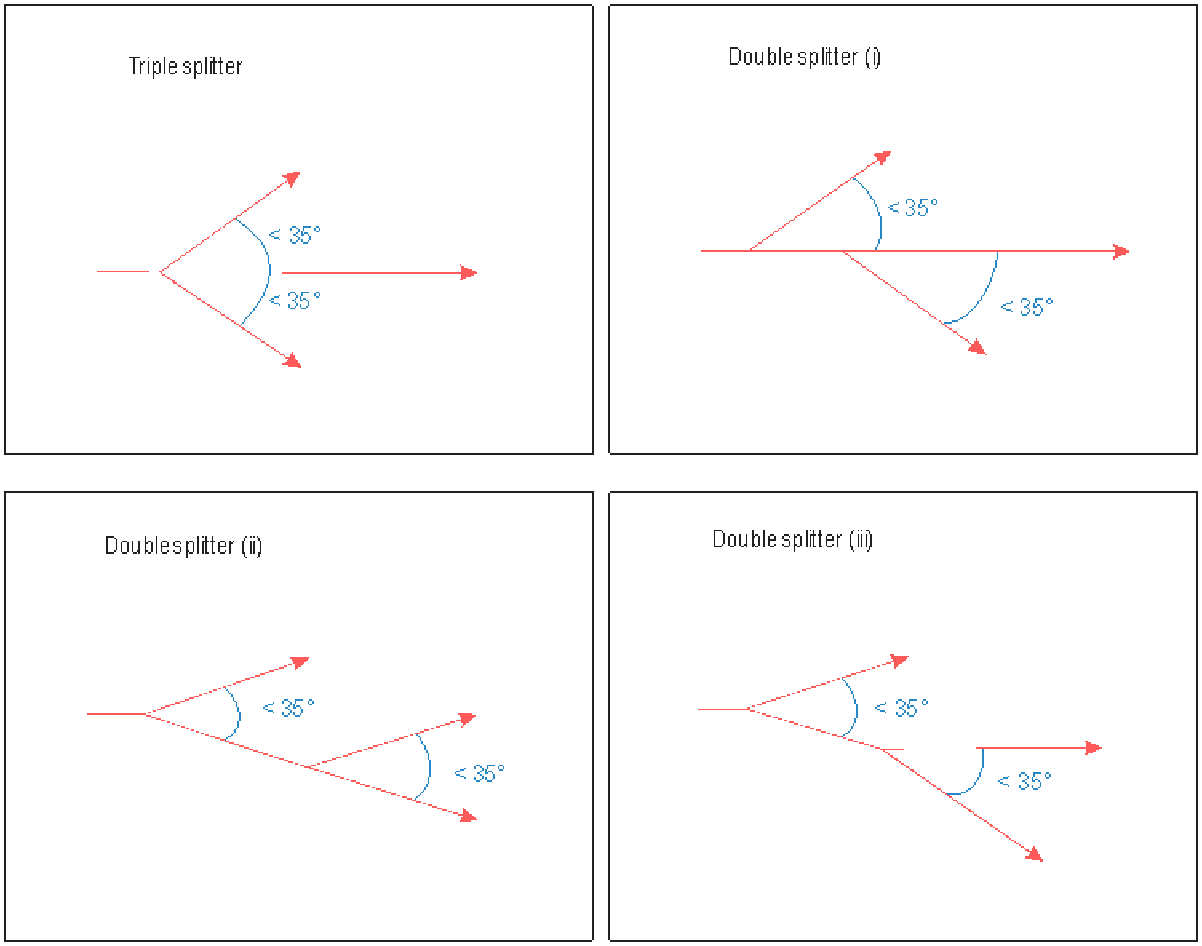


Figure 2-9. Schematic examples of splitter geometries

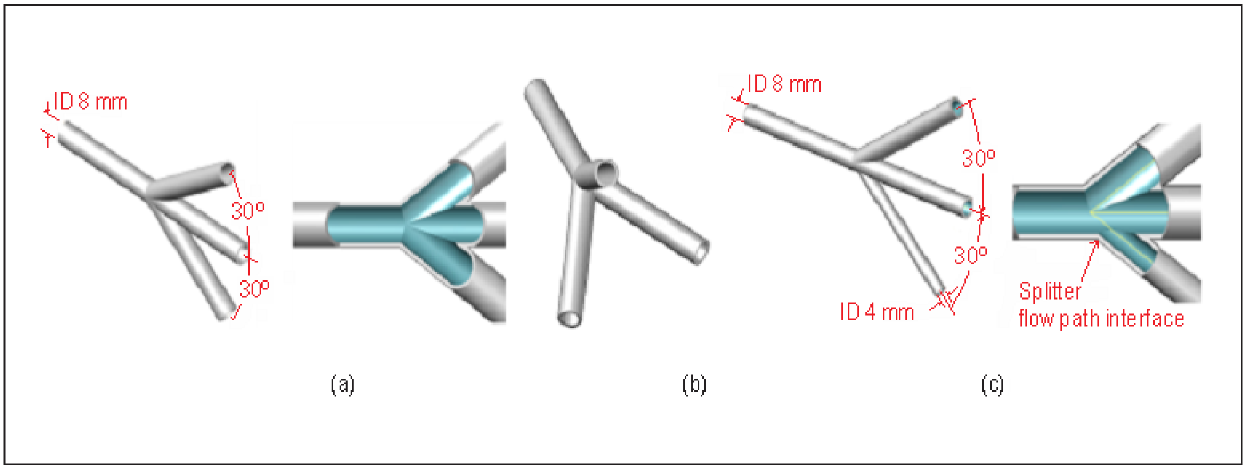


Figure 2-10. Triple splitter example geometry as (a) single plane; (b) multi-plane; and (c) line diameter change

15.13. Appendix 7, 7.2.6: Switching between CO, HC, and NOx measurements and nvPM measurement while in stable operating condition

While the engine is at a stable operating condition, sequential switching between CO, HC, and NOx measurements and nvPM measurement could be allowed.

15.14. Appendix 7, 7.2.6: Obtaining smoke measurements using the nvPM sampling system

Smoke measurements may be obtained using the nvPM sampling system. The collection part (Section 1) of the nvPM sampling and measurement system meets the specifications in A16V2, Appendix 2 and the Splitter 1 assembly allows the GL, or another heated sampling line, to be used to measure smoke number as long as the sampling line requirements in Appendix 2 are met. If smoke number measurements are taken, it is recommended to obtain them sequentially with the nvPM measurements.

Installation of the smoke sampling line at Splitter 1 for certification measurements may increase the total sampling line length for smoke measurements by up to 8 m due to the collection part. In this case, the requirement in Appendix 2, 2.2.1 for a maximum sampling line length of 25 m may be exceeded, up to a maximum combined length of 33 m.

A smoke number reduction of less than 1 SN has been determined for an additional 8 m sampling line length by FOA3 modeling and direct measurements for smoke numbers up to 15. The FAA may consider granting an increase of sampling line length for smoke measurements. It is good practice to add 1 SN to the measured data as a conservative approach for determining the smoke number in such a case.

15.15. Appendix 7, 7.5.1: Examples of system flow rates and system layouts for system flow control

Figure 2-11 shows a location example of two flow controllers installed in the make-up flow line to provide Module 3 system flow control. In the figure, Module 3 flow rate of 25 slpm is the sum of the nvPMmi (4 slpm), VPR (4 slpm), primary pump flow controller (14 slpm) and CO_2 pump flow controller (3 slpm).

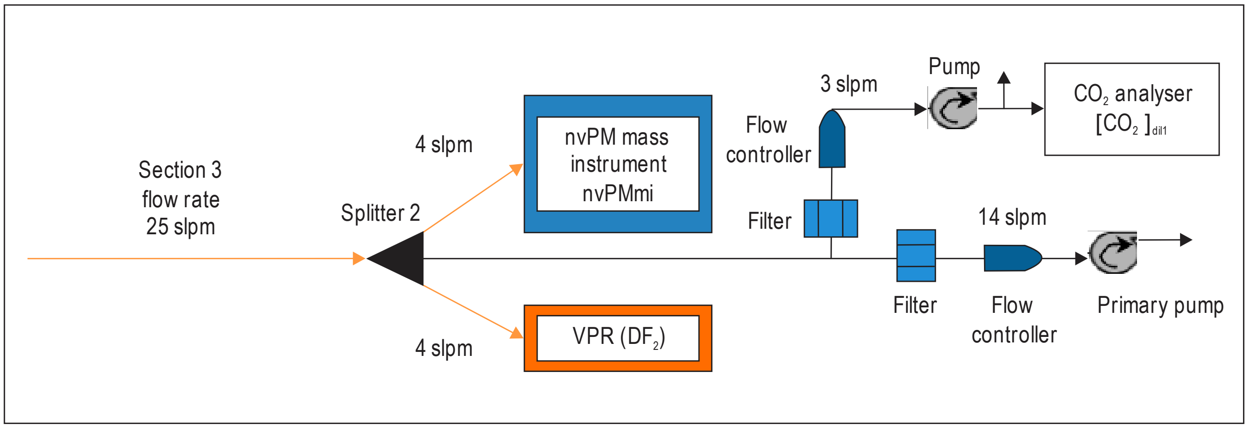


Figure 2-11. Example of system flow rates that ensure Module 3 flow rate satisfies 25 ± 2 slpm

Figure 2-12 shows examples of sampling layout options for performing nvPM sampling system flow control and $[CO_2]_{dil1}$ measurement for determination of the first stage dilution factor DF_1.

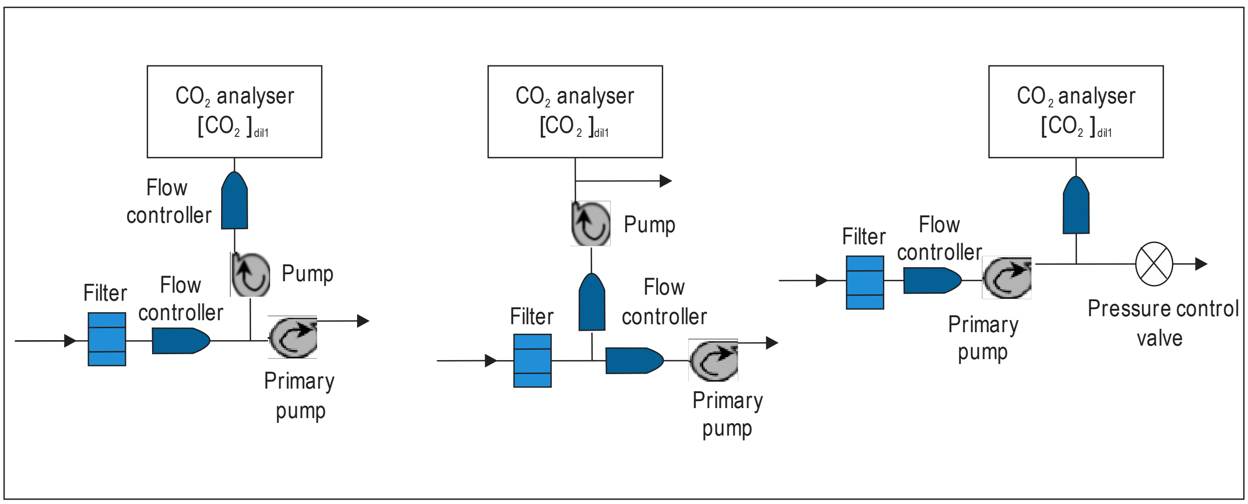


Figure 2-12. Examples of sampling layout for nvPM sampling system flow control at first stage dilution measurement

The sample gas measured downstream of Diluter 1 can be considered “dry” as it will consist of at least 88 per cent dry air or dry nitrogen. The diluted sample water content is negligible and consequently there is no “wet” correction required for the CO_2 measurement downstream of Diluter 1.

15.16. Appendix 7, 8: Using thermal optical transmittance (TOT) analysis to determine elemental carbon mass as a surrogate for black carbon mass for calibration purposes

Non-volatile PM (nvPM) is defined as those particles present at the aircraft engine exit plane which do not volatilize when heated to a temperature of 350°C. nvPM consists mainly of nanometre-size black carbon with trace amounts of ash and metallic particles emitted by aircraft engines under normal operating conditions. Total nvPM mass cannot be directly measured except by filter sampling and analysis which is expensive and time consuming. Therefore, the on-line measurement of black carbon mass concentration is considered the most appropriate method for representing the nvPM emissions from aircraft engines.

For calibration purposes, however, the mass of elemental carbon (EC), determined by thermal optical transmittance analysis, is used as a surrogate for black carbon mass since it was the most applicable method at the time the nvPM regulation was established.

15.17. Appendix 7, 8: Clarification of terms in Appendix 7

Table 2-3 provides a clarification of the terms used in Appendix 7 Section 8.

Table 2-3. Definition of select terms used in Appendix 7 *Term*	*Use*
Demonstrate Conformity (for a performance specification)	To show that a nvPMmi meets an individual Appendix 7 Performance Specification
Certificate	Received after a nvPMmi has *demonstrated conformity* to all Performance Specifications
Accuracy	Part of Performance Specifications: Determine nvPMmi agreement with EC Mass concentration determined from TOT method, by way of linear regression
Verification	Part of Performance Specifications: Verifying the combination of instrument and annual calibration source for nvPM mass measurement on an aircraft gas turbine engine exhaust
Annual Calibration	Adjust nvPMmi calibration factor to agree with EC mass concentration determined from the TOT method

15.18. Appendix 7, 8.2.1: Thermal optical transmission (TOT) method

The thermal optical transmission (TOT) method can speciate EC from organic carbon (OC), and is performed by a thermal optical analyser with timed heating ramps and “cool-down” cycles. While the method measures all carbon species that evolve during the analysis and provides total carbon (TC) loading on the filter, the EC fraction is used for calibration. In the laboratory method, all carbon evolving from the filter is oxidized to form carbon dioxide (CO_2), which is then reduced to methane (CH_4), and measured using a flame ionization detector (FID), as described below.

A red light (wavelength of 670 nm) laser and a photocell are used to monitor transmittance of a filter punch of known area, which typically darkens as refractory OC chars during a non-oxidizing heat ramp and then lightens as the char burns off during an oxidizing heat ramp. Figure 2-13 illustrates a typical heat cycle of the TOT method. Note that Figure 2-13 is provided for illustration purposes and does not reflect the required temperature profile for the TOT method analysis cycle. Instrument software divides TC into OC and EC by evaluating the split time at which the transmittance of the filter returns to its original value from the beginning of the analysis. One should note that since the instrument uses light transmittance through the filter to speciate the carbon types, any artefacts that remain on the filter (due to lack of complete charring etc.) can be determined as EC rather than OC during analysis. The range for this method is 1 to 105 µgC (micrograms carbon) per filter punch (usually about 1.5 cm^2). The limit of detection is about 0.2 µgC per cm^2.

Figure 2-13 is a typical thermogram for a filter sample containing OC, carbonate carbon (CC) and EC. PC is carbon generated by pyrolysis. The curves indicated with the OC, CC, PC, EC and CH_4 labels are CH_4 concentrations being measured by an FID for the laboratory TOT carbon analyser. The final peak is the methane calibration peak.

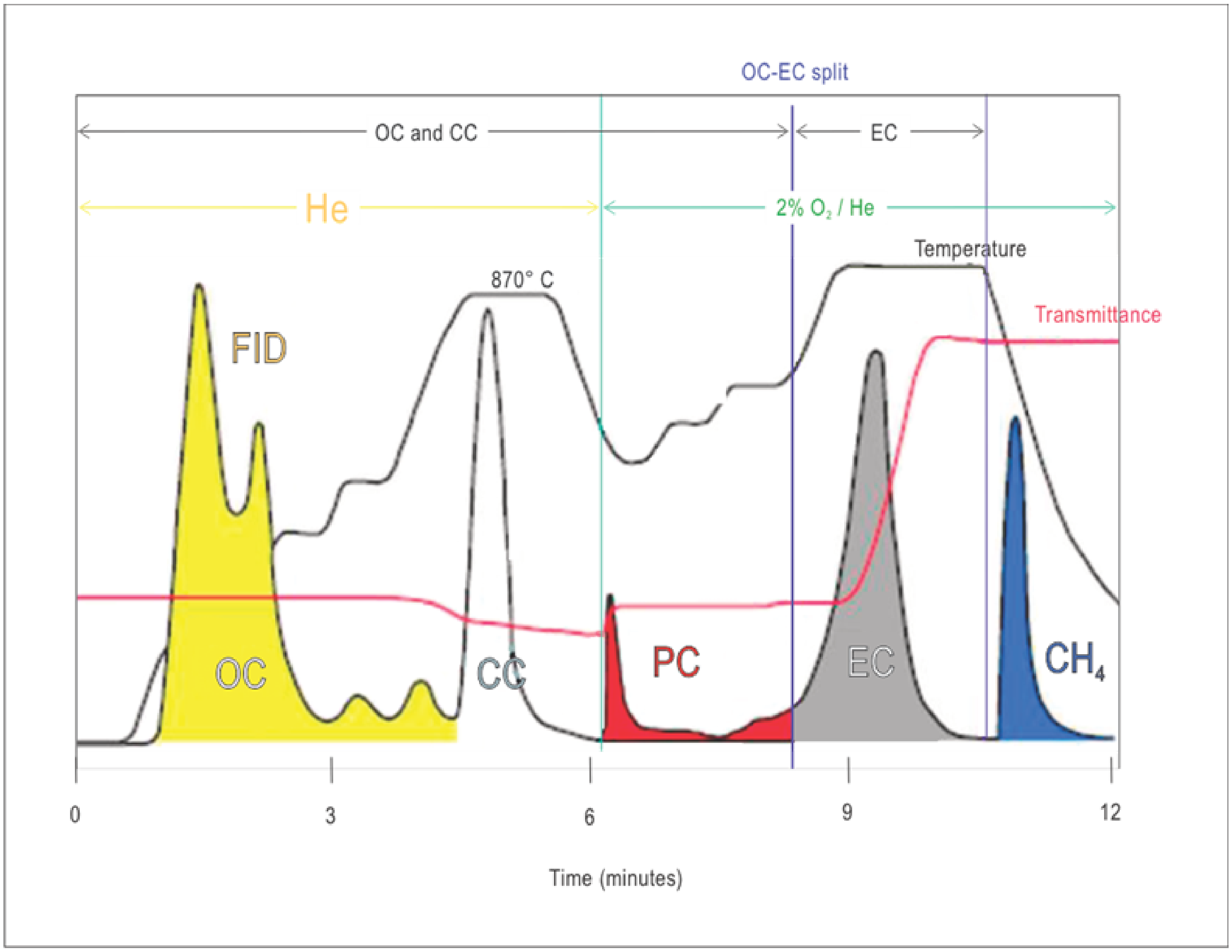


Figure 2-13. Typical thermogram for filter sample

The optical component of the analyser is used to correct for pyrolysis of OC compounds to EC in order to avoid underestimation of OC and overestimation of EC. In order to ensure a proper OC/EC split, calibration of the internal oven temperature should be conducted according to the manufacturer's specifications. The sample reflectance and transmittance are continuously monitored by a laser and a photo detector throughout the thermal cycle. When pyrolysis takes place, there is an increase in light absorption resulting in a decrease in reflectance and transmittance. Thus, by monitoring the reflectance/transmittance, the portion of the EC peak corresponding to pyrolyzed organic carbon can be correctly assigned to the organic fraction. An example of the laser transmission amplitude (curve denoted with the “transmittance” label) is shown in Figure 2-13.

In the semi-continuous TOT analyser, a quartz filter is mounted directly in the instrument and samples are collected for the desired time. Once the collection is complete, the oven is purged with helium and a stepped-temperature ramp increases the oven temperature to 870°C, thermally desorbing organic compounds and pyrolysis products into a manganese dioxide (MnO_2) oxidizing oven. As the carbon fragments flow through the MnO_2 oven, they are quantitatively converted to CO_2 gas. The CO_2 is swept out of the oxidizing oven with the helium stream and measured directly by a self-contained non-dispersive infrared (NDIR) detector. A second temperature ramp (oven temperature to 930°C) is then initiated in a He/O_2 gas stream and any EC is oxidized off the filter and into the oxidizing oven and NDIR. The EC is then detected in the same manner as the OC.

15.19. Appendix 7, 8.3: Procedure to demonstrate conformity to performance specifications

The nvPM mass instrument (nvPMmi) is required to demonstrate conformity to the performance specifications in Table A7-5 to Annex 16, Volume II, Appendix 7 using a diffusion flame combustion aerosol source (DFCAS). Specifically, for the verification performance specification, as stated in Appendix 7, an aircraft turbine engine must be used as the combustion aerosol source.

A DFCAS is a device employing diffusion flame combustion using a given fuel that emits airborne particulate matter. A diffusion flame is a mode of combustion in which the fuel and oxidizer (air) are supplied separately to the combustion zone, where mixing by molecular diffusion takes place together with the combustion reactions. Hydrocarbon-fuelled diffusion flames produce soot (a form of non-volatile particulate matter) and organic aerosols (a form of volatile particulate matter). The DFCAS is a combination of the device to produce the flame and the fuel used.

Examples of a DFCAS

Gaseous fuel — non-premixed methane inverted flame; non-premixed propane soot generator

Liquid fuel — gas turbine combustor rig; gas turbine engine; diesel direct injection engine

Diffusion flame combustion aerosol sources

The following lists guidance on how to differentiate DFCASs.

Different models of laboratory aerosol generator are considered different DFCASs.

One aircraft engine type is considered different from another aircraft engine type.

A laboratory aerosol generator is considered a different DFCAS from an aircraft engine.

A change of operating settings on a DFCAS, which results in significant changes to the nvPMmi calibration factor (the relationship between instrument response and TOT reference) is considered a change of DFCAS.

Examples of DFCAS operating settings are changing the air-to-fuel ratio of a diffusion flame or sampling from different flame height locations within the DFCAS.

Using a DFCAS with a different serial number does not constitute a change of DFCAS.

It may be possible to show that the soot produced from one DFCAS is sufficiently similar to another that they can be considered the same DFCAS.

15.20. Appendix 7, 8.3: Procedure to demonstrate conformity to nvPMmi performance specifications using a DFCAS

The Technical Procedure below provides guidance for demonstrating conformity to nvPMmi performance specifications using a DFCAS.

The flowchart below describes the process followed by an engine manufacturer to perform a nvPM mass concentration measurement, how to verify a DFCAS, and how to demonstrate conformity to the performance specifications for a nvPMmi.

The flowchart describes 3 processes:

Testing Process (blue)

This shows the procedure to measure nvPM mass concentration and perform a nvPMmi annual calibration

Calibration with a new DFCAS (red)

This shows the procedure to demonstrate that a new DFCAS can be used to calibrate the instrument. A new DFCAS may be a different particle source or the same particle source with a change in operational setting such that the calibration factor (the relationship between instrument response and TOT reference) may be significantly different.

Verifying a new DFCAS involves:

(i) Using the DFCAS to perform a nvPMmi calibration, applying the number of TOT filter tests specified in the "Calibration with a new diffusion flame combustion aerosol source" column of Appendix 7, Table A7-7.

(ii) Using an aircraft engine exhaust to demonstrate that the nvPMmi meets the verification performance specification in Appendix 7, A7-5.

If a turbine source is used as the DFCAS for nvPMmi calibration, then a different aircraft engine type is used for the verification performance specification.

A new DFCAS may be used for nvPMmi calibration after it has been used for the verification performance specification for that nvPMmi make and model.

Instrument certificate (green)

This shows the procedure to obtain a nvPMmi certificate in demonstrating conformity to the performance specifications in Appendix 7, Table A7-5. This process needs to be completed once for each nvPMmi make and model and again in the case of a change in hardware or software is made to the nvPMmi affecting the data acquisition and/or processing.

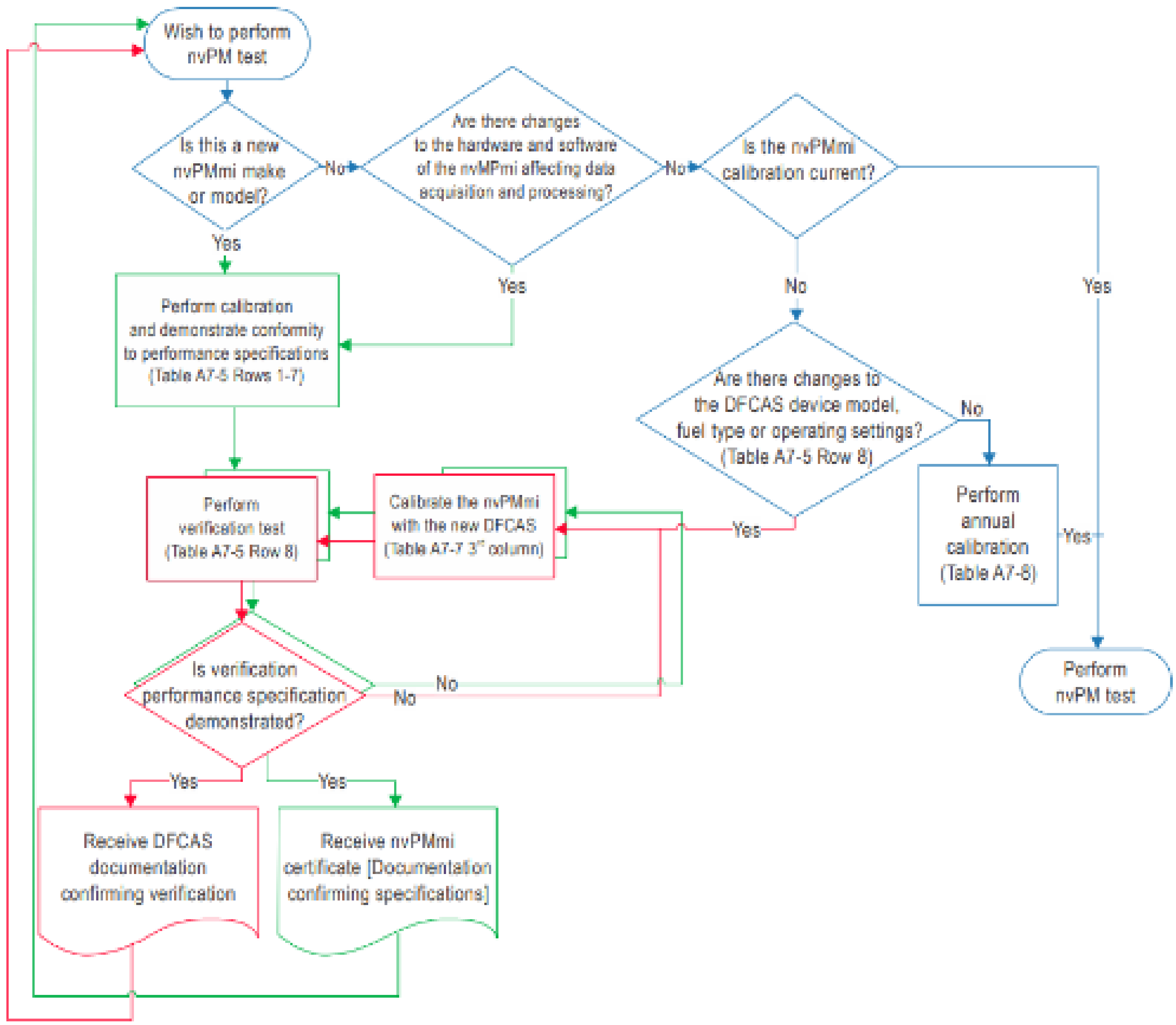
nvPMmi verification involves:

(i) Using a DFCAS to show that the nvPMmi meets the performance specifications (Repeatability, Zero drift, Linearity, Limit of Detection, Rise time and Sampling Interval) in Appendix 7, Table 7-5

(ii) Using a DFCAS calibration to show the nvPMmi meets the Accuracy performance specification in Appendix 7, Table 7-5, applying the number of TOT filter tests specified in the "Instrument Certificate" column of Appendix 7, Table A7-7.

(iii) Using an aircraft engine exhaust to demonstrate that the nvPMmi meets the verification performance specification of Appendix 7, A7-5

If a turbine source is used as the DFCAS for nvPMmi calibration, then a different aircraft engine type is used for the verification performance specification.



If the verification performance specification is not confirmed, the instrument is calibrated with a new DFCAS following the *red* (DFCAS verification) process above.

When the verification performance specification has been confirmed, the nvPMmi will receive a certificate, as stated in Appendix 7, paragraph 4.4.1.2.

The flow chart steps are detailed below:

The engine manufacturer wishes to perform a nvPM test which requires using a nvPMmi.

a) If this is a new nvPMmi make and model, then the following steps are followed:

   1) The nvPMmi demonstrates conformity to the performance specifications documented in Appendix 7, paragraph 8.1 and as stated in Appendix 7, Table 7-5, rows 2-8.

   2) The nvPMmi is calibrated as stated in Appendix 7, paragraph 8.3.2.8, using the "instrument certificate (number of tests)" column (Appendix 7, Table A7-7).

   3) The nvPMmi meets the verification performance specification requirements documented in Appendix 7, Table A7-5, ninth (last) row with the procedures stated in Appendix 7, paragraph 8.3.3.

   4) If the nvPMmi does not meet the verification performance specification requirements, the procedure in steps 1), 2) and 3) above are repeated.

   5) Once the nvPMmi meets the verification performance specification requirements, the nvPMmi will receive a certificate as stated in Appendix 7, paragraph 4.4.1.2.

   6) Restart the process at step (a).

b) Else if there are hardware or software changes to the nvPMmi affecting data acquisition and/or processing then the following step is followed:

   1) Move to Step (a.1)

c) Else if the nvPMmi calibration is not current, and the DFCAS model is new or if the DFCAS settings or fuel type are changed in a way that the calibration factor (the relationship between instrument response and TOT reference) may be significantly different, then the following steps are taken:

   1) The nvPMmi is calibrated with the new DFCAS, as stated in Appendix 7, paragraph 8.3.2.8, using the "calibration with a new diffusion flame combustion aerosol source (number of tests)" column stated in Appendix 7, Table A7-7.

   2) Move to step (a.3)

d) Else if the nvPMmi calibration is not current, and the DFCAS verification has been confirmed,

   1) then an annual calibration of the nvPMmi is performed as stated in Appendix 7, paragraph 8.5.

   2) Perform nvPM test

e) Else if the nvPMmi is an existing instrument make and model, approved and with a current calibration.

Perform nvPM test.

15.21. Appendix 7, 8.3.2: Measurement using a diffusion flame combustion aerosol source: conformity demonstration and annual calibration

The calibration system for nvPM measurements should be located in a well-ventilated area and must contain at least a diffusion flame combustion source, an adjustable dilution system, a cyclone or other large particle remover, a plenum manifold system or a splitter, a quartz filter sampler or semi-continuous EC/OC analyser and the nvPM mass measurement instrument. Other diagnostic instruments may also be used. The sampling lines downstream of the plenum or splitter should be of matching material (stainless steel or carbon loaded polytetrafluoroethylene (PTFE)) and same geometry and flow rates to match particle losses in each sample line. An example calibration system is illustrated in Figure 2-14 and the components identified in Table 2-4.

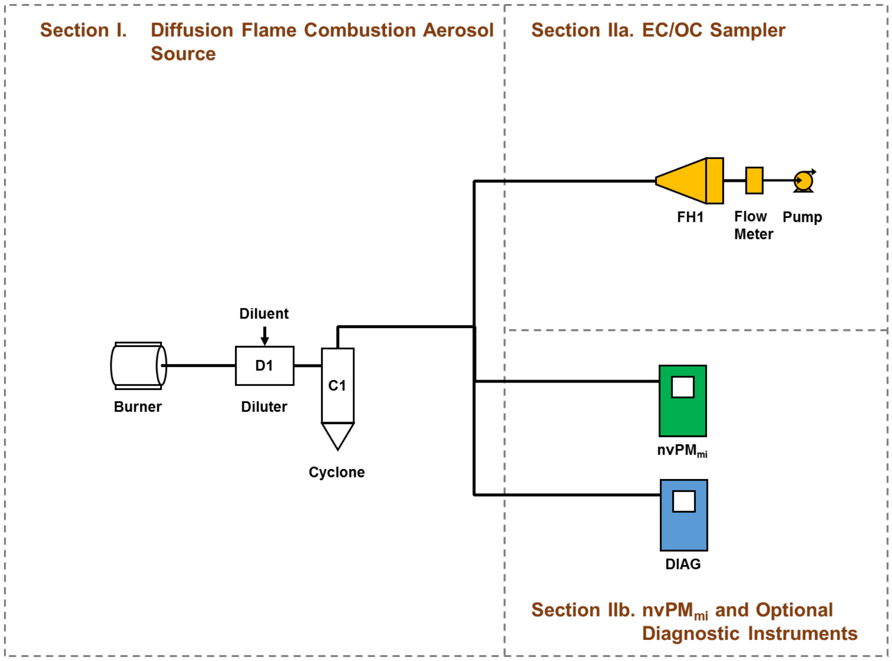


Figure 2-14. Schematic of an example instrument calibration system

Table 2-4. Breakdown of sections and major components of calibration system

Section	*I — PM combustion source*	*II — Sample collection*	
Sub-section	I. Diffusion flame combustion aerosol source	IIa. EC/OC analysis	IIb. nvPMmi and diagnostic analyser(s)
Major component(s)	Burner: diffusion flame burner C1: 1 µm cut point stainless steel cyclone D1: diluter (air or N_2) D2 : Ejector venturi pump M1 : Mixing plenum M2 : Manifold sampling region	Either: FH1: stainless steel quartz filter holder for EC/OC determination using manual filter preparation and laboratory EC/OC analyser (shown) or Semi continuous EC/OC analyser (not shown)	nvPMmi A-DIAG: optional diagnostic particle analyser

In the system shown in Figure 2-14, soot particles are created in the diffusion flame, the characteristics of which will depend on the flow of fuel, air and diluent provided to the burner. Upon leaving the burner, the exhaust stream is diluted as necessary to meet the target soot concentrations. Large particles are then removed in the cyclone and the sample stream is distributed to the various instruments for analysis.

Care should be taken if using a splitter assembly. Best aerosol physics judgement should be used to avoid a potential for particle concentration bias between sampling legs. To reduce risk of a concentration bias between the filter sampler and instrument, plenum manifold systems are typically the preferred choice for instrument calibration systems, as long as the source aerosol is well mixed.

The exact instrumentation set-up should be based on the standard operating procedure for each instrument being calibrated. One example set-up using a splitter is shown in Figure 2-15. Another suitable system using an ejector, plenum and manifold is shown in Figure 2-16.

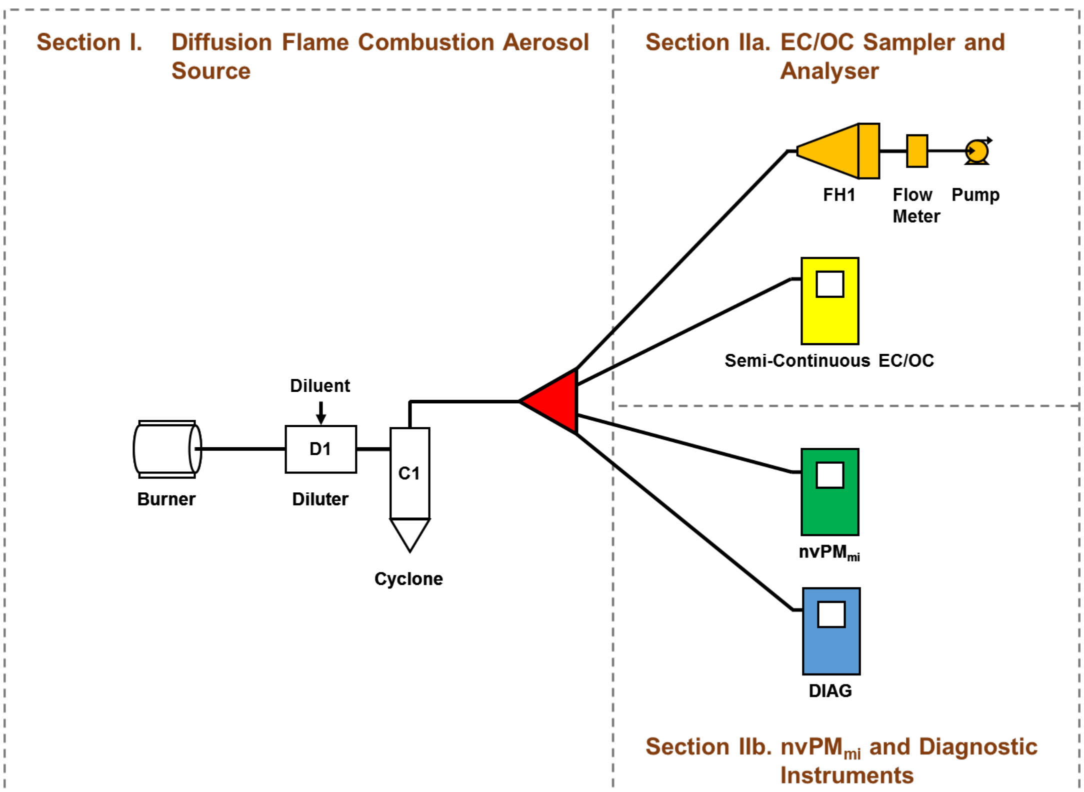


Figure 2-15. Schematic of an example instrument calibration system using a splitter

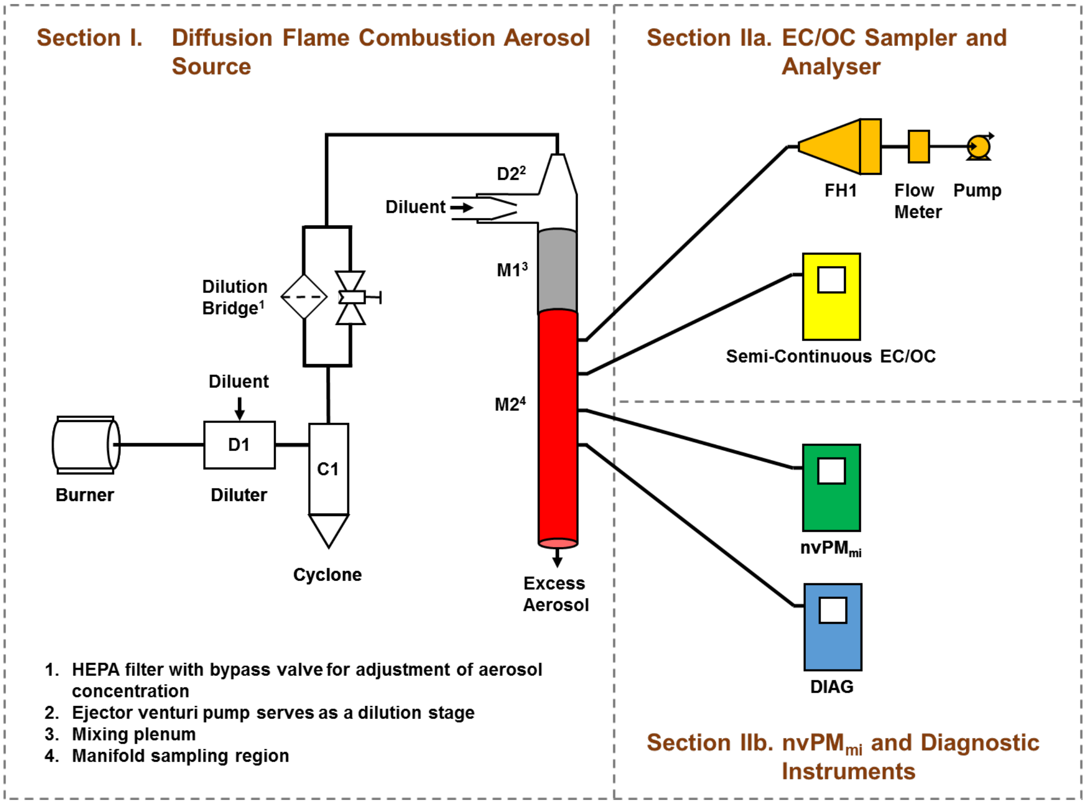


Figure 2-16. Schematic of an example instrument calibration system with a manifold located behind the cyclone

15.22. Appendix 7, 8.4.4: Determining the limit of detection (LOD) of the nvPMmi

Equivalent methods of determining the limit of detection (LOD) are present in the technical literature and international standard. ISO 11843-1: 1997 Capability of Detection Part 1 Terms and Definitions provides the following:

- **minimum detectable net concentration or amount**

  true net concentration or amount of the analyte in the material to be analysed which will lead, with probability (1 - β), to the conclusion that the concentration or amount of the analyte in the analysed material is larger than that in the blank material

International Union of Pure and Applied Chemistry (IUPAC) and ISO detection limits (minimum detectable amounts) are based on the theory of hypothesis testing and the probabilities of false positives α and false negatives β. The limit of detection is given as:

$$L_D = K_\alpha \sigma_0 + K_\beta \sigma_D$$

where K_α and α are associated with the one-sided tails of the distribution of the blank, with standard deviation σ_0 corresponding to probability levels (1-α). Similarly, K_β and β are associated with the one-sided tails of the distribution of the limit of detection with standard deviation σ_D corresponding to probability levels (1- β). The latter is obtained at a low concentration near the detection limit. Often, it can be assumed that α=β and σ=constant, such that $K_\alpha = K_\beta$ and $\sigma_D = \sigma_0$. This assumption implies that the LOD varies with twice the critical level, L_C, which is defined as:

$L_C = K_\alpha \sigma_0$.

The values of α and β recommended by IUPAC and ISO documents are 0.05 each. If σ_0 is estimated by s_0, based on v degrees of freedom, K can be replaced by Student's t, such that:

$L_C = t_{v,0.95}\, s_0$

and

$L_D = 2\, t_{v,0.95}\, s_0$

which contributed to the formulation found in ISO 9169. Based on the assumptions that α=β and σ=constant, such that $K_\alpha = K_\beta$ and $\sigma_D=\sigma_0$, then by corollary $s_D=s_0$ and:

$L_D = 2\, t_{v,0.95}\, s_D$.An equivalent procedure for determining the limit of detection is:

$$Y_{LOD,0.95} = 2 \times t_{v,0.95} \times s_{LOD}$$

where:

$Y_{LOD,0.95}$ = Limit of detection at 95 per cent confidence interval

$t_{v,0.95}$ = The one-sided Student's factor at 95 per cent confidence, degrees of freedom $v=n-1$ where n is the number of measurements (repeats at a recommended 30 second averaging time)

s_{LOD} = The standard deviation of the measurements $Y_{LOD,j}$ obtained by measuring at a concentration near the limit of detection over the averaging time.

15.23. Appendix 7, 8.5: Annual calibration using a DFCAS

The change in nvPMmi annual calibration factor should not exceed the Accuracy performance specification (±10 per cent).

15.24. Appendix 7, 8.5.6: Context of "as found" performance for nvPM mass instrument calibration

In the context of instrument calibration, "as found" is the condition in which the instrument was received by the laboratory performing the calibration prior to any alterations or adjustments. The "as found" condition is an indication of the operability of the instrument since its last calibration. Evaluating the instrument in this manner is useful for understanding instrument drift.

15.25. Appendix 7, 9.2.1: Context of "as found" performance for VPR calibration

In the context of instrument calibration, "as found" is the condition in which the instrument was received by the laboratory performing the calibration prior to any alterations or adjustments. A certificate stating the "as found" values should be requested. For the VPR, dilution factors, particle penetration and particle removal efficiency should be reported. The "as found" condition is an indication of the state of operability of the instrument since its last calibration. Evaluating the instrument in this manner is useful for understanding instrument drift.

9.2.2 CPC calibration

15.26. Appendix 7, 9.2.2: Context of "as found" performance for CPC calibration

In the context of instrument calibration, "as found" is the condition in which the instrument was received by the laboratory performing the calibration prior to any alterations or adjustments. A certificate stating the "as found" values should be requested. For a CPC, these values would include inlet flow, temperatures and pressures, laser and optic checks, zero count test, lower detection and concentration linearity tests. Evaluating the instrument in this manner is useful for understanding instrument drift.

15.27. Appendix 7, 10: Additional system checks prior to an engine test

If new system components are being utilized, it may be beneficial to perform additional system checks prior to an engine test to ensure the nvPM sampling and measurement system operates correctly during an engine test. An example of a new system component is a different type of probe.

To check that summation of the flows in Module 5 match that of Module 3 flowrate, an optional flow measurement check may be performed by disconnecting Module 3 from Module 2 and placing a flow meter at Module 3 inlet to verify that the flow is within 25 slpm ± 2 slpm, while ensuring flow rates in each Splitter 2 flow path are equal to those to be used during engine test.

To help ensure Diluter 1 operability at low power engine conditions, when probe inlet pressure is low, an optional operational check may be performed prior to the engine test using the following recommended procedure:

a) CO_2 calibration gas containing between 3 per cent to 5 per cent CO_2 should be connected to the sampling probe without over-pressurising the probe tip inlet, such that the calibration gas enters Section 1 near ambient pressure.

b) The nvPM sampling and measurement system should be operated at the flow rates and temperatures used during engine testing.

c) P_1 pressure control valve and the optional shut-off valve on the excess sample flow path should be closed.

d) DF_1 should be calculated. If DF_1 is found to be above 14, then the GL flow rate should be reduced.

Blockage of Diluter 1 orifice nozzle may cause DF_1 to increase above 14 indicating that the orifice needs to be cleaned. The flow schematic for the optional Diluter 1 operability check is shown in Figure 2-17.

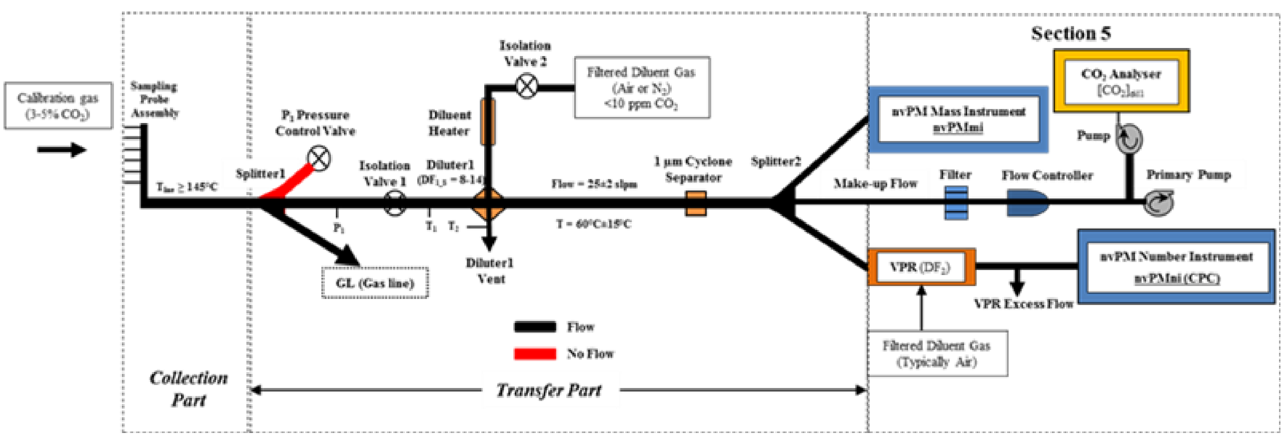


Figure 2-17. Flow schematic for Diluter 1 operability check

15.28. Appendix 7, 10.5.1.1: Ambient nvPM measurement

Ambient nvPM mass and number concentrations are measured to monitor for elevated nvPM levels entrained into the engine inlet air that could contaminate low measurements of engine exhaust nvPM emissions.

Inside an enclosed testbed, during engine preparation and prior to an engine start, there may be sources of nvPM that can cause ambient nvPM levels to be slightly elevated. For example, use of near-vicinity vehicles or cherrypickers. To reduce ambient nvPM to representative levels, the testbed air needs to be flushed through with outside ambient air. One possible flushing method is to utilise test cell fans, if installed. Another possible method is to use entrained air from a running engine. Depending on the size of the test cell and air flow, it could take a few minutes to flush through thoroughly. Thus for testbed flushing methods a minimum of 5 minutes operation is recommended prior to obtaining an ambient nvPM measurement.

15.29. Appendix 7, 10.6: VPR dilution factor calibration check using real time measurements of CO_2

An alternative to performing the operational VPR dilution checks of the DF_2 values from a competent laboratory is using real time measurements of CO_2 at the CPC inlet downstream of the second stage dilution, $[CO2]_{dil2}$, as shown in Figure 2-18.

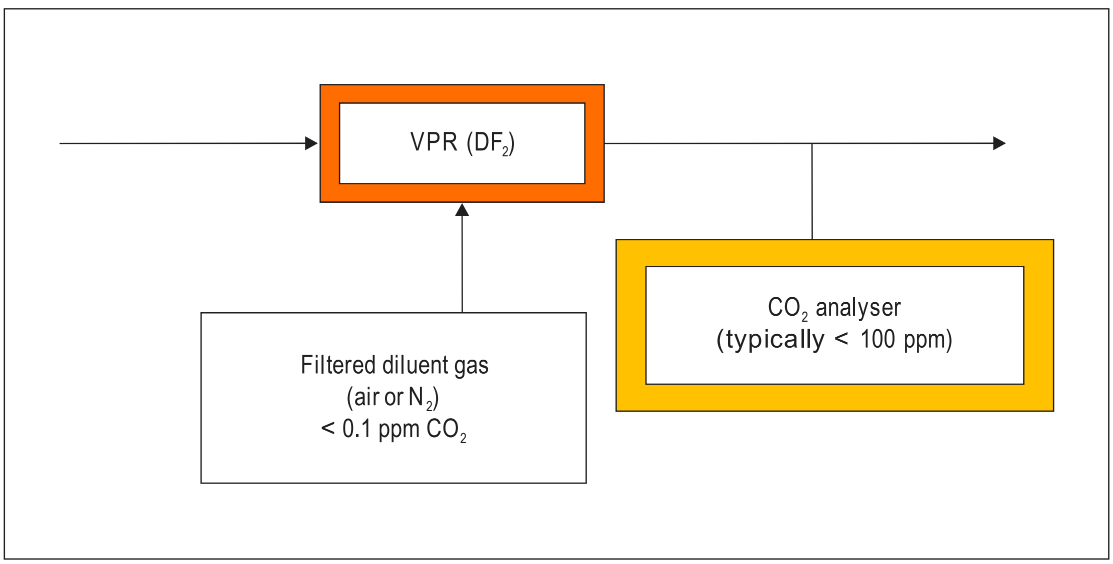


Figure 2-18. Alternative set-up to determine DF_2

CO_2 measurement capability for concentration levels as low as 5 ppm is needed for this procedure. The suitable range for the CO_2 analyser is typically 30 to 70 ppm full scale. Ideally, the measured sample gas concentrations should be in the 20 to 95 per cent full scale range. If this alternative check is performed, the VPR diluent gas should contain less than 0.1 ppm of CO_2. The sample does not need to be dried.

During an engine test, DF_2 as calculated below should be used to check if the VPR meets the calibration DF_2 values provided by the competent laboratory.

$$DF_2 = \frac{[CO_2]_{dil1}}{[CO_2]_{dil2}}$$

In addition, using this option eliminates the need for dilution factor operational checks pre and post engine test series.

16. Attachments to ICAO A16V2

16.1. Symbols

16.2. Attachment A, 1: Symbols

L is the interference effect of CO_2 on the measurement of CO interpreted in terms of a zero shift.

L' is the interference effect of CO_2 on the measurement of NO and NOx interpreted in terms of a sensitivity change.

Note.— The values of these interference effects are specific to, and must be determined for, the individual analysers.

16.3. Attachment A, 1: Symbols

M is the interference effect of H_2O on the measurement of CO interpreted in terms of a zero shift.

M' is the interference effect of H_2O on the measurement of NO and NOx interpreted in terms of a sensitivity change.

Note.— The values of these interference effects are specific to, and must be determined for, the individual analysers.

17. Basis of calculation of EI and AFR parameters

17.1. Attachment A, 2.1: Basis of Calculation of EI and AFR Parameters (AFR formulation)

This is a slightly different formulation for AFR than that stated in Annex 16, Volume II, Appendix 3, 7.1.2, “Basic parameters”. In this formulation *m,* the “number of C atoms in characteristic fuel molecule” is placed within the bracket. There is no particular advantage to using one formulation over the other.

17.2. Attachment A, 2.5: Basis of Calculation of EI and AFR Parameters (interference effects)

With a zero-shift interference effect, the interfering species creates an offset on the measurement, which does not vary with the concentration measured. This is the case for the interference of CO_2 and H_2O on CO.

With a sensitivity change interference effect, the interfering species modifies the slope of the response of the analyser; therefore, the effect is proportional to the concentration measured. This is the case for the interference of CO_2 and H_2O on NO.

Note.— The values of these interference effects are specific to, and must be determined for, the individual analysers.

18. Alternative Methodology — Numerical Solution

18.1. Attachment A, 4: Alternative Methodology – Numerical Solution

Details explaining various calculation procedures can be found in SAE Aerospace Recommended Practice (ARP) 1533C — *Procedure for the Analysis and Evaluation of Gaseous Emissions from Aircraft*

Engines. ARP1533C includes, among other things, derivation of equations, the combustion chemical equation and a matrix method of solving the combustion chemical equation.

19. Additional Guidance

19.1. Engine Emissions Data Assurance Program (EDAP)

The Engine Emissions Data Assurance Program (EDAP) consists of three products designed to provide guidance, validation and quality assurance for the acquisition and reporting of engine emissions data that is generated by manufacturers during engine certification. EDAP users may include the FAA's Office of Environment and Energy (AEE-300), FAA ACOs and ECO, ODA Unit Members, Designated Engineering Representatives (DERs) and others that are interested in the acquisition and reporting of engine emissions data.

The Engine EDAP products include 1) a spreadsheet tool that uses smoke and emissions test data to automatically calculate emissions indices in a format needed to show compliance with applicable emissions regulations, 2) a User Guide for the EDAP Spreadsheet Tool which defines the functionality of the tool, underlying calculations, and reportable emissions data, and 3) checklists that specify various gaseous emissions and smoke number sampling requirements pursuant to A16V2 and requirements for data reporting.

The Engine EDAP Spreadsheet Tool is similar to other programs that manufactures may use to manage engine test data, calculate characteristic emissions and determine compliance with part 34. EDAP enables users to assess the quality of emissions certification data that is being acquired and processed and, in turn, generated and reported for compliance purposes.

The Engine EDAP spreadsheet tool, User Guide and checklists may be obtained from AEE-300 by contacting the AEE-300 Emissions Division Manager with Office of Environment and Energy at 202-267-3576 or 202-267-3577.

19.2. Additional Information

For additional information on this AC or other aviation environmental topics, please contact the AEE-300 Emissions Division Manager with the Office of Environment and Energy at 202-267-3576 or 202-267-3577.

20. Attachment 1: 14 CFR 34.1 Definitions

As used in this Advisory Circular, all terms not defined herein shall have the meaning given them in the Clean Air Act, as amended (42 U.S.C. 7401 et. seq.):appendices

Act means the Clean Air Act, as amended (42 U.S.C. 7401 et. seq.)

Administrator means the Administrator of the Federal Aviation Administration or any person to whom he has delegated his authority in the matter concerned.

Administrator of the EPA means the Administrator of the Environmental Protection Agency and any other officer or employee of the Environmental Protection Agency to whom the authority involved may be delegated.

Aircraft as used in this part means any airplane as defined in 14 CFR part 1.1 for which a U.S. standard airworthiness certificate or equivalent foreign airworthiness certificate is issued.

Aircraft engine means a propulsion engine which is installed in, or which is manufactured for installation in, an aircraft.

Aircraft gas turbine engine means a turboprop, turbofan, or turbojet aircraft engine.

Characteristic level has the meaning given in Appendix 6 of ICAO Annex 16 as of July 2008. The characteristic level is a calculated emission level for each pollutant based on a statistical assessment of measured emissions from multiple tests.

Class TP means all aircraft turboprop engines.

Class TF means all turbofan or turbojet aircraft engines or aircraft engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines except engines of class T3, T8, and TSS.

Class T3 means all aircraft gas turbine engines of the JT3D model family.

Class T8 means all aircraft gas turbine engines of the JT8D model family.

Class TSS means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

Commercial aircraft engine means any aircraft engine used or intended for use by an “air carrier” (including those engaged in “intrastate air transportation”) or a “commercial operator” (including those engaged in “intrastate air transportation”) as these terms are defined in Title 49 of the United States Code and Title 14 of the Code of Federal Regulations.

Commercial aircraft gas turbine engine means a turboprop, turbofan, or turbojet commercial aircraft engine..

Date of manufacture of an engine is the date the inspection acceptance records reflect that the engine is complete and meets the FAA approved type design.

Derivative engine for emissions certification purposes means an engine that is similar in design to an engine that has demonstrated compliance with the applicable exhaust emission standards of this part, as determined by the FAA, and has a U.S. type certificate issued in accordance with part 33 of this chapter.

Emission measurement system means all of the equipment necessary to transport the emission sample and measure the level of emissions. This includes the sample system and the instrumentation system.

Engine model means all commercial aircraft turbine engines which are of the same general series, displacement, and design characteristics and are approved under the same type certificate.

Excepted, as used in 14 CFR § 34.9, means an engine that may be produced and sold that does not meet otherwise applicable standards. [See “except,” above.] Excepted engines must conform to regulatory conditions specified for an exception in § 34.9. Excepted engines are subject to the standards of this part even though they are not required to comply with the otherwise applicable requirements. Engines excepted with respect to certain standards must comply with other standards from which they are not specifically excepted.

Exempt means an engine that does not meet certain applicable standards but may be produced and sold under the terms allowed by a grant of exemption issued pursuant to § 34.7 of this part and part 11 of this chapter. Exempted engines must conform to regulatory conditions specified in the exemption as well as other applicable regulations. Exempted engines are subject to the standards of this part even though they are not required to comply with the otherwise applicable requirements. Engines exempted with respect to certain standards must comply with other standards as a condition of the exemption.

Exhaust emissions means substances emitted into the atmosphere from the exhaust discharge nozzle of an aircraft or aircraft engine.

In-use aircraft gas turbine engine means an aircraft gas turbine engine which is in service.

Introduction date means the date of manufacture of the first individual production engine of a given engine model or engine type certificate family to be certificated. Neither test engines nor engines not placed into service affect this date.

New aircraft turbine engine means an aircraft gas turbine engine which has never been in service.

Non-volatile particulate matter (nvPM) means emitted particles that remain at the exhaust nozzle exit plane of a gas turbine engine, and that did not volatilize after being heated to a temperature of at least 350º C.

Power setting means the power or thrust output of an engine in terms of kilonewtons thrust for turbojet and turbofan engines or shaft power in terms of kilowatts for turboprop engines.

Rated output (rO) means the maximum power/thrust available for takeoff at standard day conditions as approved for the engine by the Federal Aviation Administration, including reheat contribution where applicable, but excluding any contribution due to water injection, expressed in kilowatts or kilonewtons (as applicable), rounded to at least three significant figures.

Rated pressure ratio (rPR) means the ratio between the combustor inlet pressure and the engine inlet pressure achieved by an engine operation at rated output, rounded to at least three significant figures.

Reference day conditions means the reference ambient conditions to which the gaseous emissions (HC and smoke) are to be corrected. The reference day conditions are as follows: Temperature = 15 °C, specific humidity = 0.00634 kg H2O/kg of dry air, and pressure = 101325 Pa.

Sample system means the system which provides for the transportation of the gaseous emission sample from the sample probe to the inlet of the instrumentation system.

Shaft power means only the measured shaft power output of a turboprop engine.

Smoke means the matter in exhaust emissions which obscures the transmission of light..

Smoke number (SN) means the dimensionless term quantifying smoke emissions.

Standard day conditions means the following ambient conditions: temperature = 15 °C, specific humidity = 0.00634 kg H2O/kg dry air, and pressure = 101.325 kPa. 14 CFR 34.1.

Taxi/idle (in) means those aircraft operations involving taxi and idle between the time of landing roll-out and final shutdown of all propulsion engines.

Taxi/idle (out) means those aircraft operations involving taxi and idle between the time of initial starting of the propulsion engine(s) used for the taxi and the turn onto the duty runway. 14 CFR 34.1.

Tier, as used in [Part 14], is a designation related to the NO_X emission standard for the engine as specified in § 34.21 or § 34.23 of this part (e.g., Tier 0).

21. Attachment 2: 14 CFR 34.2 Abbreviations

The abbreviations used in this part have the following meanings in both upper and lower case:

CO_2 Carbon dioxide

CO Carbon monoxide

EI Emissions index

EPA United States Environmental Protection Agency

FAA Federal Aviation Administration, United States Department of Transportation

g Gram(s)

HC Hydrocarbon(s)

HP Horsepower

hr Hour(s)

H_2O water

kg Kilogram(s)

kJ Kilojoule(s)

kN Kilonewton(s)

kW Kilowatt(s)

lb Pound(s)

lbf Pound force

LTO Landing and takeoff

m Meter

mg Milligram

µg Microgram

min Minute(s)

NOX Oxides of nitrogen

nvPM Non-volatile particulate matter

$nvPM_{mass}$ (ICAO EImass) Non-volatile particulate matter mass

$nvPM_{num}$ (ICAO EI_{num}) Non-volatile particulate matter number

$nvPM_{MC}$ (ICAO $nvPM_{mass}$) Non-volatile particulate matter massmass concentration

Pa Pascal(s)

rO Rated output

rPR Rated pressure ratio

sec Second(s) SN Smoke number

SP Shaft power

T Temperature, degrees Kelvin

TIM Time in mode

° Degree

°C Degrees Celsius

% Percent

[Doc. No. 25613, 55 FR 32861, Aug. 10, 1990, as amended by Amdt. 34-3, 64 FR 5559, Feb. 3, 1999; Amdt. 34-5, 77 FR 76850, Dec. 31, 2012]

22. Attachment 3: ICAO Annex 16, Volume II, Amendment 9, July, 2017, Appendix 6, Table A6-1

Table A6-1. Coefficients to determine characteristic levels

Number of engines tested (i)		***CO***		***HC***		***NOx***		***SN***		***nvPM mass concentration***	***nvPM LTO mass***	***nvPM LTO number***	
1		0.814 7		0.649 3		0.862 7		0.776 9		0.776 9	0.719 4	0.719 4	
2		0.877 7		0.768 5		0.909 4		0.852 7		0.852 7	0.814 8	0.814 8	
3		0.924 6		0.857 2		0.944 1		0.909 1		0.909 1	0.885 8	0.885 8	
4		0.934 7		0.876 4		0.951 6		0.921 3		0.921 3	0.901 1	0.901 1	
5		0.941 6		0.889 4		0.956 7		0.929 6		0.929 6	0.911 6	0.911 6	
6		0.946 7		0.899 0		0.960 5		0.935 8		0.935 8	0.919 3	0.919 3	
7		0.950 6		0.906 5		0.963 4		0.940 5		0.940 5	0.925 2	0.925 2	
8		0.953 8		0.912 6		0.965 8		0.944 4		0.944 4	0.930 1	0.930 1	
9		0.956 5		0.917 6		0.967 7		0.947 6		0.947 6	0.934 1	0.934 1	
10		0.958 7		0.921 8		0.969 4		0.950 2		0.950 2	0.937 5	0.937 5	
more than 10		$1-\frac{0.130\ 59}{\sqrt{i}}$		$1-\frac{0.247\ 24}{\sqrt{i}}$		$1-\frac{0.096\ 78}{\sqrt{i}}$		$1-\frac{0.157\ 36}{\sqrt{i}}$		$1-\frac{0.157\ 36}{\sqrt{i}}$	$1-\frac{0.197\ 78}{\sqrt{i}}$	$1-\frac{0.197\ 78}{\sqrt{i}}$	