CIVIL AVIATION DIRECTIVE – 16 Vol II

ENVIRONMENTAL PROTECTION

Aircraft Engine Emissions

CIVIL AVIATION AUTHORITY OF MALAYSIA

ISSUE 02
REVISION 00 – 15TH NOVEMBER 2022

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Introduction

In exercise of the powers conferred by section 24O of the Civil Aviation Act 1969 [Act 3], the Chief Executive Officer makes this Civil Aviation Directive (CAD) 16 Volume II – Environmental Protection, Aircraft Engine Emissions, pursuant to Regulation 23, 24 and 25 of the Malaysian Civil Aviation Regulations (MCAR) 2016.

This CAD contains the standards and requirements 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. The standards and requirements in this CAD are based mainly on the Standards and Recommended Practices (SARPs) contained in the International Civil Aviation Organisation (ICAO) Annex 16 Volume II Fourth Edition to the Chicago Convention – Environmental Protection, Aircraft Engine Emissions, Amendment 10.

Civil Aviation Directive 16 Volume II – Environmental Protection, Aircraft Engine Emissions is published by the Chief Executive Officer under 24O of the Civil Aviation Act 1969 [Act 3] and comes into operation on 15th November 2022.

Non-compliance with this CAD

Any person who contravenes any provision in this CAD commits an offence and shall on conviction be liable to the punishments under section 24O of the Civil Aviation Act 1969 [Act 3] and/or under Malaysia Civil Aviation Regulation 2016.

(Datuk Captain Chester Voo Chee Soon)
Chief Executive Officer
Civil Aviation Authority of Malaysia

Civil Aviation Directive components and Editorial practices

This Civil Aviation Directive is made up of the following components and are defined as follows:

Standards: Usually preceded by words such as *"shall"* or *"must"*, are any specification for physical characteristics, configuration, performance, personnel or procedure, where uniform application is necessary for the safety or regularity of air navigation and to which Operators must conform. In the event of impossibility of compliance, notification to the CAAM is compulsory.

Recommended Practices: Usually preceded by the words such as "*should"* or "*may*", are any specification for physical characteristics, configuration, performance, personnel or procedure, where the uniform application is desirable in the interest of safety, regularity or efficiency of air navigation, and to which Operators will endeavour to conform.

Appendices: Material grouped separately for convenience but forms part of the Standards and Recommended Practices stipulated by the CAAM.

Definitions: 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.

Tables and Figures: These 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.

Notes: Included in the text, where appropriate, Notes give factual information or references bearing on the Standards or Recommended Practices in question but not constituting part of the Standards or Recommended Practices;

Attachments: Material supplementary to the Standards and Recommended Practices or included as a guide to their application.

It is to be noted that some Standards in this Civil Aviation Directive incorporates, by reference, other specifications having the status of Recommended Practices. In such cases, the text of the Recommended Practice becomes part of the Standard.

The units of measurement used in this document are in accordance with the International System of Units (SI) as specified in CAD 5. Where CAD 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 and/or title, includes all subdivisions of that portion.

Throughout this Civil Aviation Directive, the use of the male gender should be understood to include male and female persons.

Record of Revisions

Revisions to this CAD shall be made by authorised personnel only. After inserting the revision, enter the required data in the revision sheet below. The *'Initials'* has to be signed off by the personnel responsible for the change.

Rev No.	Revision Date	Revision Details	Initials
ISS02/REV00	15th November 2022	Refer to summary highlights	CAAM

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Summary of Changes

ISS/REV no.	Item no.	Revision Details
ISS02/REV00	Part I, Chapter 1	Incorporated content of CAC 02/2022
	Part III, Chapter 1, Para 1.1	Incorporated content of CAC 02/2022
	Part III, Chapter 1, Para 1.6	Incorporated content of CAC 02/2022
	Part III, Chapter 1, Para 1.7	Incorporated content of CAC 02/2022
	Part III, Chapter 2, Para 2.1.1.1	Incorporated content of CAC 02/2022
	Part III, Chapter 2, Para 2.1.1.3	Incorporated content of CAC 02/2022
	Part III, Chapter 2, Para 2.2.1	Incorporated content of CAC 02/2022
	Part III, Chapter 2, Para 2.3.2	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.1.1	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.1.2	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.1.3	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.1.4.2	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.1.5.4	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.2.1	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.2.2	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.2.3	Incorporated content of CAC 02/2022
	Part III, Chapter 4, Para 4.3	Incorporated content of CAC 02/2022
	Part IV	Incorporated content of CAC 02/2022

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1 General

1.1 Citation

1.1.1 These Directives are the Civil Aviation Directives 16 Volume II – Environmental Protection, Aircraft Engine Emissions, Issue 02/Revision 00, and comes into operation on 15th November 2022.

1.1.2 This CAD 16 Volume II – Environmental Protection, Aircraft Engine Emissions, Issue 02/Revision 00 will remain current until withdrawn or superseded.

1.2 Applicability

1.2.1 This CAD applies to:

a) applicant for a Type Certificate or validation to a Type Certificate;

b) person designing modifications and repairs.

1.3 Revocation

1.3.1 This CAD revokes Civil Aviation Circular 02/2022 – Revised CADs Requirements and Guidance published on 10th June 2022 and Civil Aviation Directives 16 Volume II – Environmental Protection, Aircraft Engine Emissions (CAD 16 Vol II) Issue 01/Revision 00, dated 1st August 2021.

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PART I. Definitions and Symbols

1 Definitions

Where the following expressions are used in this CAD, they have the meanings ascribed to them below:

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

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

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

Date of manufacture means 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 means 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 CAAM, have not changed.

Exhaust nozzle means 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) means emitted particles that exist at a gas turbine engine exhaust nozzle exit plane that do not volatilise when heated to a temperature of 350°C.

Oxides of nitrogen means 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 means for engine emissions purposes, the maximum take-off thrust approved by CAAM 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 means 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.

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

Smoke Number means the dimensionless term quantifying smoke emissions (*see* 3 of ICAO Annex 16 Volume II Appendix 2).

State of Design means the State having jurisdiction over the organization responsible for the type design.

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

Taxi/ground idle means 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 means a document issued by CAAM or other national aviation authorities to define the design of an aircraft, engine or propeller type and to certify that this design meets the appropriate airworthiness requirements of CAAM or other related national aviation authority.

Unburned hydrocarbons means 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.

2 Symbols

Where the following symbols are used in this CAD, 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 (*see* definition)
F^*_{oo}	Rated thrust with afterburning applied
HC	Unburned hydrocarbons (*see* definition)
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen (*see* definition)
nvPM	Non-volatile particulate matter (*see* definition)
SN	Smoke Number (*see* definition)
π_{oo}	Reference pressure ratio (*see* definition)

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PART II. Vented Fuel

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 CAAM on the basis of satisfactory evidence that either the aircraft or the aircraft engines comply with requirements of Chapter 2.

1.3 CAAM may recognize as valid a certification relating to fuel venting granted by the certificating authority of another Contracting State provided the requirements under which such certification was granted are not less stringent than the provision of this CAD or ICAO Annex 16 Volume II.

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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

1 Administration

1.1 The provisions of 1.2 to 1.4 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 granted by CAAM are on the basis of satisfactory evidence that the engine complies with requirements which are at least equal to the stringency of the provisions of this CAD. Compliance with the emissions levels of Chapters 2 and 3 shall be demonstrated using the procedure described in ICAO Annex 16 Volume II Appendix 6.

1.3 *RESERVED*.

1.4 CAAM may recognise as valid emissions certification granted by the certificating authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of this CAD or ICAO Annex 16, Volume II.

1.5 *RESERVED*.

1.6 Unless otherwise specified in this CAD, the date to be used by the applicant in determining the applicability of the Standards in this CAD shall be the date when the application for a Type Certificate for engines of a type or model was submitted to the CAAM, or the date of submission under an equivalent application procedure prescribed by the CAAM.

1.7 An application for a Type Certificate for engines of a type or model shall be effective for the period specified in the designation of the airworthiness regulations appropriate to the engine of a type or model, except in special cases where the CAAM accepts an extension of this period. When this period of effectivity is exceeded and an extension is approved, the date to be used in determining the applicability of the Standards in this CAD shall be the date of issue of the Type Certificate or approval of the change in the type design, or the date of issue of approval under an equivalent procedure prescribed by the CAAM, less the period of effectivity.

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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 the certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engine grants 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 *RESERVED*.

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 and which are designed as an integrated propulsive power plant and certified with a rated thrust.

Note.– Guidance material is provided in the ICAO 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 (NOx).

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 NOx 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 CAAM:

LTO operating mode	*Thrust setting*
Take-off	100 per cent F_{00}
Climb	85 per cent F_{00}
Approach	30 per cent F_{00}
Taxi/ground idle	7 per cent F_{00}

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.

LTO operating mode	*Time in operating mode, minutes*
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 ICAO Annex 16 Volume II 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* ICAO Annex 16 Volume II 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 ICAO Annex 16 Volume II Appendix 3.

2.2 Smoke

2.2.1 Applicability

The provisions of 2.2.2 shall apply:

a) to engines whose date of manufacture is on or after 1 January 1983 and before 1 January 2023; and

b) to engines with a maximum rated thrust of less than or equal to 26.7 kN whose date of manufacture is on or after 1 January 2023.

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 ICAO Annex 16 Volume II Appendix 2, or equivalent procedures as agreed by CAAM, and converted to a characteristic level by the procedures of ICAO Annex 16 Volume II Appendix 6 shall not exceed the level determined from the following formula:

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

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 ICAO Annex 16 Volume II Appendix 3 and converted to characteristic levels by the procedures of ICAO Annex 16 Volume II Appendix 6, or equivalent procedures as agreed by CAAM, shall not exceed the regulatory levels determined from the following formulas:

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

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 and for which an application for a Type Certificate was submitted before 1 January 2023:

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:

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

f) for engines of a type or model for which an application for a Type Certificate was submitted on or after 1 January 2023:

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:

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

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 × 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.

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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 (NOx).

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 NOx 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^*_{oo} is used, it shall be replaced by F_{oo} for engines which do not employ afterburning. For taxi/ground idle thrust setting, F_{oo} 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 CAAM.

Operating mode	*Thrust setting*
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.

LTO Operating mode	*Time in operating mode, minutes*
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 ICAO Annex 16 Volume II 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 ICAO Annex 16 Volume II 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 ICAO Annex 16 Volume II 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 ICAO Annex 16 Volume II Appendix 2 and converted to a characteristic level by the procedures of ICAO Annex 16 Volume II

Appendix 6 shall not exceed the regulatory level determined from the following formula:

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

or a value of 50, whichever is lower

3.3 Gaseous emissions

3.3.1 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of ICAO Annex 16 Volume II Appendix 3 or ICAO Annex 16 Volume II Appendix 5, as applicable, and converted to characteristic levels by the procedures of ICAO Annex 16 Volume II Appendix 6 shall not exceed the regulatory levels determined from the following formulas:

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

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

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 ICAO Annex 16 Volume II 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 × 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 ICAO Annex 16 Volume II Appendix 6.

4 Particulate Matter Emissions

4.1 General

4.1.1 Applicability

4.1.1.1 The provisions of this chapter shall apply to all aircraft engines, as further specified in 4.2, intended for propulsion only at subsonic speeds.

4.1.1.2 Specific provisions for the relevant engine categories shall apply as detailed in section 4.2, except when the certificating authority or the competent authority having jurisdiction over the organization responsible for production of the engines grants exemptions for a limited number of engines over a specific period of time beyond the dates of applicability specified in 4.2 for the manufacture of the individual engine.

4.1.1.3 *RESERVED*.

4.1.2 Emissions involved

The purpose of this section is to control non-volatile particulate matter mass (nvPM) emissions.

4.1.3 Units of measurement

4.1.3.1 The concentration of nvPM mass shall be measured and reported in micrograms/m^3.

4.1.3.2 The nvPM mass emitted during the reference emissions landing and take-off (LTO) cycle, defined in 4.1.4.2 (LTO_{mass}), shall be measured and reported in milligrams.

4.1.3.3 The nvPM number emitted during the reference emissions landing and take-off (LTO) cycle, defined in 4.1.4.2 (LTO_{num}), shall be measured and reported in number of particles.

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 $nvPM_{mass}$ concentration, maximum EI_{mass} and maximum EI_{num} as agreed by the certificating authority.

For the calculation and reporting of nvPM emissions, the reference emissions LTO cycle shall be represented by the following thrust setting and time in each following operating mode:

LTO operating mode	*Thrust setting* *Per cent F_{oo}*	*Time in operating mode* *Minutes*
Take-off	100	0.7
Climb	85	2.2
Approach	30	4.0
Taxi/ground idle	7	26.0

4.1.4.3 *Fuel specifications*

The fuel used during tests shall meet the specifications of ICAO Annex 16 Volume II 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* ICAO Annex 16 Volume II 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 ICAO Annex 16 Volume II Appendix 7.

4.1.5.4 The maximum nvPM mass concentration shall be corrected for dilution and thermophoretic losses in the Collection Part of the sampling system in accordance with the procedures of ICAO Annex 16 Volume II Appendix 7. The EI_{mass} and EI_{num} shall be corrected for thermophoretic losses in the Collection Part of the sampling system and fuel composition in accordance with the procedures of ICAO Annex 16 Volume II Appendix 7.

4.2 Non-volatile particulate matter emissions

4.2.1 Applicability

4.2.1.1 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 with a rated thrust greater than 26.7 kN.

4.2.1.2 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines and which are designed as an integrated propulsive powerplant and certified with a rated thrust.

4.2.2 Regulatory levels

4.2.2.1 *Maximum nvPM mass concentration*

For an engine whose date of manufacture of the individual engine is on or after 1 January 2020, the maximum nvPM mass concentration 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 ICAO Annex 16 Volume II Appendix 7 and converted to characteristic levels by the procedures of ICAO Annex 16 Volume II Appendix 6, or equivalent procedures as agreed by the certificating authority, shall not exceed the regulatory level determined from the following formula:

$$\text{Regulatory limit concentration of nvPM}_{mass} = 10^{(3 + 2.9\, F_{oo}^{-0.274})}$$

Note.— Since there is a correlation between nvPM mass concentration and Smoke Number, the regulatory level in 4.2.2.1 was derived from the Smoke Number regulatory level. Further information is provided in the Environmental Technical Manual (Doc 9501), Volume II — Procedures for the Emissions Certification of Aircraft Engines.

4.2.2.2 *nvPM mass and nvPM number emitted during the reference LTO cycle*

The nvPM mass and nvPM number emission levels when measured and computed in accordance with the procedures of ICAO Annex 16 Volume II Appendix 7 and converted to characteristic levels by the procedures of ICAO Annex 16 Volume II Appendix 6, or equivalent procedures as agreed by the certificating authority, shall not exceed the regulatory levels determined from the following formulas:

a) LTO_{mass}:

1) for engines of a type or model for which the date of manufacture of the individual engine was on or after 1 January 2023:

   i) for engines with a maximum rated thrust of more than 200 kN:
   $LTO_{mass}/F_{oo} = 347.5$

   ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 200 kN:
   $LTO_{mass}/F_{oo} = 4646.9 - 21.497F_{oo}$

2) for engines of a type or model for which an application for a Type Certificate was submitted on or after 1 January 2023:

   i) for engines with a maximum rated thrust of more than 150 kN:
   $LTO_{mass}/F_{oo} = 214.0$

   ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 150 kN:
   $LTO_{mass}/F_{oo} = 1251.1 - 6.914F_{oo}$

b) LTO_{num}:

1) for engines of a type or model for which the date of manufacture of the individual engine was on or after 1 January 2023:

   i) for engines with a maximum rated thrust of more than 200 kN:
   $LTO_{num}/F_{oo} = 4.170 \times 10^{15}$

   ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 200 kN:
   $LTO_{num}/F_{oo} = 2.669 \times 10^{16} - 1.126 \times 10^{14} F_{oo}$

2) for engines of a type or model for which an application for a Type Certificate was submitted on or after 1 January 2023:

   i) for engines with a maximum rated thrust of more than 150 kN:
   $LTO_{num}/F_{oo} = 2.780 \times 10^{15}$

   ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 150 kN:
   $LTO_{num}/F_{oo} = 1.490 \times 10^{16} - 8.080 \times 10^{13} F_{oo}$

4.2.3 Reporting requirement

The manufacturer shall report the following values of nvPM emissions measured and computed in accordance with the procedures of ICAO Annex 16 Volume II Appendix 7, or any equivalent procedures as agreed by CAAM:

a) maximum EI_{mass} (milligrams/kg of fuel); and

b) maximum EI_{num} (particles/kg of fuel).

4.3 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; and 2) the data obtained from the engine test(s); and 3) derived information.

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; and

g) the method of data analysis.

4.3.2 Test information

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

a) fuel net heat of combustion (MJ/kg);

b) fuel hydrogen content (mass %);

c) fuel total aromatics content (volume %);

d) fuel naphthalenes content (volume %); and

e) fuel sulphur content (ppm by mass).

4.3.2.2 The following information, as measured and computed in accordance with the procedures of ICAO Annex 16 Volume II Appendix 7, or any equivalent procedures as agreed by the certificating authority, shall be provided for each engine tested for certification purposes:

a) fuel flow (kg/s) at each thrust setting of the LTO cycle;

b) EI_{mass} (milligrams/kg of fuel) at each thrust setting of the LTO cycle;

c) EI_{num} (particles/kg of fuel) at each thrust setting of the LTO cycle.

4.3.3 Derived information

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

a) emission rate, i.e. EI_{mass} × fuel flow, (milligrams/s) for nvPM mass;

b) emissions rate, i.e. EI_{num} × fuel flow, (particles/s) for nvPM number;

c) total gross emission of nvPM mass measured over the LTO cycle (milligrams);

d) total gross emission of nvPM number measured over the LTO cycle (particles);

e) values of LTO_{mass}/F_{oo} (milligrams/kN);

f) values of LTO_{num}/F_{oo} (particles/kN); and

g) maximum nvPM mass concentration (micrograms/m^3).

4.3.3.2 The characteristic levels shall be provided for the maximum nvPM mass concentration, the LTO_{mass}/F_{oo} and the LTO_{num}/F_{oo} for each engine type for which emissions certification is sought.

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PART IV. Non-Volatile Particulate Matter Assessment for Inventory and Modelling Purposes

For engines of a type or model subject to Part III, Chapter 4, and for which the date of manufacture of the individual engine was on or after 1 January 2023, the nvPM mass and nvPM number system loss correction factors (k_{SL_mass} and k_{SL_num}), and EI_{mass} and EI_{num} corrected for system losses shall be reported to the certificating or competent authority as designated by the State in accordance with the procedures of ICAO Annex 16 Volume II Appendix 8, or equivalent procedures as agreed by the certificating authority.

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