



ICAO

International Standards
and Recommended Practices

Annex 16 to the Convention on International Civil Aviation

Environmental Protection

Volume II — Aircraft Engine Emissions
Fourth Edition, July 2017



This edition supersedes, on 1 January 2018, all previous editions of Annex 16, Volume II.

For information regarding the applicability of the Standards and Recommended Practices, see the Foreword.

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AMENDMENTS

Amendments are announced in the supplements to the *Products and services Catalogue*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

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FOREWORD

Historical background

In 1972 the United Nations Conference on the Human Environment was held in Stockholm. The position of ICAO at this Conference was developed in Assembly Resolution A18-11 which contained the following clause among others:

- “2. in fulfilling this role ICAO is conscious of the adverse environmental impact that may be related to aircraft activity and its responsibility and that of its member States to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the human environment;”

The 18th Assembly also adopted Resolution A18-12 relating to the environment which states:

“THE ASSEMBLY:

1. REQUESTS the Council, with the assistance and co-operation of other bodies of the Organization and other international organizations to continue with vigour the work related to the development of Standards, Recommended Practices and Procedures and/or guidance material dealing with the quality of the human environment;”

This resolution was followed up by the establishment of an ICAO Action Programme Regarding the Environment. As part of this Action Programme a Study Group was established to assist the Secretariat in certain tasks related to aircraft engine emissions. As a result of the work of this Study Group, an ICAO Circular entitled *Control of Aircraft Engine Emissions* (Circular 134) was published in 1977. This Circular contained guidance material in the form of a certification procedure for the control of vented fuel, smoke and certain gaseous emissions for new turbojet and turbofan engines intended for propulsion at subsonic speeds.

It was agreed by the Council that the subject of aircraft engine emissions was not one that was solely confined to objective technical issues but was one that needed consideration by experts in many fields and included the direct views of Member States. A Council committee, known as the Committee on Aircraft Engine Emissions (CAEE) was therefore established in 1977 to pursue a number of aspects of the subject.

At the second meeting of the Committee on Aircraft Engine Emissions, held in May 1980, proposals were made for material to be included in an ICAO Annex. After amendment following the usual consultation with Member States of the Organization, the proposed material was adopted by the Council to form the text of this document. The Council agreed that it was desirable to include all provisions relating to environmental aspects of aviation in one Annex. It therefore renamed Annex 16 as “Environmental Protection”, making the existing text of the Annex into “Volume I — Aircraft Noise”, the material contained in this document becoming “Volume II — Aircraft Engine Emissions”.

Applicability

Part I of Volume II of Annex 16 contains definitions and symbols and Part II contains Standards relating to vented fuel. Part III contains Standards relating to emissions certification applicable to the classes of aircraft engines specified in the individual chapters of the Part, where such engines are fitted to aircraft engaged in international civil aviation. Part IV provides recommendations for non-volatile particular matter assessment for inventory and modelling purposes.

Action by Contracting States

Notification of differences. The attention of Contracting States is drawn to the obligation imposed by Article 38 of the Convention by which Contracting States are required to notify the Organization of any differences between their national regulations and practices and the International Standards contained in this Annex and any amendments thereto. Contracting States are invited to extend such notification to any differences from the Recommended Practices contained in this Annex, and any amendments thereto, when the notification of such differences is important for the safety of air navigation. Further, Contracting States are invited to keep the Organization currently informed of any differences which may subsequently occur, or of the withdrawal of any differences previously notified. A specific request for notification of differences will be sent to Contracting States immediately after the adoption of each amendment to this Annex.

The attention of States is also drawn to the provisions of Annex 15 related to the publication of differences between their national regulations and practices and the related ICAO Standards and Recommended Practices through the Aeronautical Information Service, in addition to the obligation of States under Article 38 of the Convention.

Use of the Annex text in national regulations. The Council, on 13 April 1948, adopted a resolution inviting the attention of Contracting States to the desirability of using in their own national regulations, as far as is practicable, the precise language of those ICAO Standards that are of a regulatory character and also of indicating departures from the Standards, including any additional national regulations that were important for the safety or regularity of international air navigation. Wherever possible, the provisions of this Annex have been written in such a way as to facilitate incorporation, without major textual changes, into national legislation.

Status of Annex components

An Annex is made up of the following component parts, not all of which, however, are necessarily found in every Annex; they have the status indicated.

1.— Material comprising the Annex proper:

- a) *Standards and Recommended Practices* adopted by the Council under the provisions of the Convention. They are defined as follows:

Standard: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as necessary for the safety or regularity of international air navigation and to which Contracting States will conform in accordance with the Convention; in the event of impossibility of compliance, notification to the Council is compulsory under Article 38.

Recommended Practice: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as desirable in the interest of safety, regularity or efficiency of international air navigation, and to which Contracting States will endeavour to conform in accordance with the Convention.

- b) *Appendices* comprising material grouped separately for convenience but forming part of the Standards and Recommended Practices adopted by the Council.
- c) *Provisions* governing the applicability of the Standards and Recommended Practices.
- d) *Definitions* of terms used in the Standards and Recommended Practices which are not self-explanatory in that they do not have accepted dictionary meanings. A definition does not have an independent status but is an essential part of each Standard and Recommended Practice in which the term is used, since a change in the meaning of the term would affect the specification.

- e) *Tables and Figures* which add to or illustrate a Standard or Recommended Practice and which are referred to therein, form part of the associated Standard or Recommended Practice and have the same status.

2.— Material approved by the Council for publication in association with the Standards and Recommended Practices:

- a) *Forewords* comprising historical and explanatory material based on the action of the Council and including an explanation of the obligations of States with regard to the application of the Standards and Recommended Practices ensuing from the Convention and the Resolution of Adoption.
- b) *Introductions* comprising explanatory material introduced at the beginning of parts, chapters or sections of the Annex to assist in the understanding of the application of the text.
- c) *Notes* included in the text, where appropriate, to give factual information or references bearing on the Standards or Recommended Practices in question, but not constituting part of the Standards or Recommended Practices.
- d) *Attachments* comprising material supplementary to the Standards and Recommended Practices, or included as a guide to their application.

Disclaimer regarding patents

Attention is drawn to the possibility that certain elements of Standards and Recommended Practices in this Annex may be the subject of patents or other intellectual property rights. ICAO shall not be responsible or liable for not identifying any or all such rights. ICAO takes no position regarding the existence, validity, scope or applicability of any claimed patents or other intellectual property rights, and accepts no responsibility or liability therefore or relating thereto.

Selection of language

This Annex has been adopted in six languages — English, Arabic, Chinese, French, Russian and Spanish. Each Contracting State is requested to select one of those texts for the purpose of national implementation and for other effects provided for in the Convention, either through direct use or through translation into its own national language, and to notify the Organization accordingly.

Editorial practices

The following practice has been adhered to in order to indicate at a glance the status of each statement: *Standards* have been printed in light face roman; *Recommended Practices* have been printed in light face italics, the status being indicated by the prefix **Recommendation**; *Notes* have been printed in light face italics, the status being indicated by the prefix *Note*.

It is to be noted that in the English text the following practice has been adhered to when writing the specifications: Standards employ the operative verb “shall” while Recommended Practices employ the operative verb “should”.

The units of measurement used in this document are in accordance with the International System of Units (SI) as specified in Annex 5 to the Convention on International Civil Aviation. Where Annex 5 permits the use of non-SI alternative units, these are shown in parentheses following the basic units. Where two sets of units are quoted it must not be assumed that the pairs of values are equal and interchangeable. It may, however, be inferred that an equivalent level of safety is achieved when either set of units is used exclusively.

Any reference to a portion of this document which is identified by a number includes all subdivisions of that portion.

Coordination with ISO activity

In the provisions related to certification procedures, use is made of the related specifications developed by the International Organization for Standardization (ISO). In most cases, these specifications have been incorporated by direct reference. However, in some cases, it has been found necessary to modify the specifications to suit ICAO requirements and in such cases the modified material is included in full in this document. The assistance provided by ISO in the development of detailed specifications is recognized.

Table A. Amendments to Annex 16

Amendment	Source(s)	Subject(s)	Adopted Effective Applicable
1st Edition	Special Meeting on Aircraft Noise in the Vicinity of Aerodromes (1969)		2 April 1971 2 August 1971 6 January 1972
1	First Meeting of the Committee on Aircraft Noise	Noise certification of future production and derived versions of subsonic jet aeroplanes and updating of terminology used to describe aircraft weight.	6 December 1972 6 April 1973 16 August 1973
2	Third Meeting of the Committee on Aircraft Noise	Noise certification of light propeller-driven aeroplanes and subsonic jet aeroplanes of 5 700 kg and less maximum certificated take-off weight and guidance on discharge of functions by States in the cases of lease, charter and interchange of aircraft.	3 April 1974 3 August 1974 27 February 1975
3 (2nd Edition)	Fourth Meeting of the Committee on Aircraft Noise	Noise certification standards for future subsonic jet aeroplanes and propeller-driven aeroplanes, other than STOL aeroplanes, and guidelines for noise certification of future supersonic aeroplanes, propeller-driven STOL aeroplanes and installed APU and associated aircraft systems when operating on the ground.	21 June 1976 21 October 1976 6 October 1977
4 (3rd Edition)	Fifth Meeting of the Committee on Aircraft Noise	Introduction of a new parameter, viz. number of engines in the noise certification standards for subsonic jet aeroplanes, improvements in detailed test procedures to ensure that the same level of technology is applied to all types of aircraft, and editorial changes to simplify the language and eliminate inconsistencies.	6 March 1978 6 July 1978 10 August 1978
5 (Annex 16, Volume I — 1st Edition)	Sixth Meeting of the Committee on Aircraft Noise	<ol style="list-style-type: none"> Annex retitled <i>Environmental Protection</i> and to be issued in two volumes as follows: Volume I — <i>Aircraft Noise</i> (incorporating provisions in the third edition of Annex 16 as amended by Amendment 5) and Volume II — <i>Aircraft Engine Emissions</i>. Introduction in Volume I of noise certification Standards for helicopters and for future production of existing SST aeroplanes, updating of guidelines for noise certification of installed APU and associated aircraft systems and editorial amendments including changes to units of measurement to bring the Annex in line with Annex 5 provisions. 	11 May 1981 11 September 1981 26 November 1981
6 (Annex 16, Volume II — 1st Edition)	Second Meeting of the Committee on Aircraft Engine Emissions	Introduction of Volume II containing Standards relating to the control of fuel venting, smoke and gaseous emissions from newly manufactured turbojet and turbofan engines intended for subsonic and supersonic propulsion.	30 June 1981 30 October 1981 18 February 1982

<i>Amendment</i>	<i>Source(s)</i>	<i>Subject(s)</i>	<i>Adopted Effective Applicable</i>
1	First Meeting of the Committee on Aviation Environmental Protection	Changes in test fuel specifications, Appendix 4.	4 March 1988 31 July 1988 17 November 1988
2 (2nd Edition)	Second Meeting of the Committee on Aviation Environmental Protection	a) increased stringency of NOx emissions limits; b) improvements in the smoke and gaseous emissions certification procedure.	24 March 1993 26 July 1993 11 November 1993
3	Third Meeting of the Committee on Aviation Environmental Protection	Amendment of the criteria on calibration and test gases in Appendices 3 and 5.	20 March 1997 20 March 1997
4	Fourth Meeting of the Committee on Aviation Environmental Protection	Increased stringency of NOx emissions limits.	26 February 1999 19 July 1999 4 November 1999
5	Sixth Meeting of the Committee on Aviation Environmental Protection	Increase in stringency of the NOx emissions Standards.	23 February 2005 11 July 2005 24 November 2005
6 (3rd Edition)	Seventh meeting of the Committee on Aviation Environmental Protection	a) clarification of applicable corrections to reference day and reference engine conditions and of the humidity terminology used; b) amendments allowing the use of test fuels outside those specified with certificating authority approval; c) standardization of terminology relating to thrust setting; d) clarification of the appropriate value of fuel flow to be used at each LTO point; and e) amendments to the requirements specifying the materials that may be used in sampling rates.	7 March 2008 20 July 2008 20 November 2008
7	Eighth meeting of the Committee on Aviation Environmental Protection (CAEP/8).	a) increase in stringency of the NOx emissions Standards; b) an update to the references to the <i>Environmental Technical Manual</i> (Doc 9501), Volume II — <i>Procedures for the Emissions Certification of Aircraft Engines</i> ; c) updates to the text to replace “variations in procedures” by “equivalent procedures”, in order to improve consistency and harmonization within Annex 16, Volume II and with the <i>Environmental Technical Manual</i> (Doc 9501), Volume II — <i>Procedures for the Emissions Certification of Aircraft Engines</i> ; d) the format of applicability dates in 2.3.2 made consistent with the convention used in Annex 6 and Annex 16, Volume I; e) improved readability by moving some paragraphs to more appropriate places; and f) minor editorial changes.	4 March 2011 18 July 2011 17 November 2011

<i>Amendment</i>	<i>Source(s)</i>	<i>Subject(s)</i>	<i>Adopted Effective Applicable</i>
8	Ninth meeting of the Committee on Aviation Environmental Protection (CAEP/9)	<ul style="list-style-type: none"> a) amendments to Attachment A to Appendix 3 to update the hydrocarbon (HC) analyser oven temperature range; b) amendments to allow the use of modern instruments for humidity measurement and to update the location of the humidity instrument during emissions certification tests; and c) minor editorial changes associated with terminology, document numbering and typographical changes. 	3 March 2014 14 July 2014 1 January 2015
9 (4th Edition)	Tenth meeting of the Committee on Aviation Environmental Protection (CAEP/10)	<ul style="list-style-type: none"> a) addition of the definition for “type certificate” in Annex 16, Volume II, Part I, Chapter 1; b) clarification of the requirements for the sampling line temperature; c) changes to the calibration gas for the NO_x analyser; d) changes to the naphthalene content for the emissions test fuel specification; e) non-volatile particulate matter (nvPM) engine emissions Standard for turbofan and turbojet engines, with rated thrust greater than 26.7 kN, manufactured from 1 January 2020; f) Annex 16, Volume II consistency with the new nvPM engine emissions Standard; g) correction of minor errors or for consistency. 	3 March 2017 21 July 2017 1 January 2018

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

Where the following expressions are used in Volume II of this Annex, they have the meanings ascribed to them below:

Afterburning. A mode of engine operation wherein a combustion system fed (in whole or part) by vitiated air is used.

Approach phase. The operating phase defined by the time during which the engine is operated in the approach operating mode.

Climb phase. The operating phase defined by the time during which the engine is operated in the climb operating mode.

Date of manufacture. The date of issue of the document attesting that the individual aircraft or engine as appropriate conforms to the requirements of the type or the date of an analogous document.

Derivative version. An aircraft gas turbine engine of the same generic family as an originally type-certificated engine and having features which retain the basic core engine and combustor design of the original model and for which other factors, as judged by the certificating authority, have not changed.

Note.— Attention is drawn to the difference between the definition of “derived version of an aeroplane” in Volume I of Annex 16 and the definition of “derivative version” in this Volume.

Exhaust nozzle. In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines, for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.

Non-volatile particulate matter (nvPM). Emitted particles that exist at a gas turbine engine exhaust nozzle exit plane that do not volatilize when heated to a temperature of 350°C.

Oxides of nitrogen. The sum of the amounts of the nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide.

Rated thrust. For engine emissions purposes, the maximum take-off thrust approved by the certificating authority for use under normal operating conditions at ISA sea level static conditions, and without the use of water injection. Thrust is expressed in kilonewtons.

Reference pressure ratio. The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating in ISA sea level static conditions.

Note.— Methods of measuring reference pressure ratio are given in Appendix 1.

Smoke. The carbonaceous materials in exhaust emissions which obscure the transmission of light.

Smoke Number. The dimensionless term quantifying smoke emissions (*see* 3 of Appendix 2).

Take-off phase. The operating phase defined by the time during which the engine is operated at the rated thrust.

Taxi/ground idle. The operating phases involving taxi and idle between the initial starting of the propulsion engine(s) and the initiation of the take-off roll and between the time of runway turn-off and final shutdown of all propulsion engine(s).

Type certificate. A document issued by a Contracting State to define the design of an aircraft, engine or propeller type and to certify that this design meets the appropriate airworthiness requirements of that State.

Note.— In some Contracting States a document equivalent to a type certificate may be issued for an engine or propeller type.

Unburned hydrocarbons. The total of hydrocarbon compounds of all classes and molecular weights contained in a gas sample, calculated as if they were in the form of methane.

CHAPTER 2. SYMBOLS

Where the following symbols are used in Volume II of this Annex, they have the meanings ascribed to them below:

CO	Carbon monoxide
D_p	The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle
F_n	Thrust in International Standard Atmosphere (ISA), sea level conditions, for the given operating mode
F_{oo}	Rated thrust (<i>see definition</i>)
F^*_{oo}	Rated thrust with afterburning applied
HC	Unburned hydrocarbons (<i>see definition</i>)
NO	Nitric oxide
NO ₂	Nitrogen dioxide
NO _x	Oxides of nitrogen (<i>see definition</i>)
nvPM	Non-volatile particulate matter (<i>see definition</i>)
SN	Smoke Number (<i>see definition</i>)
π_{oo}	Reference pressure ratio (<i>see definition</i>)

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PART II. VENTED FUEL

CHAPTER 1. ADMINISTRATION

1.1 The provisions of this part shall apply to all turbine engine powered aircraft intended for operation in international air navigation manufactured after 18 February 1982.

1.2 Certification related to the prevention of intentional fuel venting shall be granted by the certifying authority on the basis of satisfactory evidence that either the aircraft or the aircraft engines comply with requirements of Chapter 2.

Note.— The document attesting certification relating to fuel venting may take the form of a separate fuel venting certificate or a suitable statement contained in another document approved by the certifying authority.

1.3 Contracting States shall recognize as valid a certification relating to fuel venting granted by the certifying authority of another Contracting State provided the requirements under which such certification was granted are not less stringent than the provision of Volume II of this Annex.

CHAPTER 2. PREVENTION OF INTENTIONAL FUEL VENTING

Aircraft shall be so designed and constructed as to prevent the intentional discharge into the atmosphere of liquid fuel from the fuel nozzle manifolds resulting from the process of engine shutdown following normal flight or ground operations.

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PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

1.1 The provisions of 1.2 to 1.5 shall apply to all engines and their derivative versions included in the classifications defined for emission certification purposes in Chapters 2, 3 and 4 where such engines are fitted to aircraft engaged in international air navigation.

1.2 Emissions certification shall be granted by the certifying authority on the basis of satisfactory evidence that the engine complies with requirements which are at least equal to the stringency of the provisions of Volume II of this Annex. Compliance with the emissions levels of Chapters 2 and 3 shall be demonstrated using the procedure described in Appendix 6.

Note.— The document attesting emissions certification may take the form of a separate emissions certificate or a suitable statement contained in another document approved by the certifying authority.

1.3 The document attesting emissions certification for each individual engine shall include at least the following information which is applicable to the engine type:

- a) name of certifying authority;
- b) manufacturer's type and model designation;
- c) statement of any additional modifications incorporated for the purpose of compliance with the applicable emissions certification requirements;
- d) rated thrust;
- e) reference pressure ratio;
- f) a statement indicating compliance with Smoke Number requirements;
- g) a statement indicating compliance with gaseous pollutant requirements.

1.4 Contracting States shall recognize as valid emissions certification granted by the certifying authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of Volume II of this Annex.

1.5 Contracting States shall recognize as valid engine exemptions for an engine production cut-off requirement granted by a certifying authority of another Contracting State provided that the exemptions are granted in accordance with the process and criteria defined in the *Environmental Technical Manual* (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines*.

CHAPTER 2. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

2.1 General

2.1.1 Applicability

2.1.1.1 The provisions of this chapter shall apply to all turbojet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when certificating authorities make exemptions for:

- a) specific engine types and derivative versions of such engines for which the type certificate of the first basic type was issued or other equivalent prescribed procedure was carried out before 1 January 1965; and
- b) a limited number of engines over a specific period of time beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture of the individual engine.

2.1.1.2 In such cases, an exemption document shall be issued by the certificating authority, the identification plates on the engines shall be marked “EXEMPT NEW” or “EXEMPT SPARE” and the grant of exemption shall be noted in the permanent engine record. Exemptions shall be reported by engine serial number and made available via an official public register.

2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines.

Note.— In considering exemptions, certificating authorities should take into account the probable numbers of such engines that will be produced and their impact on the environment. When such an exemption is granted, the certificating authority should consider imposing a time limit on the production of such engines for installation on new aircraft. Further guidance on issuing exemptions is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

2.1.2 Emissions involved

The following emissions shall be controlled for certification of aircraft engines:

Smoke

Gaseous emissions

Unburned hydrocarbons (HC);
Carbon monoxide (CO); and
Oxides of nitrogen (NO_x).

2.1.3 Units of measurement

2.1.3.1 The smoke emission shall be measured and reported in terms of Smoke Number (SN).

2.1.3.2 The mass (D_p) of the gaseous pollutant HC, CO or NO_x emitted during the reference emissions landing and take-off (LTO) cycle, defined in 2.1.4.2 and 2.1.4.3, shall be measured and reported in grams.

2.1.4 Reference conditions

2.1.4.1 Atmospheric conditions

The reference atmospheric conditions for engine performance shall be ISA at sea level except that the reference absolute humidity shall be 0.00634 kg water/kg dry air.

2.1.4.2 Thrust settings

The engine shall be tested at sufficient thrust settings to define the gaseous and smoke emissions of the engine so that mass emission rates and Smoke Numbers can be determined at the following specific percentages of rated thrust as agreed by the certificating authority:

<i>LTO operating mode</i>	<i>Thrust setting</i>
Take-off	100 per cent F_{oo}
Climb	85 per cent F_{oo}
Approach	30 per cent F_{oo}
Taxi/ground idle	7 per cent F_{oo}

2.1.4.3 Reference emissions landing and take-off (LTO) cycle

The reference emissions LTO cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode.

<i>LTO operating mode</i>	<i>Time in operating mode, minutes</i>
Take-off	0.7
Climb	2.2
Approach	4.0
Taxi/ground idle	26.0

2.1.4.4 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4.

2.1.5 Test conditions

2.1.5.1 The tests shall be made with the engine on its test bed.

2.1.5.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

2.1.5.3 When test conditions differ from the reference atmospheric conditions in 2.1.4.1, the gaseous emissions test results shall be corrected to the reference atmospheric conditions in accordance with the procedures of Appendix 3.

2.2 Smoke

2.2.1 Applicability

The provisions of 2.2.2 shall apply to engines whose date of manufacture is on or after 1 January 1983.

2.2.2 Regulatory Smoke Number

The Smoke Number at any of the four LTO operating mode thrust settings when measured and computed in accordance with the procedures of Appendix 2, or equivalent procedures as agreed by the certifying authority, and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

$$\text{Regulatory Smoke Number} = 83.6 (F_{oo})^{-0.274} \\ \text{or a value of 50, whichever is lower}$$

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

2.3 Gaseous emissions

2.3.1 Applicability

The provisions of 2.3.2 shall apply to engines whose rated thrust is greater than 26.7 kN and whose date of manufacture is on or after 1 January 1986 and as further specified for oxides of nitrogen.

2.3.2 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6, or equivalent procedures as agreed by the certifying authority, shall not exceed the regulatory levels determined from the following formulas:

$$\text{Hydrocarbons (HC): } D_p/F_{oo} = 19.6$$

$$\text{Carbon monoxide (CO): } D_p/F_{oo} = 118$$

Oxides of nitrogen (NOx):

- a) for engines of a type or model for which the date of manufacture of the first individual production model was before 1 January 1996 and for which the date of manufacture of the individual engine was before 1 January 2000:

$$D_p/F_{oo} = 40 + 2\pi_{oo}$$

- b) for engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 1996 or for which the date of manufacture of the individual engine was on or after 1 January 2000:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

- c) for engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2004:

- 1) for engines with a pressure ratio of 30 or less:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 19 + 1.6\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 37.572 + 1.6\pi_{oo} - 0.2087F_{oo}$$

- 2) for engines with a pressure ratio of more than 30 but less than 62.5:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 7 + 2.0\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 42.71 + 1.4286\pi_{oo} - 0.4013F_{oo} + 0.00642\pi_{oo} \times F_{oo}$$

- 3) for engines with a pressure ratio of 62.5 or more:

$$D_p/F_{oo} = 32 + 1.6\pi_{oo}$$

- d) for engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2008 or for which the date of manufacture of the individual engine was on or after 1 January 2013:

- 1) for engines with a pressure ratio of 30 or less:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = 16.72 + 1.4080\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 38.5486 + 1.6823\pi_{oo} - 0.2453F_{oo} - 0.00308\pi_{oo}F_{oo}$$

- 2) for engines with a pressure ratio of more than 30 but less than 82.6:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p/F_{oo} = -1.04 + 2.0\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p/F_{oo} = 46.1600 + 1.4286\pi_{oo} - 0.5303F_{oo} + 0.00642\pi_{oo}F_{oo}$$

- 3) for engines with a pressure ratio of 82.6 or more:

$$D_p / F_{oo} = 32 + 1.6\pi_{oo}$$

- e) for engines of a type or model for which the date of manufacture of the first individual production model was on or after 1 January 2014:

- 1) for engines with a pressure ratio of 30 or less:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p / F_{oo} = 7.88 + 1.4080\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p / F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\pi_{oo}F_{oo}$$

- 2) for engines with a pressure ratio of more than 30 but less than 104.7:

- i) for engines with a maximum rated thrust of more than 89.0 kN:

$$D_p / F_{oo} = -9.88 + 2.0\pi_{oo}$$

- ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$$D_p / F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} F_{oo}$$

- 3) for engines with a pressure ratio of 104.7 or more:

$$D_p / F_{oo} = 32 + 1.6\pi_{oo}$$

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

2.4 Information required

Note.— The information required is divided into three groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; 2) the data obtained from the engine test(s); and 3) the results derived from the test data.

2.4.1 General information

The following information shall be provided for each engine type for which emissions certification is sought:

- a) engine identification;
- b) rated thrust (kN);
- c) reference pressure ratio;

- d) fuel specification reference;
- e) fuel hydrogen/carbon ratio;
- f) the methods of data acquisition;
- g) the method of making corrections for ambient conditions; and
- h) the method of data analysis.

2.4.2 Test information

The following information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in 2.1.4.2. The information shall be provided after correction to the reference ambient conditions where applicable:

- a) fuel flow (kg/s);
- b) emission index (grams/kg) for each gaseous pollutant; and
- c) measured Smoke Number.

2.4.3 Derived information

2.4.3.1 The following derived information shall be provided for each engine tested for certification purposes:

- a) emission rate, i.e. emission index $\times$ fuel flow, (grams/s) for each gaseous pollutant;
- b) total gross emission of each gaseous pollutant measured over the LTO cycle (grams);
- c) values of D_p/F_{oo} for each gaseous pollutant (grams/kN); and
- d) maximum Smoke Number.

2.4.3.2 The characteristic Smoke Number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

CHAPTER 3. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION AT SUPERSONIC SPEEDS

3.1 General

3.1.1 Applicability

The provisions of this chapter shall apply to all turbojet and turbofan engines intended for propulsion at supersonic speeds whose date of manufacture is on or after 18 February 1982.

3.1.2 Emissions involved

The following emissions shall be controlled for certification of aircraft engines:

Smoke

Gaseous emissions

Unburned hydrocarbons (HC);
Carbon monoxide (CO); and
Oxides of nitrogen (NO_x).

3.1.3 Units of measurement

3.1.3.1 The smoke emission shall be measured and reported in terms of Smoke Number (SN).

3.1.3.2 The mass (D_p) of the gaseous pollutants HC, CO, or NO_x emitted during the reference emissions landing and take-off (LTO) cycle, defined in 3.1.5.2 and 3.1.5.3 shall be measured and reported in grams.

3.1.4 Nomenclature

Throughout this chapter, where the expression F^*_{∞} is used, it shall be replaced by F_{∞} for engines which do not employ afterburning. For taxi/ground idle thrust setting, F_{∞} shall be used in all cases.

3.1.5 Reference conditions

3.1.5.1 *Atmospheric conditions*

The reference atmospheric conditions shall be ISA at sea level except that the reference absolute humidity shall be 0.00634 kg water/kg dry air.

3.1.5.2 Thrust settings

The engine shall be tested at sufficient thrust settings to define the gaseous and smoke emissions of the engine so that mass emission rates and Smoke Numbers corrected to the reference ambient conditions can be determined at the following specific percentages of rated thrust as agreed by the certificating authority.

<i>Operating mode</i>	<i>Thrust setting</i>
Take-off	100 per cent F_{oo}^*
Climb	65 per cent F_{oo}^*
Descent	15 per cent F_{oo}^*
Approach	34 per cent F_{oo}^*
Taxi/ground idle	5.8 per cent F_{oo}

3.1.5.3 Reference emissions landing and take-off (LTO) cycle

The reference emissions LTO cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode.

<i>LTO operating mode</i>	<i>Time in operating mode, minutes</i>
Take-off	1.2
Climb	2.0
Descent	1.2
Approach	2.3
Taxi/ground idle	26.0

3.1.5.4 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

3.1.6 Test conditions

3.1.6.1 The tests shall be made with the engine on its test bed.

3.1.6.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

3.1.6.3 Measurements made for determination of emission levels at the thrusts specified in 3.1.5.2 shall be made with the afterburner operating at the level normally used, as applicable.

3.1.6.4 When test conditions differ from the reference conditions in 3.1.5, the test results shall be corrected to the reference conditions in accordance with the procedures of Appendix 5.

3.2 Smoke

3.2.1 Regulatory Smoke Number

The Smoke Number at any thrust setting when measured and computed in accordance with the procedures of Appendix 2 and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the regulatory level determined from the following formula:

$$\text{Regulatory Smoke Number} = 83.6 (F_{oo}^*)^{-0.274}$$

or a value of 50, whichever is lower

Note.— Certifying authorities may alternatively accept values determined using afterburning provided that the validity of these data is adequately demonstrated.

3.3 Gaseous emissions

3.3.1 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 or Appendix 5, as applicable, and converted to characteristic levels by the procedures of Appendix 6 shall not exceed the regulatory levels determined from the following formulas:

$$\text{Hydrocarbons (HC): } D_p/F_{oo}^* = 140(0.92)^{\pi_{oo}}$$

$$\text{Carbon monoxide (CO): } D_p/F_{oo}^* = 4\,550(\pi_{oo})^{-1.03}$$

$$\text{Oxides of nitrogen (NOx): } D_p/F_{oo}^* = 36 + 2.42\pi_{oo}$$

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.

3.4 Information required

Note.— The information required is divided into three groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; 2) the data obtained from the engine test(s); and 3) the results derived from the test data.

3.4.1 The following information shall be provided for each engine type for which emissions certification is sought:

- a) engine identification;
- b) rated thrust (kN);
- c) rated thrust with afterburning applied, if applicable (kN);

- d) reference pressure ratio;
- e) fuel specification reference;
- f) fuel hydrogen/carbon ratio;
- g) the methods of data acquisition;
- h) the method of making corrections for ambient conditions; and
- i) the method of data analysis.

3.4.2 Test information

The following information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in 3.1.5.2. The information shall be provided after correction to the reference ambient conditions where applicable:

- a) fuel flow (kg/s);
- b) emission index (grams/kg) for each gaseous pollutant;
- c) percentage of thrust contributed by afterburning; and
- d) measured Smoke Number.

3.4.3 Derived information

3.4.3.1 The following derived information shall be provided for each engine tested for certification purposes:

- a) emission rate, i.e. emission index $\times$ fuel flow, (grams/s), for each gaseous pollutant;
- b) total gross emission of each gaseous pollutant measured over the LTO cycle (grams);
- c) values of D_p/F^*_{oo} for each gaseous pollutant (grams/kN); and
- d) maximum Smoke Number.

3.4.3.2 The characteristic Smoke Number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.

CHAPTER 4. PARTICULATE MATTER EMISSIONS

4.1 General

4.1.1 Applicability

The provisions of this chapter shall apply to all aircraft engines, intended for propulsion only at subsonic speeds, for which an application for type certification is submitted to the certificating authority. Specific provisions for the relevant engine categories shall apply as detailed in section 4.2.

4.1.2 Emissions involved

The purpose of this section is to control non-volatile particulate matter mass ($\text{nvPM}_{\text{mass}}$) emissions.

4.1.3 Units of measurement

The concentration of nvPM mass ($\text{nvPM}_{\text{mass}}$) shall be reported in $\mu\text{g}/\text{m}^3$.

4.1.4 Reference conditions

4.1.4.1 Atmospheric conditions

The reference atmospheric conditions for the reference standard engine shall be ISA at sea level except that the reference absolute humidity shall be 0.00634 kg water/kg dry air.

4.1.4.2 Reference emissions landing and take-off (LTO) cycle

The engine shall be tested at sufficient thrust settings to define the nvPM emissions of the engine so that nvPM mass emission indices (EI_{mass}) and nvPM number emission indices (EI_{num}) can be determined at the following specific percentages of rated thrust and at thrusts producing maximum $\text{nvPM}_{\text{mass}}$ concentration, maximum EI_{mass} and maximum EI_{num} as agreed by the certificating authority:

<i>LTO operating mode</i>	<i>Thrust setting</i>
Take-off	100 per cent F_{oo}
Climb	85 per cent F_{oo}
Approach	30 per cent F_{oo}
Taxi/ground idle	7 per cent F_{oo}

4.1.4.3 Fuel specifications

The fuel used during tests shall meet the specifications of Appendix 4.

4.1.5 Test conditions

4.1.5.1 The tests shall be made with the engine on its test bed.

4.1.5.2 The engine shall be representative of the certificated configuration (see Appendix 6); off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

4.1.5.3 When test conditions differ from the reference atmospheric conditions in 4.1.4.1, EI_{mass} and EI_{num} shall be corrected to the engine combustor inlet temperature under the reference atmospheric conditions in accordance with the procedures of Appendix 7.

4.1.5.4 The maximum $nvPM_{\text{mass}}$ concentration and EI_{mass} and EI_{num} shall be corrected for thermophoretic losses in the collection part of the sampling system in accordance with the procedures of Appendix 7.

4.2 Non-volatile particulate matter emissions

4.2.1 Applicability

The provisions further specified in 4.2.2 and 4.2.3 shall apply to all turbofan and turbojet engines of a type or model, and their derivative versions, with a rated thrust greater than 26.7 kN and whose date of manufacture of the individual engine is on or after 1 January 2020.

4.2.2 Regulatory levels

The maximum $nvPM_{\text{mass}}$ concentration [$\mu\text{g}/\text{m}^3$] obtained from measurement at sufficient thrust settings, in such a way that the emission maximum can be determined, and computed in accordance with the procedures of Appendix 7 and converted to characteristic levels by the procedures of Appendix 6, or equivalent procedures as agreed by the certifying authority, shall not exceed the level determined from the following formula:

$$\text{Regulatory limit concentration of } nvPM_{\text{mass}} = 10^{(3 + 2.9 F_{\text{OO}}^{-0.274})}$$

4.2.3 Reporting requirement

The manufacturer shall report the following values of $nvPM$ emissions measured and computed in accordance with the procedures of Appendix 7, or any equivalent procedures as agreed by the certifying authority:

- a) characteristic level for the maximum $nvPM_{\text{mass}}$ concentration ($\mu\text{g}/\text{m}^3$);
- b) fuel flow (kg/s) at each thrust setting of the LTO cycle;
- c) EI_{mass} (mg/kg of fuel) at each thrust setting of the LTO cycle;

- d) EI_{num} (particles/kg of fuel) at each thrust setting of the LTO cycle;
- e) maximum EI_{mass} (mg/kg of fuel); and
- f) maximum EI_{num} (particles/kg of fuel).

4.3 Information required

Note.— The information required is divided into two groups: 1) general information to identify the engine characteristics, the fuel used and the method of data analysis; and 2) the data obtained from the engine test(s).

4.3.1 General information

The following information shall be provided for each engine type for which emissions certification is sought:

- a) engine identification;
- b) rated thrust (kN);
- c) reference pressure ratio;
- d) fuel specification reference;
- e) fuel hydrogen/carbon ratio;
- f) the methods of data acquisition;
- g) the method of making corrections for thermophoretic losses in the collection part of the sampling system; and
- h) the method of data analysis.

4.3.2 Test information

For each test the following information shall be reported:

- a) net heat of combustion (MJ/kg);
- b) fuel hydrogen content (mass %);
- c) fuel total aromatics content (volume %);
- d) fuel naphthalenes (volume %); and
- e) fuel sulphur (mass %).

PART IV. NON-VOLATILE PARTICULATE MATTER ASSESSMENT FOR INVENTORY AND MODELLING PURPOSES

Note 1.— The purpose of this part is to provide recommendations on how to calculate the nvPM mass and number correction factors for the nvPM system losses other than the collection part thermophoretic losses. The nvPM system, the collection part and the thermophoretic losses calculation are described in Appendix 7.

Note 2.— The nvPM mass and number system loss correction factors permit an estimation of the concentration of the nvPM mass and number at the exhaust of the aircraft engine from the nvPM mass and number concentration obtained in accordance with the procedures of Appendix 7.

Recommendation 1.— *For inventory and modelling purposes, the aircraft turbine engine manufacturers should determine the nvPM mass and nvPM number system loss correction factors (k_{SL_mass} and k_{SL_num}) using the methodology described in Appendix 8 and should report these factors to the appropriate authority.*

Recommendation 2.— *For inventory and modelling purposes, the nvPM mass and number concentration obtained in accordance with the procedures of Appendix 7 should be corrected for system losses using the methodology described in Appendix 8.*

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APPENDIX 1. MEASUREMENT OF REFERENCE PRESSURE RATIO

1. GENERAL

1.1 Pressure ratio shall be established using a representative engine.

1.2 Reference pressure ratio shall be derived by correlating measured pressure ratio with engine thrust corrected to standard day ambient pressure and entering this correlation at the standard day rated take-off thrust.

2. MEASUREMENT

2.1 Total pressure shall be measured at the last compressor discharge plane and the first compressor front face by positioning at least four probes so as to divide the air flow area into four equal sectors and taking a mean of the four values obtained.

Note.— Compressor discharge total pressure may be obtained from total or static pressure measured at a position as close as possible to the compressor discharge plane. However, the certificating authority may approve alternative means of estimating the compressor discharge total pressure if the engine is so designed that the provision of the probes referred to above is impractical for the emissions test.

2.2 Necessary correlation factors shall be determined during type certification testing using a minimum of one engine and any associated engine component tests and analysis.

2.3 Procedures shall be acceptable to the certificating authority.

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APPENDIX 2. SMOKE EMISSION EVALUATION

1. INTRODUCTION AND DEFINITIONS

Note.— The procedures specified in this appendix are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system.

1.1 Any equivalent procedures to those contained in this appendix shall only be allowed after prior application to and approval by the certifying authority.

1.2 Where the following expressions and symbols are used in this appendix, they have the meanings ascribed to them below:

Sample reference size. The sample mass, 16.2 kg/m^2 of stained filter area, which if passed through the filter material results in a change of reflectance which gives a value of the SN parameter.

Sample size. A chosen exhaust sample, the magnitude of whose mass (expressed in kilograms per square metre of stained filter surface area) lies in the range prescribed in 2.5.3 h) of this appendix which, when passed through the filter material, causes a change in reflectance yielding a value for the SN parameter.

Sample volume. The chosen sample volume (expressed in cubic metres) whose equivalent mass, calculated as indicated in 3 of this appendix, conforms to the above definition of sampling size.

SN Smoke Number; Dimension less term quantifying smoke emission level based upon the staining of a filter by the reference mass of exhaust gas sample, and rated on a scale of 0 to 100 (see 3 of this appendix).

SN' Smoke Number obtained from an individual smoke sample, not necessarily of the sample reference size, as defined in 3 of this appendix.

W Mass of individual exhaust gas smoke sample, in kilograms, calculated from the measurements of sample volume, pressure and temperature (see 3 of this appendix).

2. MEASUREMENT OF SMOKE EMISSIONS

2.1 Sampling probe for smoke emissions

The sampling probe shall meet the following requirements:

- a) The probe material with which the exhaust emission sample is in contact shall be stainless steel or any other non-reactive material.
- b) If a probe with multiple sampling orifices is used, all sampling orifices shall be of equal diameter. The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.
- c) The number of locations sampled shall not be less than 12.
- d) The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameters of the exit plane.

- e) The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed thrust setting.

2.2 Sampling line for smoke emissions

2.2.1 The sample shall be transferred from the probe to the sample collection system via a line of 4.0 to 8.5 mm inside diameter taking the shortest route practicable which shall in no case be greater than 25 m. The line temperature shall be maintained at a temperature between 60°C and 175°C with a stability of $\pm 15^\circ\text{C}$, except for the distance required to cool the gas from the engine exhaust temperature down to the line control temperature.

2.2.2 Sampling lines shall be as “straight through” as possible. Any necessary bends shall have radii which are greater than 10 times the inside diameter of the lines. The material of the lines shall be such as to discourage build-up of particulate matter or static electricity.

Note.— Stainless steel or carbon-loaded grounded polytetrafluoroethylene (PTFE) meets these requirements.

2.3 Smoke analysis system

Note.— The method prescribed herein is based upon the measurement of the reduction in reflectance of a filter when stained by a given mass flow of exhaust sample.

The arrangement of the various components of the system for acquiring the necessary stained filter samples shall be as shown schematically in Figure A2-1. An optional bypass around the volume meter may be installed to facilitate meter reading. The major elements of the system shall meet the following requirements:

- a) *sample size measurement*: a wet or dry positive displacement volume meter shall be used to measure sample volume to an accuracy of ± 2 per cent. The pressure and temperature at entry to this meter shall also be measured to accuracies of 0.2 per cent and $\pm 2^\circ\text{C}$ respectively;
- b) *sample flow rate measurement*: the sample flow rate shall be maintained at a value of 14 ± 0.5 L/min and the flowmeter for this purpose shall be able to make this measurement with an accuracy of ± 5 per cent;
- c) *filter and holder*: the filter holder shall be constructed in corrosion-resistant material and shall have the flow channel configuration shown in Figure A2-1. The filter material shall be Whatman type No. 4, or any equivalent approved by the certificating authority;
- d) *valves*: four valve elements shall be provided as indicated in Figure A2-1:
 - 1) valve A shall be a quick-acting, full-flow, flow diverter enabling the incoming sample to be directed through the measuring filter or around the bypass circuits or shut-off;

Note.— Valve A may, if necessary, consist of two valves interlocked to give the requisite function.

- 2) valves B and C shall be throttling valves used to establish the system flow rate;
 - 3) valve D shall be a shut-off valve to enable the filter holder to be isolated;
- all valves shall be made of corrosion-resistant material;

- e) *vacuum pump*: this pump shall have a no-flow vacuum capability of -75 kPa with respect to atmospheric pressure; its full-flow rate shall not be less than 28 L/min at normal temperature and pressure;

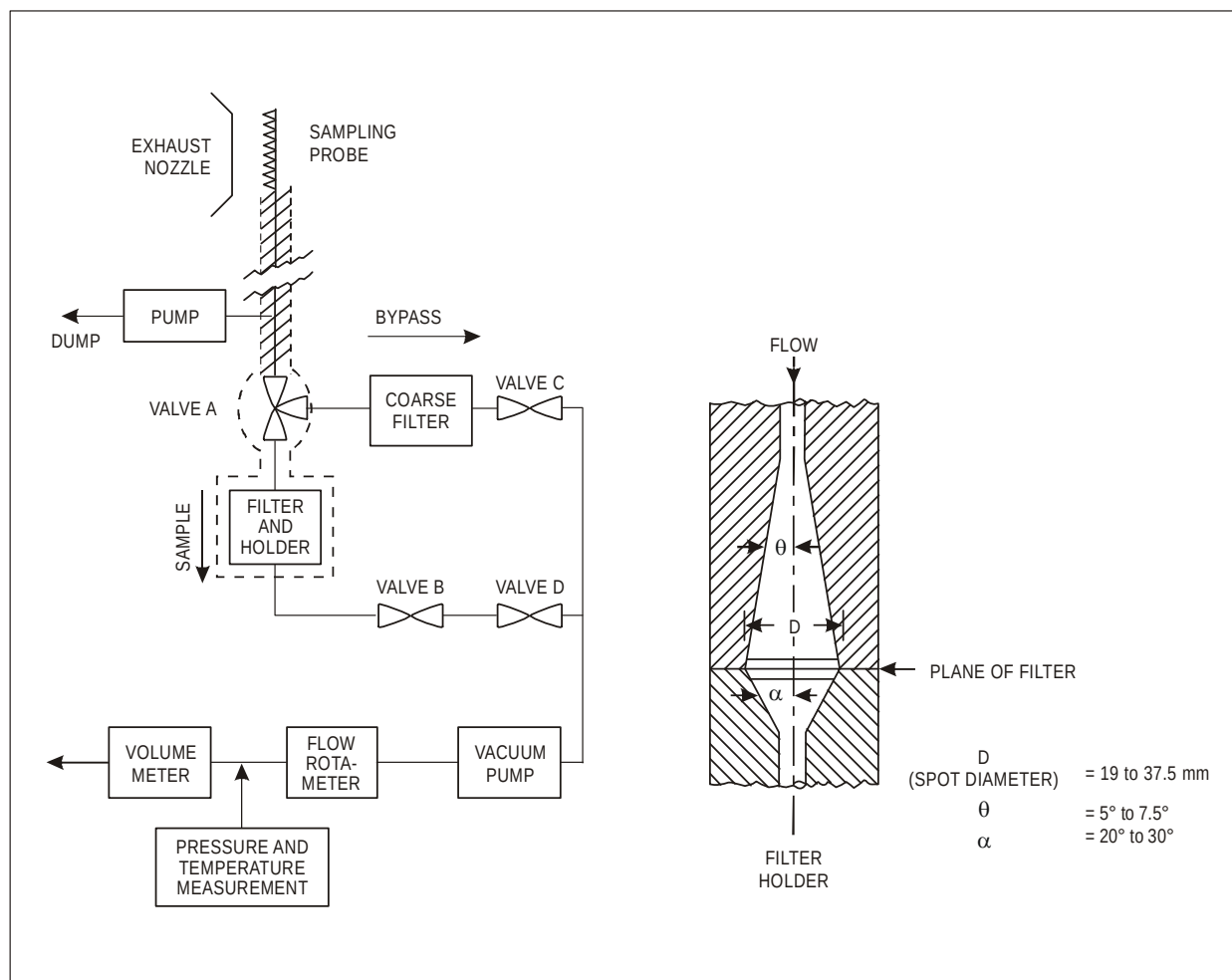


Figure A2-1. Smoke analysis system

- f) *temperature control*: the analyser internal sample line through to the filter holder shall be maintained at a temperature between 60°C and 175°C with a stability of $\pm 15^\circ\text{C}$;

Note.— The objective is to prevent water condensation prior to reaching the filter holder and within it.

- g) If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and valve A (Figure A2-1), to dump excess flow. The dump line shall be as close as possible to probe off-take and shall not affect the ability of the sampling system to maintain the required 80 per cent pressure drop across the probe assembly. The dump flow may also be sent to the CO₂ analyser or complete emissions analysis system.
- h) If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

- i) *leak performance*: the subsystem shall meet the requirements of the following test:
 - 1) clamp clean filter material into holder,
 - 2) shut-off valve A, fully open valves B, C and D.
 - 3) run vacuum pump for one minute to reach equilibrium conditions;
 - 4) continue to pump and measure the volume flow through the meter over a period of five minutes. This volume shall not exceed 5 L (referred to normal temperature and pressure) and the system shall not be used until this standard has been achieved.
- j) *reflectometer*: the measurements of the diffuse reflection density of the filter material shall be by an instrument conforming to the International Organization for Standardization, Standard No. ISO 5-4¹. The diameter of the reflectometer light beam on the filter paper shall not exceed $D/2$ nor be less than $D/10$ where D is the diameter of filter stained spot as defined in Figure A2-1.

2.4 Fuel specifications

The fuel shall meet the specifications of Appendix 4.

2.5 Smoke measurement procedures

2.5.1 Engine operation

2.5.1.1 The engine shall be operated on a static test facility which is suitable and properly equipped for high accuracy performance testing.

2.5.1.2 The tests shall be made at the thrust settings approved by the certifying authority. The engine shall be stabilized at each setting.

2.5.2 Leakage and cleanliness checks

No measurements shall be made until all sample transfer lines and valves are warmed up and stable. Prior to a series of tests the system shall be checked for leakage and cleanliness as follows:

- a) *leakage check*: isolate probe and close off end of sample line, perform leakage test as specified in 2.3 h) with the exceptions that valve A is opened and set to “bypass”, valve D is closed and that the leakage limit is 2 L. Restore probe and line interconnection;
- b) *cleanliness check*:
 - 1) open valves B, C and D

1. International Organization for Standardization, Standard No. ISO 5-4: 1995 entitled *Photography – Density measurements – Part 4: Geometric conditions for reflection density*.

- 2) run vacuum pump and alternately set valve A to “bypass” and “sample” to purge the entire system with clean air for five minutes;
- 3) set valve A to “bypass”;
- 4) close valve D and clamp clean filter material into holder. Open valve D;
- 5) set valve A to “sample” and reset back to “bypass” after 50 kg of air per square metre of filter has passed through the filter material;
- 6) measure resultant filter spot SN’ as described in paragraph 3 of this appendix;
- 7) if this SN’ exceeds 3, the system shall be cleaned (or otherwise rectified) until a value lower than 3 is obtained.

The system shall not be used until the requirements of these leakage and cleanliness checks have been met.

2.5.3 Smoke measurement

Smoke measurement shall be made independently of other measurements unless the smoke values so measured are significantly below the limiting values, or unless it can be demonstrated that the smoke values from simultaneous smoke and gaseous emissions measurements are valid, in which case smoke measurements may be made simultaneously with gaseous emissions measurements. In all cases the bend radius requirements for sampling lines detailed in 2.2.2 shall be strictly observed. The smoke analysis subsystem shall be set up and conform to the specifications of 2.3. Referring to Figure A2-1, the following shall be the major operations in acquiring the stained filter specimens:

- a) during engine operation with the probe in position, valve A shall not be placed in the no-flow condition, otherwise particulate build-up in the lines might be encouraged;
- b) set valve A to “bypass”, close valve D and clamp clean filter into holder. Continue to draw exhaust sample in the bypass setting for at least five minutes while the engine is at or near to the required operating condition, valve C being set to give a flow rate of 14 ± 0.5 L/min;
- c) open valve D and set valve A to “sample”, use valve B to set flow rate again to value set in b);
- d) set valve A to “bypass” and close valve D, clamp clean filter material into the holder;
- e) when the engine is stabilized on condition, allow one minute of sample flow with settings as at d);
- f) open valve D, set valve A to “sample”, reset flow rate if necessary, and allow chosen sample volume (see h)) to pass, before setting valve A back to “bypass” and close valve D;
- g) set aside stained filter for analysis, clamp clean filter into holder;
- h) the chosen sample sizes shall be such as to be within the range of 12 kg to 21 kg of exhaust gas per square metre of filter, and shall include samples which are either at the value of 16.2 kg of exhaust gas per square metre of filter or lie above and below that value. The number of samples at each engine operating condition shall not be less than 3 and e) to g) shall be repeated as necessary.

3. CALCULATION OF SMOKE NUMBER FROM MEASURED DATA

3.1 The stained filter specimens obtained as outlined in 2.5.3 shall be analysed using a reflectometer as specified in 2.3. The backing material used shall be black with an absolute reflectance of less than 3 per cent. The absolute reflectance reading R_S of each stained filter shall be used to calculate the reduction in reflectance by

$$SN' = 100(1 - R_S / R_W)$$

where R_W is the absolute reflectance of clean filter material.

3.2 The masses of the various samples shall be calculated by

$$W = 0.348 PV/T \times 10^{-2}(\text{kg})$$

where P and T are, respectively, the sample pressure in Pascal and the temperature in Kelvin, measured immediately upstream of the volume meter. V is the measured sample volume in cubic metres.

3.3 For each engine condition in the case that the sample sizes range above and below the reference value, the various values of SN' and W shall be plotted as SN' versus $\log W/A$, where A is the filter stain area (m^2). Using a least squares straight line fit, the value of SN' for $W/A = 16.2 \text{ kg/m}^2$ shall be estimated and reported as the Smoke Number (SN) for that engine mode. Where sampling at the sample reference size value only is employed, the reported SN shall be the arithmetic average of the various individual values of SN' .

4. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY

The measured data shall be reported to the certificating authority. In addition the following data shall be reported for each test:

- a) sample temperature;
- b) sample pressure;
- c) actual sample volume at sampling conditions;
- d) actual sample flow rate at sampling conditions; and
- e) leak and cleanliness checks substantiation (*see* 2.5.2).