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THE CIVIL AVIATION ACT,
(CAP. 80)

REGULATIONS

THE CIVIL AVIATION (ENVIRONMENTAL PROTECTION AIRCRAFT ENGINE EMISSIONS) REGULATIONS, 2026

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THE CIVIL AVIATION ACT,
(CAP. 80)

REGULATIONS

(Made under section 5)

THE CIVIL AVIATION (ENVIRONMENTAL PROTECTION AIRCRAFT ENGINE EMISSIONS) REGULATIONS, 2026

PART I
PRELIMINARY PROVISIONS

Citation

1. These Regulations may be cited as the Civil Aviation (Environmental Protection Aircraft Engine Emissions) Regulations, 2026.

Application

2. These Regulations shall apply to-

(a) aircrafts registered in United Republic, wherever it operates; and

(b) aircrafts registered in other states operating in the United Republic.

Interpretation

3. In these Regulations, unless the context otherwise requires-

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"Act" means the Civil Aviation Act;

"afterburning" means a mode of engine operation wherein a combustion system fed in whole or part by vitiated air is used;

"aircraft" means any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface;

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"Authority" means the Tanzania Civil Aviation Authority established under the Act;

"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 the certificating authority, have not changed;

"equivalent procedure" means a test or analysis procedure which, while differing from the one specified in these Regulations of, in the technical judgement of the certificating authority, yields effectively the same emissions levels as the specified procedure;

"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 instance the nozzle considered is that for the gas generator or core flow only, and where the jet efflux is mixed the nozzle considered is the total exit nozzle;

"non-volatile particulate matter" means 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;

"operator" means the person, organisation or enterprise engaged in or offering to engage in an aircraft operation;

"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;

"performance model" means an analytical tool or method validated from corrected flight test data that can be used to determine the specific air range (km/kg) values for calculating the CO2 emissions evaluation metric value at the reference conditions;

"rated thrust" means, for engine emissions purposes, the maximum take-off thrust approved by the certificating authority for use under normal operating conditions at international standard atmosphere sea level static conditions, and without the use of water injection;

"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 international standard atmosphere sea level static conditions of which its methods of measuring are prescribed in the First Schedule;

"smoke" means the carbonaceous materials in exhaust emissions which obscure the transmission of light;

"smoke number" or in its acronym "SN" means the dimensionless term quantifying smoke emissions;

"state of design" means the state having jurisdiction over the organization responsible for the type design;

"taxi or ground idle" means the operating phases involving taxi and idle between the initial starting of the propulsion engine and the initiation of the take-off roll and between the time of runway turn-off and final shutdown of all propulsion engine;

"type certificate" means a document issued by 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; and

"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.

PART II
VENTED FUEL

Application and administration

4.-(1) The provisions in this Part shall apply to all turbine engine powered aircraft intended for operation in international air navigation manufactured after 18th February 1982.

(2) The Authority shall accept certification related to the prevention of intentional fuel venting on the basis of satisfactory evidence that either the aircraft or the aircraft engines comply with requirements of regulation 5.

(3) The Authority shall recognise as valid a certification relating to fuel venting granted by the authority of another state provided the requirements under which such certification was granted are not less stringent than the provisions of these Regulations.

Prevention of intentional fuel venting

5. An operator shall not operate an aircraft unless it is designed and constructed 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.

PART III
EMISSIONS CERTIFICATION

Application and administration

6.-(1) The requirements of subregulations (2) to (6) shall apply to all engines and their derivative version included in the classifications defined for emissions certification purposes under Subparts (a), (d) and (e) of this Part where such engines are fitted to aircraft engaged in international air navigation.

(2) The Authority shall accept emissions certification on the basis of satisfactory evidence that the engine complies with the following requirements:

(a) at least equal to the stringency of the provisions of these Regulations; and
(b) the compliance with the emissions levels specified under this Part shall be demonstrated using the procedure specified in the Sixth Schedule.

(3) 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 Authority.

(4) The document attesting emissions certification for each individual engine shall include at least the information which is applicable to the engine type as follows:

(a) name of certificating 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; and
(h) a statement indicating compliance with particulate matter requirements.

(5) The Authority shall recognise as valid emissions certification granted by the authority of another state provided that the requirements under which such certification was granted are not less stringent than the provisions of these Regulations.

(6) The Authority shall recognise as valid engine exemptions granted by the competent authority of another state having jurisdiction over the organisation

responsible for production of the engine, provided that an acceptable process was used.

(7) Unless otherwise specified in these Regulations, the date to be used by the Authority in determining the applicability of these requirements shall be the date when the application for a type certificate for engines of a type or model was submitted to the state of design, or the date of submission under an equivalent application process prescribed by the certificating authority of the state of design.

(8) 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 certificating authority accepts an extension of this period.

(9) When this period of affectivity is exceeded and an extension is approved, the date to be used in determining the applicability of the standards in these Regulations 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 process prescribed by the state of design, less the period of affectivity.

(10) In cases where the configuration of the engine or other extenuating conditions exist which would prohibit or limit the use of the procedures provided in the Second, Third, Fifth or Seventh Schedules, the Authority may approve equivalent procedures, after receiving satisfactory technical evidence that the use of the equivalent procedures yield effectively the same emissions levels, and all such equivalent procedures shall be subject to the approval of the Authority.

(a) Turbojet and Turbofan Engines Intended for Propulsion Only at Subsonic Speeds

Application

7.-(1) The provisions of this Subpart shall apply to all turbojet and turbofan engines, as further specified in regulations 12 to 16 for smoke and gaseous emissions intended for propulsion only at subsonic speeds, except when the certificating authority or the competent authority having jurisdiction over the organisation 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 1st January 1965; or

(b) a limited number of engines over a specific period of time beyond the dates of applicability specified in regulations 12 to 16 for smoke and gaseous emissions for the manufacture of the individual engine.

(2) In cases where, an exemption document shall be issued by the certificating authority or the competent authority having jurisdiction over the organisation responsible for production of the engines, the identification plates on the engines shall be marked "EXEMPT" and the grant of exemption shall be documented in the permanent engine record.

(3) The certificating authority or the competent authority having jurisdiction over the organisation responsible for production of the engines shall consider the numbers of exempted engines that will be produced and their impact on the environment.

(4) Exemptions shall be reported by engine serial number and made available through an official public register.

(5) Subject to subregulation (1), the provisions of this Part 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 rate thrust.

Emissions involved

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

(a) smoke;

(b) gaseous emissions;
(c) unburned hydrocarbons (HC);
(d) carbon monoxide (CO); and
(e) oxides of nitrogen (NOx).

Units of measurement for reporting

9.-(1) The smoke emissions shall be reported in terms of smoke number.

(2) The mass (D_P) of the gaseous pollutant HC, CO or NOx emitted during the reference emissions landing and take-off cycle, defined in regulation 10(2) and (3), shall be reported in grams.

Reference conditions

10.-(1) The reference atmospheric conditions for engine performance shall be international standard atmosphere at sea level except that the reference humidity shall be 0.00634 kg water/kg dry air.

(2) The engine shall be tested at sufficient thrust settings to define the gaseous and smoke emissions of the engine so that mass emissions rates and smoke numbers can be determined at the following specific percentages of rated thrust as agreed by the certificating authority.

ling and take-off operating mode	*Thrust setting*
Take-off	100 per cent F_{oo}
Climb	85 per cent F_{oo}
Approach	30 per cent F_{oo}
Taxi or ground idle	7 per cent F_{oo}

(3) The reference emissions landing and take-off cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode.

Landing and take-off operating mode	*Time in operating mode, minutes*
Take-Off	0.7
Climb	2.2
Approach	4.0
Taxi or ground idle	26.0

(4) The fuel used during tests shall meet the specifications provided in the Fourth Schedule.

Test conditions

11.-(1) The tests shall be made with the engine on its test bed.

(2) The engine shall be representative of the certificated configuration as specified in the Sixth Schedule.

(3) Off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

(4) When test conditions differ from the reference atmospheric conditions as specified in regulation 10(1), the gaseous emissions test results shall be corrected to the reference atmospheric conditions in accordance with the procedures specified in the Third Schedule.

(b) Smoke

Application

12. This Subpart shall apply to-

(a) engines for which the date of manufacture is on or after 1st January 1983 and before 1st January 2023; and

(b) engines with a rated thrust of less than or equal to 26.7 kN for which the date of manufacture is on or after January 2023.

Regulatory smoke number

13. The smoke number at any of the four landing and take-off operating mode thrust settings when measured and computed in accordance with the procedures specified in the Second Schedule and converted to a characteristic level by the procedures specified in the Sixth Schedule shall not exceed the level determined from the following formula:

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

or a value of 50, whichever is lower.

(c) Gaseous Emissions

Application

14. The provisions of regulation 15 shall apply to engines for which the rated thrust is greater than 26.7 kN and for which the date of manufacture is on or after

1st January 1986 and as further specified for oxides of nitrogen.

Regulatory levels

15. Gaseous emissions levels when measured and computed in accordance with the procedures specified in the Third Schedule and converted to characteristic levels by the procedures specified in the Sixth Schedule 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) for-

(a) engines for which the date of manufacture of the first individual production model is before 1st January 1996 and for which the date of manufacture of the individual engine is before 1st January 2000;

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

(b) engines for which the date of manufacture of the first individual production model is on or after 1st January 1996 or for which the date of manufacture of the individual engine is on or after 1st January 2000;

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

(c) engines for which the date of manufacture of the first individual production model is on or after 1st January 2004;

(i) for engines with a reference pressure ratio of 30 or less:

(aa) for engines with a rated thrust of more than 89.0 kN:
$D_p/F_{oo} = 19 + 1.6\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p/F_{oo} = 37.572 + 1.6\pi_{oo} – 0.2087F_{oo}$

(ii) for engines with a reference pressure ratio of more than 30 but less than 62.5:

(aa) for engines with a rated thrust of more than 89.0 kN:
$D_p / F_{oo} = 7 + 2.0\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p / F_{oo} = 42.71 + 1.4286\pi_{oo} - 0.4013F_{oo} + 0.00642\pi_{oo} \times F_{oo}$

(iii) for engines with a reference pressure ratio of 62.5 or more:
$D_p / F_{oo} = 32 + 1.6\pi_{oo}$

(d) engines for which the date of manufacture of the first individual production model is on or after 1st January 2008 or for which the date of manufacture of the individual engine is on or after 1st January 2013;

(i) for engines with a reference pressure ratio of 30 or less:

(aa) for engines with a rated thrust of more than 89.0 kN:
$D_p / F_{oo} = 16.72 + 1.4080\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p/F_{oo} = 38.5486 + 1.6823\pi_{oo} - 0.2453F_{oo} - 0.00308\pi_{oo}F_{oo}$

(ii) for engines with a reference pressure ratio of more than 30 but less than 82.6:

(aa) for engines with a rated thrust of more than 89.0 kN:
$D_p / F_{oo} = -1.04 + 2.0\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p / F_{oo} = 46.1600 + 1.4286\pi_{oo} - 0.5303F_{oo} + 0.00642\pi_{oo}F_{oo}$

(iii) for engines with a reference pressure ratio of 82.6 or more:
$D_p / F_{oo} = 32 + 1.6\pi_{oo}$

(e) engines for which the date of manufacture of the first individual production model is on or after 1st January 2014 and for which an application for a type Certificate is submitted before 1st January 2023;
  - (i) for engines with a reference pressure ratio of 30 or less:
    - (aa) for engines with a rated thrust of more than 89.0 kN: $D_p / F_{oo} = 7.88 + 1.4080\pi_{oo}$
    - (bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN: $D_p / F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\pi_{oo}F_{oo}$
  - (ii) for engines with a reference pressure ratio of more than 30 but less than 104.7:
    - (aa) for engines with a rated thrust of more than 89.0 kN: $D_p / F_{oo} = -9.88 + 2.0\pi_{oo}$
    - (bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN: $D_p / F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} F_{oo}$
  - (iii) for engines with a reference pressure ratio of 104.7 or more: $D_p / F_{oo} = 32 + 1.6\pi_{oo}$

(f) engines of a type or model for which an application for a type certificate is submitted on or after 1st January 2023:
  - (i) for engines with a reference pressure ratio of 30 or less:
    - (aa) for engines with a rated thrust of more than 89.0 kN: $D_p / F_{oo} = 7.88 + 1.4080\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p / F_{oo} = 40.052 + 1.5681\pi_{oo} - 0.3615F_{oo} - 0.0018\pi_{oo}F_{oo}$

(ii) for engines with a reference pressure ratio of more than 30 but less than 104.7:

(aa) for engines with a rated thrust of more than 89.0 kN:
$D_p/F_{oo} = -9.88 + 2.0\pi_{oo}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 89.0 kN:
$D_p / F_{oo} = 41.9435 + 1.505\pi_{oo} - 0.5823F_{oo} + 0.005562\pi_{oo} F_{oo}$

(iii)for engines with a reference pressure ratio of 104.7 or more:
$D_p / F_{oo} = 32 + 1.6\pi_{oo}$

Information required

16.-(1) Information required shall be divided into three groups namely-

(a) general information to identify the engine characteristics, the fuel used and the method of data analysis;
(b) the data obtained from the engine test; and
(c) the results derived from the test data.

(2) The following general 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 or carbon ratio;
(f) the methods of data acquisition;
(g) the method of making corrections for ambient conditions; and
(h) the method of data analysis.

(3) The following test information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in regulation 10(2):

(a) fuel flow (kg/s);
(b) emissions index (grams/kg) for each gaseous pollutant; and
(c) measured smoke number.

(4) The information under subregulation (3) shall be provided after correction to the reference ambient conditions, where applicable.

(5) The following derived information shall be provided for each engine tested for certification purposes:

(a) emissions rate, i.e. emissions index× fuel flow, (grams/s) for each gaseous pollutant;
(b) total gross emissions of each gaseous pollutant measured over the landing and take-off cycle (grams);
(c) values of D_p / F_{oo} for each gaseous pollutant (grams/kN); and
(d) maximum smoke number.

(6) The characteristic smoke number and gaseous pollutant emissions levels shall be provided for each engine type for which emissions certification is sought.

(d) Turbojet and Turbofan Engines Intended for Propulsion at Supersonic Speeds

Application

17. This Sub-part 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.

Emissions involved

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

(a) smoke;
(b) gaseous emissions;
(c) unburned hydrocarbons (HC);

(d) carbon monoxide (CO); and
(e) oxides of nitrogen (NOx).

Units of measurement

19.-(1) The smoke emission shall be measured and reported in terms of smoke number.

(2) The mass (D_p) of the gaseous pollutants HC, CO, or NOx emitted during the reference emissions landing and take-off cycle, defined in regulation 21(2) and (3) shall be measured and reported in grams.

Nomenclature

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

Reference conditions

21.-(1) The reference atmospheric conditions shall be international standard atmosphere at sea level except that the reference absolute humidity shall be 0.00634 kg water/kg dry air.

(2) 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.

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 or ground idle	5.8 per cent F_{oo}

(3) The reference emissions landing and take-off cycle for the calculation and reporting of gaseous emissions shall be represented by the following time in each operating mode:

Landing and Take-Off Operating Mode	*Time in Operating Minutes*
Take-off	1.2
Climb	2.0
Descent	1.2
Approach	2.3

Taxi or ground idle	26. 0

(4) The fuel used during tests shall meet the specifications set out in the Fourth Schedule, and additives used for the purpose of smoke suppression, such as organo-metallic compounds, shall not be present.

Test conditions

22.-(1) The tests shall be made with the engine on its test bed.

(2) The engine shall be representative of the certificated configuration prescribed in Sixth Schedule, and off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

(3) Measurements made for determination of emission levels at the thrusts specified in regulation 21(2) shall be made with the afterburner operating at the level normally used, as applicable.

(4) When test conditions differ from the reference conditions in regulation 21, the test results shall be corrected to the reference conditions in accordance with the procedures prescribed in the Fifth Schedule.

Regulatory smoke number

23. The smoke number at any thrust setting, when measured and computed in accordance with the procedures specified in the Second Schedule and converted to a characteristic level by the procedures specified in the Sixth Schedule, 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.

Gaseous emissions regulatory levels

24. Gaseous emission levels, when measured and computed in accordance with the procedures set out in the Third Schedule or Fifth Schedule, as applicable, and converted to characteristic levels by the procedures set out in the Sixth Schedule, 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): $D_p / F^*_{oo} = 36 + 2.42\pi_{oo}$

Information required

25.-(1) Information required shall be divided into three groups namely-

(a) general information to identify the engine characteristics, the fuel used and the method of data analysis;
(b) the data obtained from the engine test; and
(c) the results derived from the test data.

(2) 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 or 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) The following information shall be provided for each engine tested for certification purposes at each of the thrust settings specified in regulation 21(2):

(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.

(4) The information under subregulation (3) shall be provided after correction to the reference ambient conditions, where applicable.

(5) 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 landing and take-off cycle (grams);

(c) values of D_p / F^*_{oo} for each gaseous pollutant (grams/kN); and

(d) maximum smoke number.

(6) The characteristic smoke number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

(e) Particulate Matter Emissions

Application

26.-(1) The provisions of this Sub-Part shall apply to all aircraft engines, as further specified in regulations 31 to 34, intended for propulsion only at subsonic speeds.

(2) Specific provisions for the relevant engine categories shall apply as detailed in regulations 31 to 34, except when the certificating authority or the competent authority having jurisdiction over the organisation 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 regulations 31 to 34 for the manufacture of the individual engine.

(3) In granting the exemption under subregulation (2), the certificating authority or the competent authority having jurisdiction over the organisation responsible for production of the engines shall issue an exemption document, and the identification plates on the engines shall be marked "EXEMPT" and the grant of exemption shall be documented in the permanent engine record.

(4) The certificating authority or the competent authority having jurisdiction over the organisation responsible for production of the engines shall consider the number of exempted engines that will be produced and their impact on the environment.

(5) Subject to subregulation (2), exemptions shall be reported by engine serial number and made available via an official public register.

Emissions involved

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

Units of measurement for reporting

28.-(1) The concentration of nvPM mass shall be reported in micrograms/m^3.

(2) The nvPM mass emitted during the reference emissions landing and take-off (LTO) cycle, defined in regulation 29(2) (LTO_{mass}), shall be reported in milligrams.

(3) The nvPM number emitted during the reference emissions landing and take-off (LTO) cycle, defined in regulation 29(2) (LTO_{num}), shall be reported in number of particles.

Reference conditions

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

(2) Reference emissions landing and take-off cycle-

(a) the engine shall be tested at sufficient thrust settings to define the nvPM emissions of the engine so that nvPM mass emissions indices (EI_{mass}) and nvPM number emissions indices (EI_{num}) can be determined at the reference emissions LTO cycle thrust settings and at thrusts producing maximum nvPM mass concentration, maximum EI_{mass} and maximum EI_{num} as agreed by the certificating authority;

(b) for the calculation and reporting of nvPM emissions, the reference emissions landing and take-off cycle shall be represented by the thrust setting and time in each following operating mode:

Landing and take-off operating mode	*Thrust setting*	*Time in operating mode per cent F_{oo} Minutes*
Take-off	100	0.7
Climb	85	2.2
Approach	30	4.0
Taxi or ground idle	7	26.0

(3) The fuel used during tests shall meet the specifications specified in the Fourth Schedule.

Test conditions

30.-(1) The tests shall be made with the engine on its test bed.

(2) The engine shall be representative of the certificated configuration specified in the Sixth Schedule.

(3) Subject to subregulation (2), off-take bleeds and accessory loads other than those necessary for the engine's basic operation shall not be simulated.

(4) When test conditions differ from the reference atmospheric conditions in regulation 29(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 specified in the Seventh Schedule.

(f) Non-Volatile Particulate Matter Emissions

Application

31.-(1) The requirements specified in regulations 32 and 33 shall apply to all turbofan and turbojet engines of a type or model with a rated thrust greater than 26.7 kN.

(2) The requirements of this Part 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.

Regulatory levels

32.-(1) For engines for which the date of manufacture is on or after 1st January 2020, the maximum nvPM mass concentration obtained from measurement at sufficient thrust settings, in such a way that the emissions maximum can be determined, and computed in accordance with the procedures specified in the Seventh Schedule and converted to characteristic levels by the procedures specified in the Sixth Schedule, shall not exceed the regulatory level determined from the following formula:

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

(2) The nvPM mass and nvPM number emissions levels when measured and computed in accordance with the procedures specified in the Seventh Schedule and converted to characteristic levels by the procedures specified in the Sixth Schedule, shall not exceed the regulatory levels determined from the following formulas:

(a) LTO_{mass}:

(i) for engines for which the date of manufacture is on or after 1st January 2023:

(aa) for engines with a rated thrust of more than 200 kN:

$LTO_{mass}/F_{oo} = 347.5$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 200 kN:

$LTO_{mass}/F_{oo} = 4646.9 - 21.497F_{oo}$

(ii) for engines of a type or model for which an application for a type certificate is submitted on or after 1 January 2023:

(aa) for mass engines with a rated thrust of more than 150 kN:

$LTO_{mass}/F_{oo} = 214.0$

(bb) for engines with a 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}:

(i) for engines for which the date of manufacture is on or after 1st January 2023:

(aa) for engines with a rated thrust of more than 200 kN:

$LTO_{num}/F_{oo} = 4.170 \times 10^{15}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 200 kN:

$LTO_{num}/F_{oo} = 2.669 \times 10^{16} - 1.126 \times 10^{14}F_{oo}$

(iii) for engines of a type or model for which an application for a type certificate is submitted on or after 1st January 2023:

(aa) for engines with a rated thrust of more than 150 kN:

$LTO_{num}/F_{oo} = 2.780 \times 10^{15}$

(bb) for engines with a rated thrust of more than 26.7 kN but not more than 150 kN:

$LTO_{num}/F_{oo} = 1.490 \times 10^{16} - 8.080 \times 10^{13}F_{oo}$

Reporting requirement

33. The manufacturer shall report the following values of nvPM emissions measured and computed in accordance with the procedures specified in the Seventh Schedule:

(a) maximum EI_{mass} (milligrams/kg of fuel); and
(b) maximum EI_{num} (particles/kg of fuel).

Information required

34.-(1) The information required shall be divided into three groups-:

(a) general information to identify the engine characteristics, the fuel used and the method of data analysis;
(b) the data obtained from the engine tests; and
(c) derived information.

(2) The following general 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 or carbon ratio;
(f) the methods of data acquisition; and
(g) the method of data analysis.

(3) The following test information shall be provided for each engine tested for certification purposes:

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

(4) The following information, as measured and computed in accordance with the procedures specified in the Seventh Schedule, 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; and
(c) EI_{num} (particles/kg of fuel) at each thrust setting of the LTO cycle.

(5) The following derived information shall be provided for each engine tested for certification purposes:

(a) emissions rate, (EI_{mass}) × fuel flow, (milligrams/s) for nvPM mass;
(b) emissions rate, (EI_{num}) × fuel flow, (particles/s) for nvPM number;
(c) total gross emissions of nvPM mass measured over the LTO cycle (milligrams);
(d) total gross emissions 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 nvPMmass concentration (micrograms/m3)

(6) 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.

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

Non-volatile particulate matter assessment for inventory and modelling purposes

35.-(1) 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 prescribed in the Seventh Schedule.

(2) For engines of a type or model subject to regulations 31 to 34, and for which the date of manufacture of the individual engine is on or after 1st 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 estimated

in accordance with the procedures prescribed in the Eighth Schedule, or alternative procedures as approved by the competent authority as designated by the Authority, with the resulting estimates for k_{SL_mass}, k_{SL_num}, EI_{mass} and EI_{num} reported to the certificating or competent authority as designated by the Authority.

PART V
EXEMPTIONS

Requirements for application for exemption

36.-(1) A person may apply to the Authority for an exemption from any provision of these Regulations.

(2) A person requiring exemptions from any of these Regulations shall, unless in case of emergency, make an application to the Authority at least sixty days prior to the proposed effective date, giving the following information:

(a) name and contact address including electronic mail and fax, if any;

(b) telephone number;

(c) a citation of the specific requirement from which the applicant seeks exemption;

(d) justification for the exemption;

(e) a description of the type of operations to be conducted under the proposed exemption;

(f) the proposed duration of the exemption;

(g) an explanation of how the exemption would be in the public interest;

(h) a detailed description of the alternative means by which the applicant will ensure a level of safety equivalent to that established by the regulation in question;

(i) a safety risk assessment carried out in respect of the exemption applied for;

(j) where the applicant handles international operations and seeks to operate under the proposed exemption, an indication whether the exemption would contravene any provision of the standards and recommended practices of the International Civil Aviation Organization; and

(k) any other relevant information that the Authority may require.

(3) Where the applicant seeks emergency processing of an application for exemption, the application shall contain supporting facts and reasons for not filing the application within the time specified in subregulation (2) and satisfactory reason for deeming the application an emergency.

(4) The Authority may, where it does not satisfy itself with the reasons given for the emergency, in writing, refuse an application made under subregulation (3).

(5) The application for exemption shall be accompanied by a fee to be prescribed by the Authority.

Publication of request for exemption

37.-(1) The Authority shall review the application for exemption and upon being satisfied that the application complies with the requirements of regulation 36, publish a detailed summary of the application for comments, within a prescribed time, in either-

(a) the *Gazette*;
(b) aeronautical information circular; or
(c) widely circulated newspaper.

(2) Where application requirements have not been fully complied with, the Authority shall request the applicant in writing, to comply with the necessary requirements prior to publication or making a decision.

(3) Where the request is for emergency relief, the Authority shall publish the decision as soon as possible after processing the application.

Review of request for exemption

38.-(1) Where the application requirements have been satisfied, the Authority shall conduct an evaluation of the request to-

(a) determine whether an exemption is in the public interest;

(b) determine, after a technical evaluation, whether the applicant's proposal would provide a level of safety equivalent to that established by the relevant regulation, although where the Authority decides that a technical evaluation of the request would impose a significant burden on the Authority's technical resources, the Authority may deny the exemption on that basis;

(c) determine whether the grant of the exemption would contravene these Regulations; and

(d) grant or deny the exemption based on the preceding elements, and with or without conditions.

(2) The Authority shall notify the applicant in writing of, the decision to grant or deny the request and publish a detailed summary of its evaluation and decision.

(3) The summary referred to in subregulation (2) shall specify the duration of the exemption and any conditions or limitations of the exemption.

(4) Where the exemption affects a significant population of the aviation community of the United Republic, the Authority shall publish the summary in aeronautical information circular.

PART VI
MISCELLANEOUS PROVISIONS

Suspension and revocation

39.-(1) The Authority may, where a person contravenes conditions of any certificate, exemption or other documents granted under these Regulations, revoke or suspend such certificate, exemption or document.

(2) The Authority shall, before suspending or revoking the certificate, exemption or document, issue

fourteen days' notice, to the holder in writing stating its intention to suspend or revoke the certificate, exemption or document and the reasons thereof.

(3) A holder of a certificate, exemption or other documents may, within fourteen days from the receipt of notice, submit his response to the Authority or rectify the contravention.

(4) The Authority may, where a holder of a certificate, exemption or other documents fails to respond within prescribed period or provide unsatisfactory response or rectify the contravention, continue to suspend or revoke such certificate, exemption or document, as the case may be.

Offences and penalties

40. A person who contravenes any provision of these Regulations commits an offence and on conviction shall be liable to a penalty provided in the Act.

FIRST SCHEDULE

(Made under regulation 3)

MEASUREMENT OF THE REFERENCE PRESSURE RATIO

1. GENERAL

1.1 Pressure ratio shall be established using a representative engine.

1.2 The reference pressure ratio shall be derived by correlating the measured pressure ratio or pressure ratios 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.

SECOND SCHEDULE

(Made under regulations 6(10), 13 and 23)

SMOKE EMISSIONS EVALUATION

1. INTRODUCTION AND DEFINITIONS

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

Where the following expressions and symbols are used in this Schedule, 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 Schedule 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 Schedule, conforms to the above definition of sampling size.

SN	Smoke Number; Dimension less term quantifying smoke emissions 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 Schedule).
SN′	Smoke Number obtained from an individual smoke sample, not necessarily of the sample reference size, as defined in 3 of this Schedule.
W	Mass of individual exhaust gas smoke sample, in kilograms, calculated from the measurements of sample volume, pressure and temperature (see 3 of this schedule).

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 emissions sample is in contact shall be stainless steel or any other non-reactive material.
(b) If a sampling probe with multiple sampling orifices is used:
  1) all sampling orifices shall be of equal diameter; and
  2) the sampling 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 ±15°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 S2-1. 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 ±2°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 flow meter 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 S2-1. The filter material shall be What man type No. 4, or any equivalent approved by the certificating authority;

(d) ***valves:*** four valve elements shall be provided as indicated in Figure S2-1:
  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- Depending on the configuration, Valve A may 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;

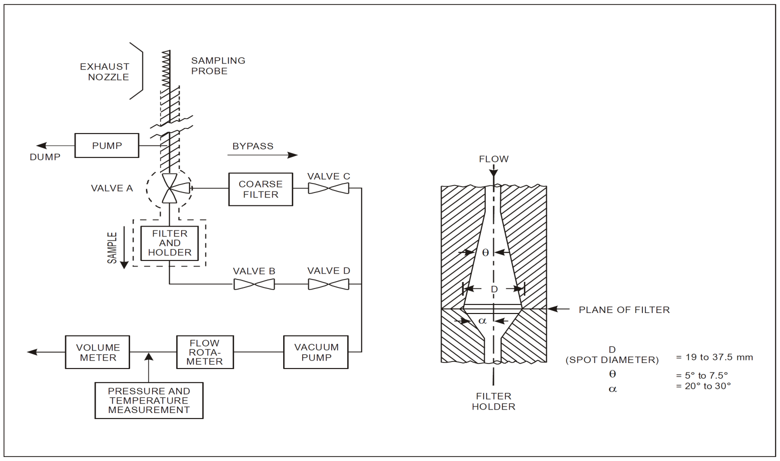
all valves shall be made of corrosion-resistant material;

(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 26 L/min at standard temperature and pressure;

(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 ±15°C;

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

Figure S2-1. Smoke analysis system



(a) 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 S2-1), 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 CO_2 analyser or complete emissions analysis system.

(b) 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.

(c) ***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 flow rate through the meter over a period of five minutes. This flow rate shall not exceed 1 L/min (referred to standard temperature and pressure) and the system shall not be used until this standard has been achieved.

(d) ***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 5-4[1]. 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 S2-1.

2.4 Fuel specifications

The fuel shall meet the specifications specified in the Fourth Schedule.

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 certificating 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 0.4 L/min at standard temperature and pressure. Restore probe and line interconnection;

(b) cleanliness check:
  1) open valves B, C and D
  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 section 3 of this schedule;
  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 S2-1, 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) (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 reflect meter 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

$$\mathrm{SN}' = 100(1 - R_S/R_W)$$

where R_W is the absolute reflectance of clean filter material.

3.2 The masses of the various samples shall be calculated by

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

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 $W/A = 16.2\ kg/m^2$ 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).

THIRD SCHEDULE

(Made under regulations 6(10), 11(4), 15 and 24)

PART A

INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

1. INTRODUCTION

Note- The procedures specified in this Schedule are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. The procedures do not apply to engines employing afterburning. The methods proposed are representative of the best readily available and most established practice.

2. DEFINITIONS

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

Accuracy. The closeness with which a measurement approaches the true value established independently.

Air/fuel ratio. The mass rate of airflow through the hot section of the engine divided by the mass rate of fuel flow to the engine.

Calibration gas. A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.

Gas concentration. The volume fraction of the component of interest in the gas mixture—expressed as volume percentage or as parts per million.

Flame ionization detector. A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass-flow rate of hydrocarbons entering the flame per unit of time — generally assumed responsive to the number of carbon atoms entering the flame.

Interference. Instrument response due to presence of components other than the gas (or vapour) that is to be measured.

Noise. Random variation in instrument output not associated with characteristics of the sample to which the instrument is responding, and distinguishable from its drift characteristics.

Non-dispersive infrared analyser. An instrument that by absorption of infrared energy selectively measures specific components.

Parts per million (ppm). The unit volume gas concentration of a gas per million unit volume of the gas mixture of which it is apart.

Parts per million carbon (ppmC). The mole fraction of hydrocarbon multiplied by 10^6measured on a methane-equivalence basis. Thus, 1 ppm of methane is indicated as 1 ppmC. To convert ppm concentration of any hydrocarbon to an equivalent ppmC value, multiply ppm gas concentration by the number of carbon atoms per molecule of the gas. For example, 1 ppm propane translates as 3 ppmC hydrocarbon; 1 ppm hexane as 6 ppmC hydrocarbon.

Reference gas. A mixture of gases of specified and known composition used as the basis for interpreting instrument response in terms of the gas concentration of the gas to which the instrument is responding.

Repeatability. The closeness with which a measurement upon a given invariant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

Resolution. The smallest change in a measurement which can be detected.

Response. The change in instrument output signal that occurs with change in sample gas concentration.

Stability. The closeness with which repeated measurements upon a given invariant sample can be maintained over a given period of time.

Zero drift. Time-related deviation of instrument output from zero set point when it is operating on gas free of the component to be measured.

Zero gas. A gas to be used in establishing the zero, or no-response, adjustment of an instrument.

3. DATA REQUIRED

3.1 Gaseous emissions

Gas concentrations of the following emissions shall be determined:

(a) hydrocarbons (HC): a combined estimate of all hydrocarbon compounds present in the exhaust gas;

(b) carbon monoxide (CO);

(c) carbon dioxide (CO_2);

Note- CO_2 is not a regulated engine gaseous pollutant but CO_2 concentration is required for calculation and check purposes.

(d) oxides of nitrogen (NO_x): an estimate of the sum of the two oxides, nitric oxide (NO) and nitrogen dioxide (NO_2); and

(e) nitric oxide (NO).

3.2 Other information

In order to normalize the emissions measurement data and to quantify the engine test characteristics, the following additional information shall be provided:

(a) inlet temperature;

(b) inlet humidity;

(c) atmospheric pressure;

(d) hydrogen/carbon ratio of fuel; and

(e) other required engine parameters (for example, thrust, rotor speeds, turbine temperatures and gas-generator air flow).

This data shall be obtained either by direct measurement or by calculation, as presented in 3.2.1 of this Schedule.

3.2.1 Specifications for additional data

As required in 3.2 of this Schedule, in addition to the measured sample constituent gas concentrations, the following data shall also be provided:

(a) inlet temperature: measured as the total temperature at a point within one diameter of the engine intake plane to an accuracy of ±0.5°C;

(b) inlet humidity (kg water/kg dry air): measured at a point within 50 m of the intake plane ahead of the engine to an accuracy of:

1) ±5 per cent of reading for ambient air humidity greater than or equal to 0.00634 kg water/kg dry air; or

2) ±0.000317 kg water/kg dry air of reading for ambient air humidity less than 0.00634 kg water/kg dry air;

(c) atmospheric pressure: measured within 1 km of the engine test location and corrected as necessary to the test stand altitude to an accuracy of ±100 Pa;

(d) fuel mass flow: by direct measurement to an accuracy of ±2 per cent;

(e) fuel H/C ratio: defined as n/m, where C_mH_n is the equivalent hydrocarbon representation of the fuel used in the test and evaluated by reference to the engine fuel type analysis;

(f) engine parameters:

(i). thrust: by direct measurement to an accuracy of ±1 per cent at take-off power and ±5 per cent at the minimum thrust used in the certification test, with linear variation between these points;

(ii). rotation speed(s): by direct measurement to an accuracy of at least ±0.5 per cent;

(iii). gas generator airflow: determined to an accuracy of ±2 per cent by reference to engine performance calibration.

The parameters specified in (a), (b), (d) and (f) shall be determined at each engine emissions test setting, while the parameter specified in (c) shall be determined at intervals of not less than 1 hour over a period encompassing that of the emissions tests.

4. GENERAL ARRANGEMENT OF THE SYSTEM

No desiccants, dryers, water traps or related equipment shall be used to treat the exhaust sample flowing to the oxides of nitrogen and the hydrocarbon analysis instrumentation. Requirements for the various component subsystems are given in 5, but the following list gives some qualifications and variations:

(a) It is assumed that each of the various individual subsystems includes the necessary flow control, conditioning and measurement facilities.
(b) The necessity for a dump and/or a hot-sample pump will depend on the ability to meet the sample transfer time and analysis subsystem sample flow rate requirements. This in turn depends on the exhaust sample driving pressure and line losses. It is considered that these pumps usually will be necessary at certain engine running conditions.
(c) The position of the hot pump, relative to the gas analysis subsystems, may be varied as required. (For example, some HC analysers contain hot pumps and so may be judged capable of being used upstream of the system hot pump.)

Note.— Figure S3-1 is a schematic drawing of the exhaust gas sampling and analytical system and typifies the basic requirements for emissions testing.

5. DESCRIPTION OF COMPONENT PARTS

Note.— A general description and specification of the principal elements in the engine exhaust emissions measurement system follows. Greater detail, where necessary, will be found in 5.2.1, 5.3.1 and 5.4.1 of this Schedule.

5.1 Sampling system

5.1.1 Sampling probe

The sampling probe shall meet the following requirements:

(a) The probe material with which the exhaust emissions sample is in contact shall be stainless steel or any other non-reactive material.
(b) If a sampling probe with multiple sampling orifices is used:
  1) all sampling orifices shall be of equal diameter; and
  2) the sampling 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 diameter 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.

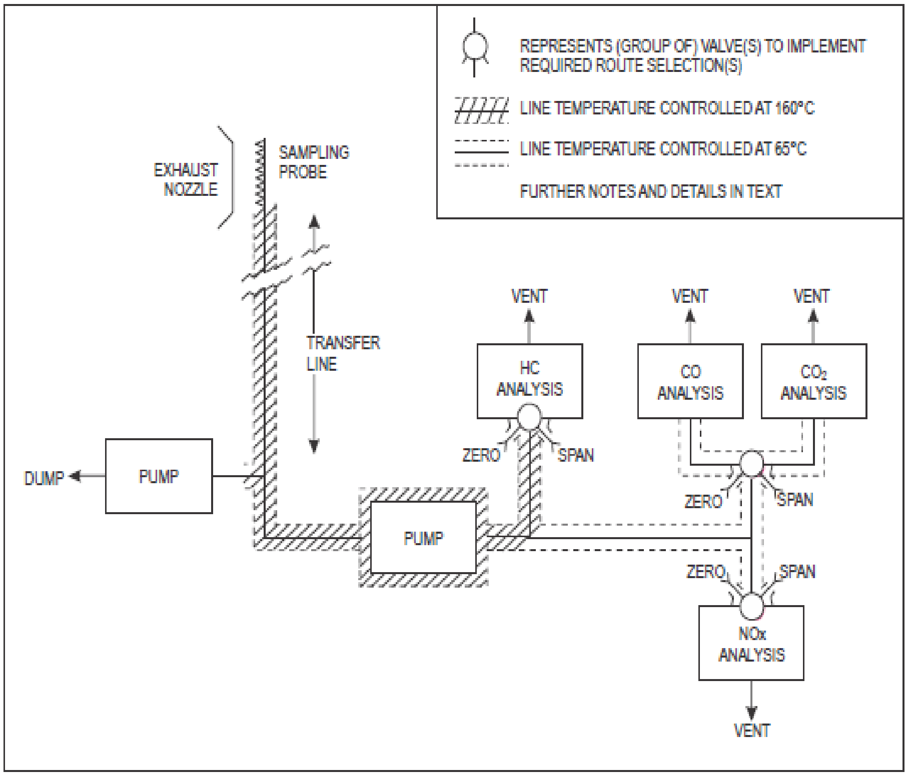


Figure S3-1. Sampling and analysis system, schematic

5.1.2 Sampling lines

The sample shall be transferred from the probe to the analysers via a line of 4.0 to 8.5 mm inside diameter, taking the shortest route practicable and using a flow rate such that the transport time is less than 10 seconds. The line shall be maintained at a temperature of 160°C ±15°C, except for (a) the distance required to cool the gas from the engine exhaust temperature down to the line control temperature, and (b) the branch which supplies samples to the CO, CO_2, and NOx analysers. This branch line shall be maintained at a temperature of 65°C ±15°C. When sampling to measure HC, CO, CO_2 and NO_x components the line shall be constructed in stainless steel or carbon-loaded grounded PTFE.

5.2 HC analyser

The measurement of total hydrocarbon sample content shall be made by an analyser using the heated flame ionization detector (FID), between the electrodes of which passes an ionization current proportional to the mass rate of hydrocarbon entering a hydrogen flame. The analyser shall be deemed to include components arranged to control temperature and flow rates of sample, sample bypass, fuel and diluent gases, and to enable effective span and zero calibration checks.

Note.— An overall specification is given in 5.2.1 of this Schedule.

5.2.1 Specification for HC analyser

Note 1.— As outlined in 5.2 of this Schedule, the measuring element in this analyser is the flame ionization detector (FID) in which the whole or a representative portion of the sample flow is admitted into a hydrogen-fuelled flame. With suitably positioned electrodes an ionization current can be established which is a function of the mass rate of hydrocarbon entering the flame. It is this current which, referred to an appropriate zero, is amplified and ranged to provide the output response as a measure of the hydrocarbon gas concentration expressed as ppmC equivalent.
Note 2.— See 6.2.4 and 6.3.3 of this Schedule for information on calibration and test gases.

5.2.1.1 General

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point not less than 150°C. The leading specification points shall be as follows, the detector response having been optimized and the instrument generally having stabilized:

(a) *Total range:* 0 to 5 000 ppmC in appropriate ranges.
(b) *Resolution:* better than 0.5 per cent of full scale of range used or 0.5 ppmC, whichever is greater.
(c) *Repeatability:* better than ±1 per cent of full scale of range used, or ±0.5 ppmC, whichever is greater.
(d) *Stability:* better than ±2 per cent of full scale of range used or ±1.0 ppmC, whichever is greater, in a period of 1 hour.
(e) *Zero drift:* less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater, in a period of 1 hour.
(f) *Noise:* 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater.
(g) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.
(h) *Linearity:* response with propane in air shall be linear for each range within ±2 per cent of full scale, otherwise calibration corrections shall be used.

5.2.1.2. Synergetic effects

Note.— In application there are two aspects of performance which can affect the accuracy of measurement:

(a) the oxygen effect (whereby differing proportions of oxygen present in the sample give differing indicated hydrocarbon gas concentration for constant actual HC gas concentrations); and
(b) the relative hydrocarbon response (whereby there is a different response to the same sample hydrocarbon gas concentrations expressed as equivalent ppmC, dependent on the class or admixture of classes of hydrocarbon compounds).

The magnitude of the oxygen effects and relative hydrocarbon responses shall be determined as follows and limited accordingly:
Oxygen response: measure the response with two blends of propane, at approximately 500 ppmC gas concentration known to a relative accuracy of ±1 per cent, as follows:

(a) propane in 10 ±1 per cent O_2, balance N_2; and
(b) propane in 21 ±1 per cent O_2, balance N_2.

If R_1 and R_2 are the respective normalized responses then $(R_1 – R_2)$ shall be less than 3 per cent of R_1.
Differential hydrocarbon response: measure the response with four blends of different hydrocarbons in air, at gas concentrations of approximately 500 ppmC, known to a relative accuracy of ±1 per cent, as follows:

(a) propane in zero air;
(b) propylene in zero air;
(c) toluene in zero air; and
(d) n-hexane in zero air.

If R_a, R_b, R_c and R_d are, respectively, the normalized responses (with respect to propane), then $(R_a – R_b)$, $(R_a – R_c)$ and $(R_a – R_d)$ shall each be less than 5 per cent of R_a.

5.2.1.3 Optimization of detector response and alignment

5.2.1.3.1 The manufacturer's instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilise. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

5.2.1.3.2 The linearity of each analyser range shall be checked by applying propane in air samples at gas concentrations of approximately 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line (fitted to the points and zero) shall not exceed ±2 per cent of full scale value. If it does, a calibration curve shall be prepared for operational use.

5.3 CO and CO_2 analysers

Non-dispersive infrared analysers shall be used for the measurements of these components, and shall be of the design which utilizes differential energy absorption in parallel reference and sample gas cells, the cell or group of cells for each of these gas constituents being sensitized appropriately. This analysis subsystem shall include all necessary functions for the control and handling of sample, zero and span gas flows. Temperature control shall be that appropriate to whichever basis of measurement, wet or dry, is chosen.

Note.— An overall specification is given in 5.3.1 of this Schedule.

5.3.1 Specification for CO and CO_2 analysers

5.3.1.1 Paragraph5.3 of this Schedule summarizes the characteristics of the analysis subsystem to be employed for the individual measurements of CO and CO_2 gas concentrations in the exhaust gas sample. The instruments are based on the principle of non-dispersive absorption of infrared radiation in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry or both. Interferences from gases with overlapping absorption bands may be minimized by gas absorption filters, optical filters, or both. However, optical filters should be used.

Note.— See 6.2.4 and 6.3.3 of this Schedule for information on calibration and test gases.

5.3.1.2 ***Precautions:*** The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

5.3.1.3 The principal performance specification shall be as follows:

CO analyser

(a) *Total range:* 0 to 2 500 ppm in appropriate ranges.
(b) *Resolution:* better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.
(c) *Repeatability:* better than ±1 per cent of full scale of range used, or ±2 ppm, whichever is greater.
(d) *Stability:* better than ±2 per cent of full scale of range used or ±2 ppm, whichever is greater, in a period of 1 hour.
(e) *Zero drift:* less than ±1 per cent of full scale of range used or ±2 ppm, whichever is greater, in a period of 1 hour.
(f) *Noise:* 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater.
(g) *Interferences:* to be limited with respect to indicated CO gas concentration as follows:
    (i). less than 500 ppm/per cent ethylene gas concentration
    (ii). less than 2 ppm/per cent CO_2 gas concentration
    (iii). less than 2 ppm/per cent water vapour.*

If the interference limitation(s) for CO_2 and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

* Need not apply where measurements are on a "dry" basis.

5.3.1.4 Correction factors for interference limitations due to CO_2 and water vapour should always be applied.

Note.— Methods for applying the appropriate correction factors for interference effects are contained in Sections 3 and 4 of Part B of this Schedule.

CO_2 Analyser

(a) *Total range:* 0 to 10 per cent in appropriate ranges.
(b) *Resolution: better than 0.5 per cent of full scale of range used or 100 ppm, whichever is greater.*
(c) *Repeatability: better than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater.*

(d) *Stability: better than ±2 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.*
(e) *Zero drift: less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater, in a period of 1 hour.*
(f) *Noise: 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±100 ppm, whichever is greater.*
(g) *The effect* of oxygen (O_2) on the CO_2 analyser response shall be checked. For a change from 0 per cent O_2 to 21 per cent O_2, the response of a given CO_2 gas concentration shall not change by more than 2 per cent of reading. If this limit cannot be met an appropriate correction factor shall be applied.

5.3.1.5 A correction factor for the effect of oxygen on the CO_2 analyser response should always be applied.

Note: A procedure for determining the appropriate correction factor for the effect of oxygen is provided in the *Environmental Technical Manual* (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines*

CO and CO_2 Analysers

(a) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system to the achievement of 90 per cent of the final reading.
(b) *Sample temperature:* the normal mode of operation is for analysis of the sample in its (untreated) “wet” condition. This requires that the sample cell and all other components in contact with the sample in this subsystem be maintained at a temperature of not less than 50°C, with a stability of ±2°C. The option to measure CO and CO2 on a dry basis (with suitable water traps) is allowed, in which case unheated analysers are permissible and the interference limits for H2O vapour removed, and subsequent correction for inlet water vapour and water of combustion is required.
(c) *Calibration curves:*
    (i). Analysers with a linear signal output characteristic shall be checked on all working ranges using calibration gases at known gas concentrations of approximately 0, 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line, fitted to the points and the zero reading, shall not exceed ±2 per cent of the full scale value. If it does then a calibration curve shall be prepared for operational use.
    (ii). Analysers with a non-linear signal output characteristic, and those that do not meet the requirements of linearity given above, shall have calibration curves prepared for all working ranges using calibration gases at known gas concentrations of approximately 0, 30, 60 and 90 per cent of full scale. Additional mixes shall be used, if necessary, to define the curve shape properly.

5.4 NO_x analyser

The measurement of NO gas concentration shall be by the chemiluminescent method in which the measure of the radiation intensity emitted during the reaction of the NO in the sample with added O_3 is the measure of the NO gas concentration. The NO_2 component shall be converted to NO in a converter of the requisite efficiency prior to measurement. The resultant NOx measurement system shall include all necessary flow, temperature and other controls and provide for routine zero and span calibration as well as for converter efficiency checks.

Note.— An overall specification is given in 5.4.1 of this Schedule.

5.4.1 Specification for NO_x analyser

Note.— See 6.2.4 and 6.3.3 of this Schedule for information on calibration and test gases.

5.4.1.1 As indicated in 5.4 of this Schedule, the measurement of the oxides of nitrogen gas concentration shall be by the chemiluminescent technique in which radiation emitted by the reaction of NO and O_3 is measured. This method is not sensitive to NO_2 and therefore the sample shall be passed through a converter in which NO_2 is converted to NO before the measurement of total NO_x is made. Both the original NO and the total NO_x gas concentrations shall be recorded. Thus, by difference, a measure of the NO_2 gas concentration shall be obtained.

5.4.1.2 The instrument to be used shall be complete with all necessary flow control components, such as regulators, valves, flowmeters, etc. Materials in contact with the sample gas shall be restricted to those which are resistant to attack by oxides of nitrogen, such as stainless steel, glass, etc. The temperature of the sample shall everywhere be maintained at values, consistent with the local pressures, which avoid condensation of water.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

5.4.1.3 The principal performance specification, determined for the instrument operated in an ambient temperature stable to within 2°C, shall be as follows:

(a) *Total range:* 0 to 2 500 ppm in appropriate ranges.
(b) *Resolution:* better than 0.5 per cent of full scale of range used or 1 ppm, whichever is greater.
(c) *Repeatability:* better than ±1 per cent of full scale of range used, or ±1 ppm, whichever is greater.
(d) *Stability:* better than ±2 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.
(e) *Zero drift:* less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 1 hour.
(f) *Noise:* 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 2 hours.
(g) *Interference:* suppression for samples containing CO_2 and water vapour, shall be limited as follows:
  1) less than 0.05 per cent reading/per cent CO_2 gas concentration;
  2) less than 0.1 per cent reading/per cent water vapour gas concentration.

If the interference limitation(s) for CO_2 and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

5.4.1.4 Correction factors for interference limitations due to CO_2 and water vapour should always be applied.

Note.— Methods for applying the appropriate correction factors for interference effects are contained in Sections 3 and 4 of Part B of this Schedule.

(a) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system to the achievement of 90 per cent of the final reading.
(b) *Linearity:* better than ±2 per cent of full scale of range used or ±2 ppm, whichever is greater.
(c) *Converter:* this shall be designed and operated in such a manner as to reduce NO_2 present in the sample to NO. The converter shall not affect the NO originally in the sample.

The converter efficiency shall not be less than 90 per cent. This efficiency value shall be used to correct the measured sample NO_2 value (i.e. $[NO_x]_c$– [NO]) to that which would have been obtained if the efficiency had not been 100 per cent.

6. GENERAL TEST PROCEDURES

6.1 Engine operation

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

6.1.2 The emissions tests shall be made at the thrust settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

6.2 Major instrument calibration

Note.— The general objective of this calibration is to confirm stability and linearity.

6.2.1 The applicant shall satisfy the certificating authority that the calibration of the analytical system is valid at the time of the test.

6.2.2 For the hydrocarbon analyser this calibration shall include checks that the detector oxygen and differential hydrocarbon responses are within the limits specified in 5.2.1 of this Schedule. The efficiency of the NO_2/NO converter shall also be checked and verified to meet the requirements in 5.4.1 of this Schedule.

6.2.3 The procedure for checking the performance of each analyser shall be as follows (using the calibration and test gases as specified in 6.2.4 and 6.3.3 of this Schedule):

(a) introduce zero gas and adjust instrument zero, recording setting as appropriate;

(b) for each range to be used operationally, introduce calibration gas of (nominally) 90 per cent range full-scale deflection (FSD) gas concentration; adjust instrument gain accordingly and record its setting;
(c) introduce approximately 30 per cent, 60 per cent, and 90 per cent range FSD gas concentration and record analyser readings;

(d) fit a least squares straight line to the zero, 30 per cent, 60 per cent and 90 per cent gas concentration points. For the CO and/or CO_2 analyser used in their basic form without linearization of output, a least squares curve of appropriate mathematical formulation shall be fitted using additional calibration points if judged necessary. If any point deviates by more than 2 per cent of the full-scale value or ±1 ppm, for the CO analyser and ±100ppm for the CO_2 analyser, whichever is greater than a calibration curve shall be prepared for operational use.

6.2.4 Calibration gases

Table S3-1. Table of calibration gases

Analyser	*Gas*	*Accuracy**
HC	propane in zero air	±2 per cent or ±0.05 ppm**
CO_2	CO_2 in zero air	±2 per cent or ±100 ppm**
CO	CO in zero air	±2 per cent or ±2 ppm**
NO_x	NO_x in zero nitrogen	±2 per cent or ±1 ppm**
* Taken over the 95 per cent confidence interval. ** Whichever is greater.		
The above gases are required to carry out the routine calibration of analysers during normal operational use.		

6.2.4.1 Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

6.2.4.2 Zero gas as specified for the CO, CO_2 and HC analysers shall be zero air (which includes "artificial" air with 20 to 22 per cent O_2 blended with N_2). For the NO_x analyser, zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following gas concentrations:

1 ppm C
1 ppm CO
100 ppm CO_2
1 ppm NO_x

6.2.4.3 The applicant shall ensure that commercial gases, as supplied, do in fact meet this specification, or are so specified by the vendor.

6.3 Operation

6.3.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

(a) leakage check: prior to a series of tests, the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump to verify that the system leakage flow rate is less than 0.4 L/min referred to standard temperature and pressure. The vacuum 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 26 L/min at standard temperature and pressure;

(b) cleanliness check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 per cent of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

6.3.1.1 Back-purging of sampling probes should occur during engine start-up and shutdown with the measurement analysers isolated.

Note 1. Back-purging ensures that no significant fuel contamination occurs in the sampling system.

Note 2. If there are significant levels of emission species present in the background air at the engine inlet due to various other sources, there may be an impact on the levels of engine exhaust emission species. In this situation, monitoring those species and accounting for this background air quality in reported emissions levels may be warranted.

6.3.1.2 If a procedure accounting for the background air quality on the reported emissions levels is warranted, then this procedure should be used, subject to the approval of the certificating authority.

6.3.2 The following procedure shall be adopted for operational measurements:

(a) apply appropriate zero gas and make any necessary instrument adjustments;

(b) apply appropriate calibration gas at a nominal 90 per cent FSD gas concentration for the ranges to be used, adjust and record gain settings accordingly;

(c) when the engine has been stabilized at the required thrust setting, continue to run it and observe pollutant gas concentrations until a stabilized reading is obtained, which shall be recorded;

(d) recheck zero and calibration points at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of range FSD, the test shall be repeated after restoration of the instrument to within its specification.

6.3.3 Test gases

Table S3-2. Table of test gases

Analyser	Gas	Accuracy*
HC	propane in 10 ±1 per cent O_2 balance zero nitrogen	±1 per cent
HC	propane in 21 ±1 per cent O_2 balance zero nitrogen	±1 per cent
HC	propylene in zero air	±1 per cent
HC	toluene in zero air	±1 per cent
HC	n-hexane in zero air	±1 per cent
HC	propane in zero air	±1 per cent
CO_2	CO_2 in zero air	±1 per cent
CO_2	CO_2 in zero nitrogen	±1 per cent
CO	CO in zero air	±1 per cent

NOx	NO in zero nitrogen	±1 per cent
* Taken over the 95 per cent confidence interval.		
The above gases are required to carry out the tests of 5.2.1, 5.3.1 and 5.4.1 of this Schedule.		

6.3.3.1 Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

6.3.3.2 Zero gas as specified for the CO, CO_2 and HC analysers shall be zero air (which includes "artificial" air with 20 to 22 per cent O_2 blended with N2). For the NOx analyser, zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following gas concentrations:

1 ppm C
1 ppm CO
100 ppm CO_2
1 ppm NO_x

6.3.3.3 The applicant shall ensure that commercial gases, as supplied, do in fact meet this specification, or are so specified by the vendor.

6.4 Carbon balance check

Each test shall include a check that the air/fuel ratio as estimated from the integrated sample total carbon gas concentration exclusive of smoke, agrees with the estimate based on engine air/fuel ratio with an accuracy of ±15 per cent for the taxi/ground idle mode, and with an accuracy of ±10 per cent for all other modes (*see* 7.1.2).

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the gas concentrations of the various gaseous emissions, as detected at their respective analysers for a range of combustor inlet temperatures (T_B) encompassing the four LTO operating modes. Using the calculations of 7.1.2, or the alternative methodology defined in section 4 of Part B of this Schedule, the measured emissions indices (EI) for each gaseous pollutant shall be established. To account for deviations from reference atmospheric conditions, the corrections of 7.1.3 shall be applied. Note that these corrections may also be used to account for deviations of the tested engine from the reference standard engine where appropriate (*see* Schedule 6, 1 f)). Using combustor inlet temperature (T_B) as a correlating parameter, the emissions indices and fuel flow corresponding to the operation at the four LTO operating modes of a reference standard engine under reference day conditions shall then be established using the procedures of 7.2.

7.1.2 Basic parameters

$$\mathrm{EI}_{\mathrm{p}}(\text{emissions indexforcomponentp}) = \frac{\text{massofpproduceding}}{\text{mass of fuel used in kg}}$$

$$\mathrm{EI(CO)} = \left(\frac{[\mathrm{CO}]}{[\mathrm{CO_2}] + [\mathrm{CO}] + [\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{CO}}}{M_{\mathrm{C}} + (^n/_m)M_{\mathrm{H}}}\right)\left(1 + [\mathrm{CO_2}]_b\left(^{\mathrm{P_0}}/_m\right)\right)$$

$$\mathrm{EI(HC)} = \left(\frac{[\mathrm{HC}]}{[\mathrm{CO_2}] + [\mathrm{CO}] + [\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{HC}}}{M_{\mathrm{C}} + (^n/_m)M_{\mathrm{H}}}\right)\left(1 + [\mathrm{CO_2}]_b\left(^{\mathrm{P_0}}/_m\right)\right)$$

$$\mathrm{EI(NOx)\ as\ NO_2} = \left(\frac{[\mathrm{NOx}]}{[\mathrm{CO_2}] + [\mathrm{CO}] + [\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{NO_2}}}{M_{\mathrm{C}} + (^n/_m)M_{\mathrm{H}}}\right)\left(1 + [\mathrm{CO_2}]_b\left(^{\mathrm{P_0}}/_m\right)\right)$$

$$\frac{\mathrm{Air}}{\mathrm{Fuel}}\,\mathrm{Ratio} = {}^{\mathrm{P_0}}/_m\left(\frac{M_{\mathrm{AIR}}}{M_{\mathrm{C}} + (^n/_m)M_{\mathrm{H}}}\right)$$

Where

$$P_0/m = \frac{2Z - n/m}{4(1 + h_{vol} - [[\mathrm{CO_2}]_b Z/2])}$$

and

$$Z = \frac{2 - [\mathrm{CO}] - ([2/x] - [y/2x])\,[\mathrm{HC}] + [\mathrm{NO_2}]}{[\mathrm{CO_2}] + [\mathrm{CO}] + [\mathrm{HC}]}$$

MAIR molecular mass of dry air = 28.966 g or, where appropriate, = (32 $[O_2]_b$+ 28.156 4 $[N_2]_b$+ 44.011 $[CO_2]_b$) g

MCO molecular mass of CO = 28.011 g
M_{HC} molecular mass of exhaust hydrocarbons, taken as CH4 = 16.043 g
$M_{\mathrm{NO_2}}$ molecular mass of NO_2= 46.008 g
M_{C} atomic mass of carbon = 12.011 g
M_{H} atomic mass of hydrogen = 1.008 g
$[O_2]_b$ gas concentration of O_2in dry air, by volume = 0.209 5
$[N_2]_b$ gas concentration of N_2+ rare gases in dry air, by volume = 0.790 2
$[CO_2]_b$ gas concentration of CO_2in dry air, by volume = 0.0003
[HC] mean gas concentration of exhaust hydrocarbons vol/vol, wet, expressed as carbon
[CO] mean gas concentration of CO in exhaust sample vol/vol, wet
$[CO_2]$mean gas concentration of CO_2in exhaust sample vol/vol, wet
[NOx] mean gas concentration of NO and NO_2in exhaust sample vol/vol, wet = [NO + NO_2]
[NO] mean gas concentration of NO in exhaust sample, vol/vol, wet
$[NO_2]$ mean gas concentration of NO_2 in exhaust sample, vol/vol, wet

$$= \frac{([\mathrm{NOx}]_c - [\mathrm{NO}])}{\eta}$$

$[\mathrm{NOx}]_c$ mean gas concentration of NO in exhaust sample after passing through the NO_2/NO converter, vol/vol, wet

η	efficiency of NO_2/NO converter
h_{vol}	humidity of ambient air, vol water/vol dry air
m	number of C atoms in characteristic fuel molecule
n	number of H atoms in characteristic fuel molecule
x	number of C atoms in characteristic exhaust hydrocarbon molecule
y	number of H atoms in characteristic exhaust hydrocarbon molecule

The value of n/m, the ratio of the atomic hydrogen to atomic carbon of the fuel used, is evaluated by fuel type analysis. The ambient air humidity, h_{vol}, shall be measured at each set condition. In the absence of contrary evidence as to the characterization (x,y) of the exhaust hydrocarbons, the values $x = 1$, $y = 4$ are to be used. If dry or semi-dry CO and CO_2measurements are to be used then these shall first be converted to the equivalent wet gas concentration

Note. — Methods for converting to the equivalent wet gas concentrations are contained in Part B of this Schedule, Sections 3 and 4.

7.1.3 Correction of emission indices to reference conditions

7.1.3.1 Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine modes to account for deviations from the reference atmospheric conditions (ISA at sea level) of the actual test inlet air conditions of temperature and pressure. These corrections may also be used to account for deviations of the tested engine from the reference standard engine where appropriate (*see* Schedule 6, 1 f)). The reference value for humidity shall be 0.00634 kg water/kg dry air. Thus, EI corrected = K × EI measured, where the generalized expression for K is:

	$K = (P_{B\mathrm{ref}}/P_B)^a \times (FAR_{ref}/FAR_B)^b \times \exp([T_{B\mathrm{ref}} - T_B]/c) \times \exp(d[h_{mass} - 0.00634])$
P_B	Combustor inlet pressure, measured
T_B	Combustor inlet temperature, measured
FAR_B	Fuel/air ratio in the combustor
h_{mass}	Ambient air humidity, kg water/kg dry air
P_{ref}	ISA sea level pressure
T_{ref}	ISA sea level temperature
$P_{B\mathrm{ref}}$	Pressure at the combustor inlet of the engine tested (or the reference engine if the data is corrected to a reference engine) associated with T_B under ISA sea level conditions.
TB_{ref}	Temperature at the combustor inlet under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine). This temperature is the temperature associated with each thrust level specified for each mode.

FAR_{ref}	Fuel/air ratio in the combustor under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).
a,b,c,d	Specific constants which may vary for each pollutant and each engine type.

The combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas.

7.1.3.2 Using the recommended curve fitting technique of 7.2 to relate emission indices to combustor inlet temperature effectively eliminates the exp $((T_{B\text{ref}} - T_B)/c)$ term from the generalized equation and for most cases the (FAR_{ref}/FAR_B) term may be considered unity. For the emissions indices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the $(P_{B\text{ref}}/P_B)$ term is close to unity. Thus,

$$\text{EI(CO) corrected} = \text{EI derived from } (P_B/P_{Bref}) \times \text{EI(CO) v. } T_B \text{ curve}$$

$$\text{EI(HC) corrected} = \text{EI derived from } (P_B/P_{Bref}) \times \text{EI(HC) v. } T_B \text{ curve}$$

$$\text{EI(NOx) corrected} = \text{EI derived from EI(NOx)} \times (P_{Bref}/P_B)^{0.5} \times \exp\left(19\,[h_{mass} - 0.00634]\right) \text{ v. } T_B \text{ curve}$$

If this recommended method for the CO and HC emissions index correction does not provide a satisfactory correlation, an alternative method using parameters derived from component tests may be used.

Any other methods used for making corrections to CO, HC and NOx emissions indices shall have the approval of the certificating authority.

7.2 Control parameter functions
(D_p, F_{oo}, π)

		7.2.1 Definitions
D_p	The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle.	
F_{oo}	Rated thrust (*see* Part I, Chapter 1, Definitions)	
F_n	Thrust at LTO operating mode *n* (kN)	
W_f	Fuel mass flow rate of the reference standard engine under ISA sea level conditions (kg/s)	
W_{fn}	Fuel mass flow rate of the reference standard engine under ISA sea level conditions at LTO operating mode η	
π	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 at ISA sea level static conditions	

7.2.2 The emissions indices (EI_n) for each pollutant, corrected to reference atmospheric conditions and, if necessary, to the reference standard engine, (EI_n

(corrected)), shall be obtained for each LTO operating mode. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined under reference atmospheric conditions for each gaseous pollutant:

(a) between EI (corrected) and T_B;

(b) between W_f and T_B ; and

(c) between F and T_B.

Note 1. These relationships are illustrated, for example, by Figure S3-2 (a), (b) and (c).

Note 2. The relationships (b) and (c) may be established directly from engine test data, or may be derived from a validated engine performance model.

7.2.2.1 A reference engine is defined as an engine substantially configured to the production standard of the engine type and with fully representative operating and performance characteristics.

7.2.2.2 The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:
(a) rated thrust (F_{oo}); and
(b) reference pressure ratio (π_{oo}).

Note . These are illustrated by Figure S3-2 (d).

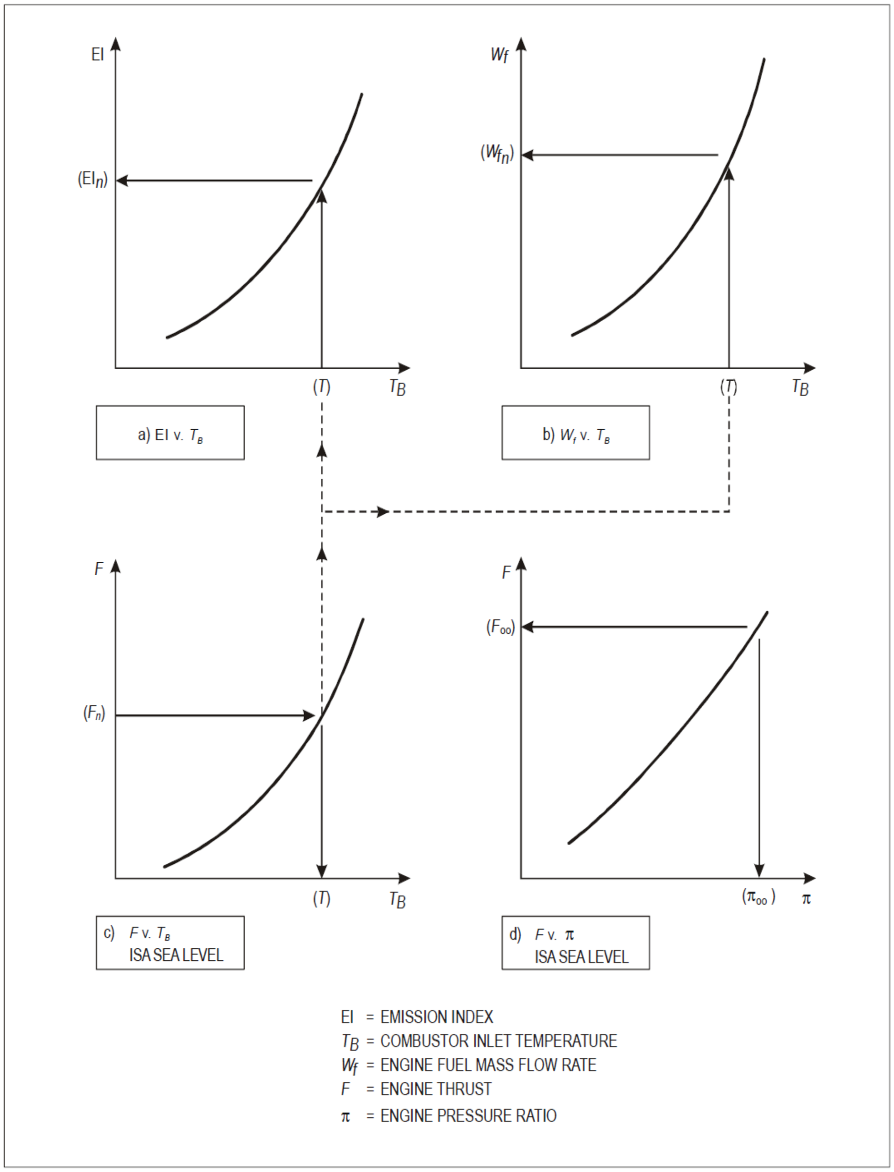


Figure S3-2. Calculation procedure

7.2.3 The estimation of EI (corrected) for each gaseous emission at the four LTO operating modes shall comply with the following general procedure:

(a) determine the combustor inlet temperature (T_B) (Figure S3-2 c)) at the values of F_n corresponding to the four LTO operating modes, $_n$, under reference atmospheric conditions;

(b) from the EI (corrected)/T_B characteristic (Figure S3-2 a)), determine the EI_n value corresponding to T_B;

(c) from the W_f/T_B characteristic (Figure S3-2 b)), determine the W_{fn} value corresponding to T_B;

(d) record the F_{oo} and $□_{oo}$ (Figure S3-2 d));

(e) calculate, for each pollutant D_p = □ (EI_n) (W_{fn}) (t) where:

t is the time in LTO mode (minutes);

W_{fn} is the fuel mass flow rate (kg/min); and

Σ is the summation for the set of modes comprising the reference LTO cycle.

Note. - While the methodology described above is the required method, the certificating authority may accept equivalent mathematical procedures which utilize mathematical expressions representing the curves illustrated if the expressions have been derived using an accepted curve fitting technique.

PART B

THE CALCULATION OF THE GASEOUS EMISSIONS PARAMETERS — BASIS, MEASUREMENT CORRECTIONS AND ALTERNATIVE NUMERICAL METHOD

1. SYMBOLS

AFR	air/fuel ratio, the ratio of the mass flow rate of dry air to that of the fuel
EI	emissions index; 10^3×mass flow rate of gaseous emissions product in exhaust per unit mass flow rate of fuel
K	ratio of gas concentration measure dwelt to that measured dry (after cold trap)
L, L'	analyser interference co efficient for interference by CO_2
M, M'	analyser interference co efficient for interference by H_2O
M_{AIR}	molecular mass of dry air=28.966gor, where appropriate, =($32R$+$28.1564S$+$44.011T$) g

MCO	molecular mass of CO=28.011g
MHC	molecular mass of exhaust hydro carbon, taken as CH_4=16.043g
$M$$NO_2$	molecular mass of NO_2=46.008g
MC	atomic mass of carbon=12.011g
MH	atomic mass of hydrogen=1.008g
P_1	number of moles of CO_2 in the exhaust sample per mole of fuel
P_2	number of moles of N_2 in the exhaust sample per mole of fuel
P_3	number of moles of O_2 in the exhaust sample per mole of fuel
P_4	number of moles of H_2O in the exhaust per mole of fuel
P_5	number of moles of CO in the exhaust per mole of fuel
P_6	number of moles of C_xH_y in the exhaust sample per mole of fuel
P_7	number of moles of NO_2in the exhaust sample per mole of fuel
P_8	number of moles of NO in the exhaust sample Per mole of fuel
$P_TP_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8$	
P_0	number of moles of air per mole of fuel in initial air/fuel mixture
Z	symbol used and define din 3.4
$[O_2]_b$	gas concentration of O_2 in dry air, by volume=0.209 5
$[N_2]_b$	gas concentration of N_2+rare gases in dry air, by Volume =0.790 2
$[CO_2]_b$	gas concentration of CO_2 in dry air, by volume = 0.000 3
$[CO_2]$	means gas concentration of CO_2 in exhaust sample, vol/vol, wet
[CO]	means gas concentration of CO in exhaust

sample, vol/vol, wet

[HC]	means gas concentration of exhaust hydrocarbons, vol/vol, wet, Expressed as carbon
[NO]	means gas concentration of NO in exhaust sample, vol/vol, wet
$[NO_2]$	means gas concentration of NO_2 in exhaust sample, vol/vol, wet

$$== \frac{([NOx]_C - [NO])}{\eta}$$

[NO	means gas concentration of NO and NO_2 in exhaust sample, vol/vol, wet=$[NO+NO_2]$
$[NOx]_C$	means gas concentration of NO in exhaust sample, after passing through the NO_2/NO converter, vol/vol, wet
$[\ ]_d$	means gas concentration in exhaust sample after cold trap, vol/vol
$[\ ]_m$	means gas concentration measurement indicated before instrument correction applied, vol/vol
h_{vol}	humidity of ambient air, vol water/ vol dry air
h_d	humidity of exhaust sample leaving “drier” or “cold trap”, vol water /vol dry sample
m	number of C atoms in characteristic fuel molecule
n	number of H atoms in characteristic fuel molecule
x	number of C atoms in characteristic exhaust hydrocarbon molecule
y	number of H atoms in characteristic exhaust hydrocarbon molecule
η	efficiency of NO_2/NO converter

2. BASIS OF CALCULATION OF EI AND AFR PARAMETERS

2.1 It is assumed that the balance between the original fuel and air mixture and the resultant state of the exhaust emissions as sampled can be represented by the following equation:

$$C_mH_n + P_0[[O_2]_b(O_2) + [N_2]_b(N_2) + [CO_2]_b(CO_2) + h_{vol}(H_2O)] = P_1(CO_2) + P_2(N_2) + P_3(O_2) + P_4(H_2O) + P_5(CO) + P_6(C_xH_y) + P_7(NO_2) + P_8(NO)$$

from which the required parameters can, by definition, bee expressed as

$$\mathrm{EI(CO)} = P_5\left(\frac{10^3 M_{\mathrm{CO}}}{mM_{\mathrm{C}} + nM_{\mathrm{H}}}\right)$$

$$\mathrm{EI(HC)} = xP_6\left(\frac{10^3 M_{\mathrm{HC}}}{mM_{\mathrm{C}} + nM_{\mathrm{H}}}\right) \text{expressed as methane equivalent}$$

$$\mathrm{EI(NOx)} = (P_7 + P_8)\left(\frac{10^3 M_{\mathrm{NO_2}}}{mM_{\mathrm{C}} + nM_{\mathrm{H}}}\right) \text{expressed as } \mathrm{NO_2} \text{ equivalent}$$

$$\mathrm{AFR} = P_0\left(\frac{M_{\mathrm{AIR}}}{mM_{\mathrm{C}} + nM_{\mathrm{H}}}\right)$$

2.2 Values for fuel hydrocarbon composition (*m,n*) are assigned by fuel specification or analysis. If only the ratio*n/m*is so determined, the value $m = 12$ may be assigned. The mole fractions of the dry air constituents ($[O_2]_b$, $[N_2]_b$, $[CO_2]_b$) are normally taken to be there commended standard values but alternative values may be assigned, subject to the restriction $[O_2]_b + [N_2]_b + [CO_2]_b = 1$ and the approval of the certificating authority.

2.3 The ambient air humidity, h_{vol}, is as measured at each test condition. It is recommended that, in the absence of contrary evidence as to the characterization (*x, y*) of the exhaust hydrocarbon, values of $x = 1$ and $y = 4$ are assigned.

2.4 Determination of the remaining unknowns requires the solution of the following set of line a simultaneous equation, where (1) to (4) derive from the fundamental atomic conservation relationships and (5) to (9) represent the gaseous product gas concentration relationships.

$$m + [CO_2]_b P_0 = P_1 + P_5 + xP_6 \quad (1)$$

$$n + 2h_{vol}P_0 = 2P_4 + yP_6 \quad (2)$$

$$(2[O_2]_b + 2[CO_2]_b + h_{vol})P_0 = 2P_1 + 2P_3 + P_4 + P_5 + 2P_7 + P_8 \quad (3)$$

$$2[N_2]_b P_0 = 2P_2 + P_7 + P_8 \quad (4)$$

$$[CO_2]\, P_T = P_1 \quad (5)$$

$$[CO]\, P_T = P_5 \quad (6)$$

$$[HC]\, P_T = xP_6 \quad (7)$$

$$[NOx]_c\, P_T = \eta\, P_7 + P_8 \quad (8)$$

$$[NO]\, P_T = P_8 \quad (9)$$

$$P_T = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 \quad (10)$$

The above set of conditional equations is for the case where all measured gas concentrations are true, that is, not subject to interference effects or to the need to correct for sample drying. In practice, interference effects are usually present to a significant degree in the CO and NO measurements, and the option to measure $CO_2$and CO on a dry or partially dry basis is often used. The necessary modifications to the relevant equations are described in 2.5 and 2.6.

2.5 The interference effects are mainly caused by the presence of CO_2 and H_2O in the sample which can affect the CO and NO_x analysers in basically different ways. The CO analyser is prone to a zero-shifting effect and the NO_x analyser to a sensitivity change, represented thus:

$$[CO] = [CO]_m + L[CO_2] + M[H_2O]$$

$$\text{and } [NOx]_c = [NOx]_{cm}\,(1 + L'[CO_2] + M'[H_2O])$$

which transform into the following alternative equations to (6), (8) and (9), when interference effects require to be corrected,

$$[CO]_m P_T + LP_1 + MP_4 = P_5 \quad \text{(6A)}$$

$$[NOx]_{cm}\,(P_T + L'P_1 + M'P_4) = \eta P_7 + P_8 \quad \text{(8A)}$$

$$[NO]_m\,(P_T + L'P_1 + M'P_4) = P_8 \quad \text{(9A)}$$

2.6 The option to measure CO_2 and CO gas concentrations on a dry or partially dry sample basis, that is, with a sample humidity reduced to h_d, requires the use of modified conditional equations as follows:

$$[CO_2]_d\,(P_T - P_4)\,(1 + h_d) = P_1 \quad \text{(5A)}$$

and

$$[CO]_d\,(P_T - P_4)\,(1 + h_d) = P_5$$

However, the CO analyser may also be subject to interference effects as described in 2.5 and so the complete alternative CO measurement gas concentration equation becomes

$$[CO]_{md}\,(P_T - P_4)\,(1 + h_d) + LP_1 + Mh_d\,(P_T - P_4) = P_5 \quad \text{(6B)}$$

3. ANALYTICAL FORMULATIONS

3.1 General

Equations (1) to (10) can be reduced to yield the analytical formulations for the EI and AFR parameters, as given in 7.1 of fifth schedule. This reduction is a process of progressive elimination of the roots P_0, P_1through P_8, P_T, making the assumptions that all gas concentration measurements are of the "wet" sample and do not require interference corrections or the like. In practice, the option is often chosen to make the $CO_2$and CO gas concentration measurements on a "dry" or "semi-dry" basis; also it is often found necessary to make interference corrections. Formulations for use in these various circumstances are given in 3.2, 3.3 and 3.4 of this Schedule.

3.2 Equation for conversion of dry gas concentration measurements to wet basis

Gas concentration wet=K×gas concentration dry; that is,

$$[\,] = K[\,]_d$$

The following expression for K applies when CO and CO2 are determined on a "dry" basis:

$$K = \frac{\{4 + (n/m)T + ([n/m]T - 2h_{vol})([NO_2] - (2[HC]/x)) + (2 + h_{vol})([y/x] - [n/m])[HC]\}(1 + h_d)}{(2 + h_{vol})\{2 + (n/m)(1 + h_d)([CO_2]_d + [CO]_d)\} - ([n/m]T - 2h_{vol})(1 - [1 + h_d][CO]_d)}$$

3.3 Interference corrections

The measurements of CO and/or NO_x and NO may require corrections for interference by the sample $CO_2$and water concentrations before use in the above analytical equations. Such corrections can normally be expressed in the following general ways:

$$[CO] = [CO]_m + L[CO_2] + M[H_2O]$$

$$[CO]_d = [CO]_{md} + L[CO_2]_d + M\left(\frac{h_d}{1 + h_d}\right)$$

$$[NO] = [NO]_m\,(1 + L'[CO_2] + M'[H_2O])$$

$$\eta[NO_2] = ([NOx]_{cm} - [NO]_m)\,(1 + L'[CO_2] + M'[H_2O])$$

3.4 Equation for estimation of sample water content

Water concentration in sample

$$[H_2O] = \frac{([n/2m] + h_{vol}[P_0/m])\,([CO_2] + [CO] + [HC])}{1 + T(P_0/m)} - (y/2x)\,[HC]$$

where

$$P_0/m = \frac{2Z - n/m}{4(1 + h_{vol} - [[CO_2]_b Z/2])}$$

and

$$Z = \frac{2 - [CO] - ([2/x] - [y/2x])\,[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}$$

It should be noted that this estimate is a function of the various analyses gas concentration readings, which may themselves require water interference correction. For better accuracy an iterative procedure is required in these cases with successive recalculation of the water concentration until the requisite stability is obtained. The use of the alternative, numerical solution methodology (4) avoids this difficulty.

3 ALTERNATIVE METHODOLOGY — NUMERICAL SOLUTION

3.1 As an alternative to the analytical procedures summarizedin3, it is possible to obtain readily the emissions indices, fuel/air ratio, corrected wet gas concentrations, etc., by a numerical solution of equations (1) to (10) for each set of measurements, using a digital computer.

4.2 In the equation set (1) to (10) the actual gas concentration measurements are substituted using whichever of the alternative equations (5A), (6A), etc. applies for the particular measuring system, to take account of interference corrections and/or dried sample measurements.

4.3 Suitable simple two-dimension a l array equation-solving computer programmes are widely available and their use for this purpose is convenient and flexible, allowing ready incorporation and identification of any sample drying options and interference or other corrections.

FOURTH SCHEDULE

(Made under regulations 10(4), 21(4) and 29(3))

SPECIFICATION FOR FUEL TO BE USED IN AIRCRAFT TURBINE ENGINE EMISSIONS TESTING

The fuel shall meet the specifications of this Schedule, unless a deviation and any necessary corrections have been agreed upon by the certificating authority. Additives used for the purpose of smoke suppression (such as organ metallic compounds) shall not be present.

Property	*Allowable range of values*
Density kg/m^3 at 15°C	780– 820
Distillation temperature, °C	
10 per cent boiling point	155– 201
Final boiling point	235– 285
Net heat of combustion, MJ/kg	42.86– 43.50
Aromatics, volume per cent	15– 23
Naphthalenes, volume per cent	0.0– 3.0
Smoke point, mm	20– 28
Hydrogen, mass per cent	13.4– 14.3

Sulphur, ppm by mass	less than 3 000
Kinematic viscosity at –20°C, mm^2/s	2.5– 6.5

FIFTH SCHEDULE:

(Made under regulations 6(10), 22(4) and 24)

PART A
INSTRUMENTATIONANDMEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS FROM AFTERBURNING GAS TURBINE ENGINES

1. INTRODUCTION

The procedures specified in this Schedule are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. These procedures only apply when afterburning is employed.

The methods proposed are representative of the best readily available and most established modern practice.

The need to correct for ambient conditions are recognised and a method will be specified when one becomes available. Any correction methods used when afterburning is employed should be approved by the certificating authority.

2. DEFINITIONS

Where the following expressions are used without further explanation in this Schedule, they have the meanings ascribed to them below:

Accuracy. The closeness with which a measurement approaches the true value established independently.

Calibration gas. A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.

Concentration. The volume fraction of the component of interest in the gas mixture — expressed as volume percentage or as parts per million.

Flame ionization detector. A hydrogen-air diffusion flame detector that produces a signal nominally proportional to the mass-flow rate of hydrocarbons entering the flame per unit of time — generally assumed responsive to the number of carbon atoms entering the flame.

Interference. Instrument response due to presence of components other than the gas (or vapour) that is to be measured.

Noise. Random variation in instrument output not associated with characteristics of the sample to which the instrument is responding, and distinguishable from its drift characteristics.

Non-dispersive infrared analyser An instrument that by absorption of infrared energy selectively measures specific components.

Parts per million (ppm). The unit volume concentration of a gas per million unit volume of the gas mixture of which it is a part.
Parts per million carbons (ppmC). The mole fraction of hydrocarbon multiplied by 10^6 measured on a methane-equivalence basis. Thus, 1 ppm of methane is indicated as1ppmC.To convert ppm concentration of any hydrocarbon to an equivalent ppmC value, multiply ppm concentration by the number of carbon atoms per molecule of the gas. For example, 1 ppm propane translates as 3 ppmC hydrocarbon; 1 ppm hexane as 6 ppmC hydrocarbon.

Plume. Total external engine exhaust flow, including any ambient air with which the exhaust mixes.

Reference gas. A mixture of gases of specified and known composition used as the basis for interpreting instrument response in terms of the concentration of the gas to which the instrument is responding.

Repeatability. The closeness with which a measurement upon a given, invariant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

Resolution. The smallest change in a measurement which can be detected.

Response. The change in instrument output signal that occurs with change in sample concentration. Also the output signal corresponding to a given sample concentration.

Stability. The closeness with which repeated measurements upon a given invariant sample can be maintained over a given period of time.

Zero drift. Time-related deviation of instrument output from zero set point when it is operating on gas free of the component to be measured.

Zero gas. A gas to be used in establishing the zero, or no response, adjustment of an instrument.

3. DATA REQUIRED

3.1 Gaseous emissions

Concentrations of the following emissions shall be determined:

a) Hydrocarbons (HC): a combined estimate of all hydrocarbon compounds present in the exhaust gas.

b) Carbon monoxide (CO).

c) Carbon dioxide (CO_2).

Note: CO_2 is not considered a pollutant but its concentration is required for calculation and check purposes.

d) Oxides of nitrogen (NO_x): an estimate of the sum of the two oxides, nitric oxide (NO) and nitrogen dioxide (NO_2).

e) Nitric oxide (NO).

3.2 Other information

In order to normalise the emissions measurement data and to quantify the engine test characteristics, other information in addition to the requirements of Part III, regulation 16 shall be provided as follows:

- In let temperature;
- In let humidity;
- atmospheric pressure;
- wind vectors relative to engine exhaust axis;
- hydrogen/carbon ratio of fuel;
- engine installation details;
- other required engine parameters (for example, thrust, rotor speeds, turbine temperatures);
- pollutant concentration data and statistical validation parameters.

This data shall be obtained either by direct measurement or by calculation, as presented in 3.2.1of this Schedule.

3.2.1 Specifications for additional data

As required in 3.2 of this Schedule, in addition to the measured sample constituent concentrations, the following data shall also be provided:

(a) inlet temperature: measured as the total temperature at a point within one diameter of the engine in take plane to an accuracy of ±0.5°C;

(b) inlet humidity (kg water/kg dry air): measured at a point within 15 m of the intake plane ahead of the engine to an accuracy of ±5 per cent of reading;

(c) atmospheric pressure: measured within 1 km of the engine test location and corrected as necessary to the test stand altitude to an accuracy of ±100 Pa;

(d) fuel mass flow: by direct measurement to an accuracy of ±2 percent;

(e) fuel H/C ratio: defined a s*n/m*, where C_mH_n is the equivalent hydrocarbon representation of the fuel used in the test and evaluated by reference to the engine fuel type analysis;
(f) engine parameters:
  1) thrust: by direct measurement to an accuracy of ±1 per cent at take-off power and ±5 per cent at the minimum thrust used in the certification test, with linear variation between these points;
  2) rotation speed(s): by direct measurement to an accuracy of at least ±0.5 percent;
  3) gas generator air flow: determined to an accuracy of ±2 percent by reference to engine performance calibration.

The parameters (a), (b), (d) and (f) shall be determined at each engine emissions test setting, while the parameter specified in (c) shall be determined at intervals of not less than 1 hour over a period encompassing that of the emissions tests.

4. GENERAL ARRANGEMENT OF THE SYSTEM

Owing to the reactive nature of the exhaust plume from engines using after burning, it is necessary to ensure that the measured emissions do in fact correspond to those actually emitted into the surrounding atmosphere. This is achieved by sampling the plume sufficiently far downstream from the engine that the exhaust gases have cooled to a temperature where reactions have ceased. No desiccants, dryers, water traps or related equipment shall be used to treat the exhaust sample flowing to the oxides of nitrogen and the hydrocarbon analysis instrumentation. Requirements for the various component sub systems are given in 5, but the following list gives some qualifications and variations:
(a) it is assumed that each of the various individual subsystems includes the necessary flow control, conditioning and measurement facilities;
(b) the necessity for a dump and/or a hot-sample pump will depend on the ability to meet the sample transfer time and analysis subsystem sample flow rate requirements. This in turn depends on the exhaust sample-driving pressure and line losses. It is considered that these pumps usually will be necessary at certain engine running conditions; and
(c) the position of the hot pump, relative to the gas analysis subsystems, may be varied as required. (For example, some HC analysers contain hot pumps and so may be judged capable of being used upstream of the system hot pump.)

Note. Figures S5-1 and S5-2 are schematic drawings of the exhaust gas sampling and analytical system and typify the basic requirements for emissions testing.

5. DESCRIPTION OF COMPONENT PARTS

Note.— A general description and specification of the principal elements in the engine exhaust emissions measurement system follows. Greater detail, where necessary, will be found in 5.2.1, 5.3.1 and 5.4.1 of this Schedule.

5.1 Sampling system

5.1.1 Sampling probe

a) The probe shall be constructed so that individual samples can be withdrawn at various locations across a diameter of the plume. Mixed samples shall not be permitted.

b) The material with which the sample is in contact shall be stainless steel and its temperature shall be maintained at a value not less than 60°C.

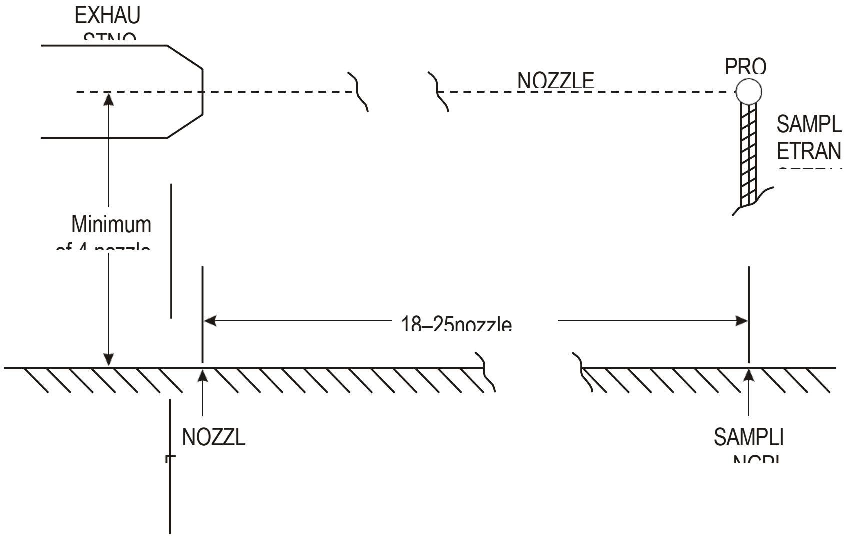


Figure S 5-1. Exhaust gas sampling system, schematic

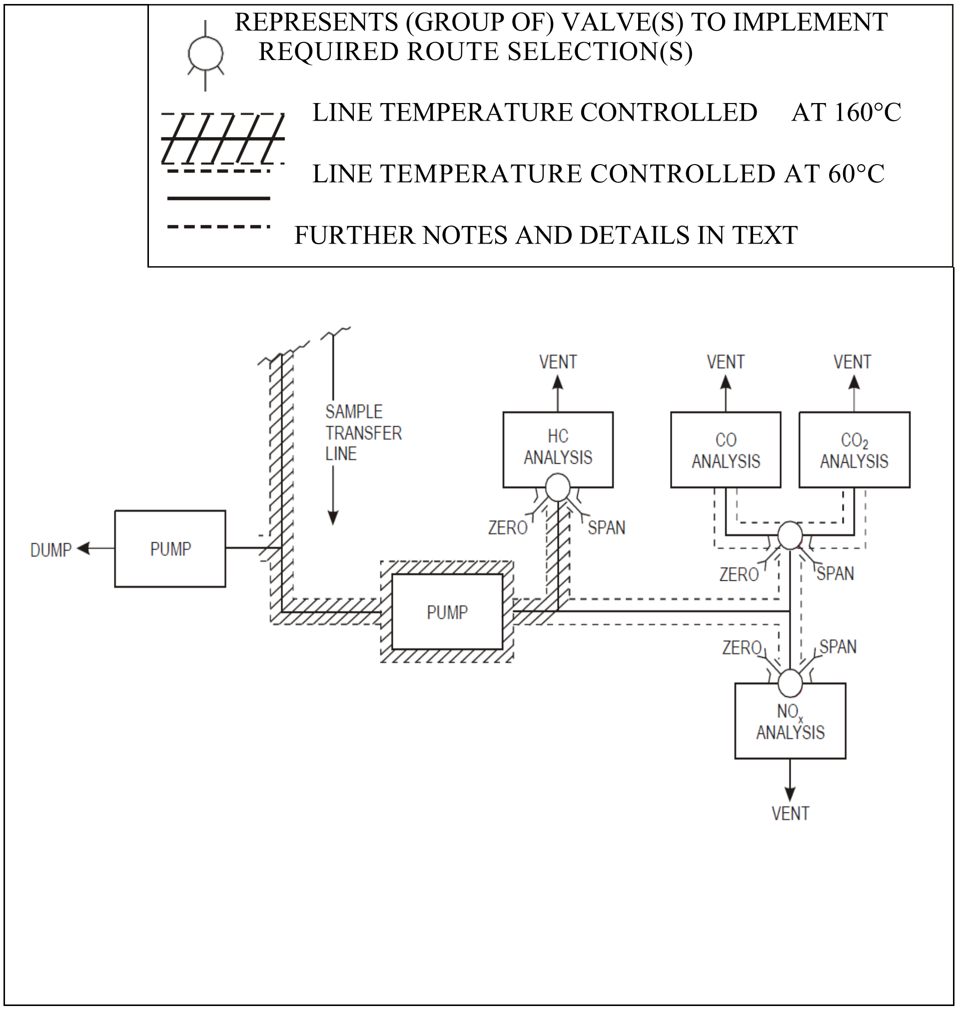


Figure S5-2. Sample transfer and analysis system, schematic

c) The sampling plane shall be perpendicular to the projected engine nozzle centre line, and shall be situated as close as possible to a position 18 nozzle diameters from the nozzle exit plane, consistent with 7.1.2, but in no case greater than 25 nozzle diameters. The nozzle exit diameter shall be for the maximum engine power condition. Between and including exit and sampling planes there shall be an unobstructed region of at least 4 nozzle exit diameters in radial distance about the project engine nozzle centre line.

d) The minimum number of sampling points shall be equal to 11. The measurement plane, located at a distance X from the engine shall be divided into three sections demarcated by circles centred around the exhaust stream axis with radii

R1=0.05*X*
R2= 0.09*X*
And a minimum of 3 samples shall be taken from each section. The difference between the number of samples in each section must be less than 3. The sample taken at the most remote distance from the axis shall be from a point located at a radius of between 0.11*X* and 0.16*X*.

5.1.2 Sampling lines

The sample shall be transferred from the probe to the analysers via a line of 4.0 to 8.5 mm inside diameter, taking the shortest route practicable and using a flow rate such that the transport time is less than 10 seconds. The line shall be maintained at a temperature of 160°C±15°C (with a stability of ±10°C). When sampling to measure HC, CO, CO2 and NOx components, the line shall be constructed in stainless steel or carbon-loaded grounded PTFE.

5.2 HC analyser

The measurement of total hydrocarbon sample content shall be made by an analyse using the heated flame ionization detector (FID), between the electrodes of which passes an ionization current proportional to the mass rate of hydrocarbon entering a hydrogen flame. The analyser shall be deemed to include components arranged to control temperature and flow rates of sample, sample bypass, fuel and diluent gases, and to enable effective span and zero calibration checks.

Note.—An overall specificationisgivenin5.2.1ofthisSchedule.

5.2.1 Specification for HC analyser

Note1.Asoutlinedin5.2ofthisSchedule, the measuring element in this analyser is the flame ionization detector (FID) in which the whole or a representative portion of the sample flow is admitted into a hydrogen-fuelled flame. With suitably positioned electrodes anionization current can be established which is a function of the mass rate of hydrocarbon entering the flame. It is this current which, referred to an appropriate zero, is amplified and ranged to provide the output response as a measure of the hydrocarbon concentration expressed as ppmC equivalent.

Note 2. See 6.3.4and 6.4.3of this Schedule for information on calibration and test gases.

5.2.1.1 General

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point temperature within the range 155°C to 165°C to a stability of ±2°C. The leading specification points shall be as follows, the detector response having been optimized and the instrument generally having stabilized:

(a) *Totalrange:*0 to 500 ppm C in appropriate ranges.

(b) *Resolution:* better than 0.5 percent of full scale of range used or 0.5ppmC, whichever is greater.

(c) *Repeatability:* better than ±1 percent of full scale of range used, or ±0.5ppmC, whichever is greater.

(d) *Stability:* better than ±2 percent of full scale of range used or ±1ppmC, whichever is greater, in a period of 1 hour.

(e) *Zero drift:* less than ±1 percent of full scale of range used or ±0.5ppmC, whichever is greater, in a period of 1 hour.

(f) *Noise:* 0.5 Hz and greater, less than ±1 percent of full scale of range used or ±0.5ppmC, whichever is greater.

(g) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.
(h) *Linearity:* response with propane in air shall be linear for each range within ±2 per cent of full scale, otherwise calibration corrections shall be used.

5.2.1.2 Synergistic effects

Note: In application there are two aspects of performance which can affect the accuracy of measurement:

(a) *The oxygen effect (where by differing proportions of oxygen present in the sample give differing indicated hydrocarbon concentration for constant actual HC concentrations); and*

(b) *the relative hydrocarbon response (whereby there is a different response to the same sample hydrocarbon concentrations expressed as equivalent ppm C, dependent on the class or admixture of classes of hydrocarbon compounds).*

The magnitude of the effects noted above shall be determined as follows and limited accordingly.

Oxygen response: measure the response with two blends of propane, at approximately 500ppmC concentration known to a relative accuracy of ±1 percent, as follows:

(i). Propane in 10±1 percent O_2, balance N_2

(ii). Propane in 21±1 percent O_2, balance N_2

If R_1 and R_2 are the respective normalized responses then (R_1–R_2) shall be less than 3 percent of R_1.

Differential hydrocarbon response: measure the response with four blends of different hydrocarbons in air, at concentrations of approximately 500 ppm C, known to a relative accuracy of ±1 per cent, as follows:

(a) propane in zero air
(b) propylene in zero air
(c) toluene in zero air
(d) n-hexane in zero air.

If R_a, R_b, $R_c$and R_d are, respectively, the normalized responses (with respect to propane), then (R_a–R_b), (R_a–R_c) and (R_a–R_d) shall each be less than 5 per cent of R_a.

5.2.1.3 Optimization of detector response and alignment

5.2.1.3.1 The manufacturer's instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilise. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

5.2.1.3.2 The linearity of each analyser range shall be checked by applying propane in air samples at concentrations of approximately 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line (fitted to the points and zero) shall not exceed ±2 per cent of full-scale value. If it does, a calibration curve shall be prepared for operational use.

5.3 CO and CO_2 analysers

Non-dispersive infrared analysers shall be used for the measurement of these components, and shall be of the design which utilizes differential energy absorption in parallel reference and sample gas cells, the cell or group of cells for each of these gas constituents being sensitised appropriately. This analysis subsystem shall include all necessary functions for the control and handling of sample, zero and spang as flows. Temperature control shall be that appropriate to whichever basis of measurement, wet or dry, is chosen.

Note.—An overall specification is givenin5.3.1of this Schedule.

5.3.1 Specification for CO and CO_2 analysers

Note 1.– 5.3 of this Schedule summarizes the characteristics of the analysis subsystem to be employed for the individual measurements of CO and CO_2 concentrations in the exhaust gas sample. The instruments are based on the principle of non-dispersive absorption of infrared radiation in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry or both. Interferences from gases with overlapping absorption bands may be minimized by gas absorption filters, optical filters, or both. However, optical filters should be used.

Note 2.—See 6 .3.4 and 6.4.3 of this Schedule for information on calibration and test gases.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

The principal performance specification shall be as follows:

CO Analyser

(a) *Total range:*0 to 2500ppmin appropriate ranges.

(b) *Resolution:* better than 0.5 percent of full scale of range used or 1ppm, whichever is greater.

(c) *Repeatability:* better than ±1 percent of full scale of range used, or ±2ppm, whichever is greater.

(d) *Stability:* better than ± 2 percent of full scale of range used or ±2ppm, whichever is greater, in a period of 1hour.

(e) *Zero drift:* less than ±1 percent of full scale of range used or±2ppm, whichever is greater, in a period of 1hour.

(f) *Noise:*0. 5Hz and greater, less than ±1 percent of full scale of range used or ±1ppm, whichever is greater.

(g) *Interferences:* to be limited with respect to indicated CO concentration as follows:

   1) Less than 500ppm/percent ethylene concentration

   2) Less than 2ppm/percent CO_2concentration

   3) less than 2ppm/ percent water vapour.[*]

---

[*] *Need not apply where measurements are on a "dry" basis.*

If the interference limitation(s) for CO_2 and/ or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

Note.— It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

CO_2Analyser

(a) *Totalrange:*0 to10 percent in appropriate ranges.

(b) *Resolution:* better than 0.5 percent of full scale of range used or 100ppm, whichever is greater.

(c) *Repeatability:* better than ±1 percent of full scale of range used or ±100ppm, whichever is greater.

(d) *Stability:* better than± 2 percent of full scale of range used or ±100ppm, whichever is greater, in a period of 1hour.

(e) *Zero drift:* less than±1 percent of full scale of range used or ±100ppm, whichever is greater, in a period of 1 hour.

(f) *Noise:*0.5 Hz and greater, less than ±1 percent of full scale of range used or ±100ppm, whichever is greater.

(g) The effect of oxygen (O_2) on the CO_2 analyser response shall be checked. For a change from 0 per cent $O_2$to 21 per cent O_2 the response of a given CO_2 concentration shall not change by more than 2 per cent of reading. If this limit cannot be met an appropriate correction factor shall be applied.

Note.—It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

CO and CO_2 Analysers

(a) *Response time:* shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading.

(b) *Sample temperature:* the normal mode of operation is for analysis of the sample in its (untreated) “wet” condition. This requires that the sample cell and all other components in contact with the sample in this sub system be maintained at a temperature of not less than 50°C, with a stability of ±2°C. The option to measure CO and CO_2 on a dry basis (with suitable water traps) is allowed, in which case unheated analysers are permissible and the interference limits for H_2O vapour removed, and subsequent correction for inlet water vapour and water of combustion is required.

(c) *Calibration curves:*

(i). Analysers with a linear signal output characteristic shall be checked on all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. The maximum response deviation of any of these points from a least squares straight line, fitted to the points and the zero reading, shall not exceed ±2 percent of the full scale value. If it does then a calibration curve shall be prepared for operational use.

(ii). Analysers with a non-linear signal output characteristic, and those that do not meet the requirements of linearity given above, shall have calibration curves prepared for all working ranges using calibration gases at known concentrations of approximately 0, 30, 60 and 90 per cent of full scale. Additional mixes shall be used, if necessary, to define the curve shape properly.

5.4 NOx analyser

The measurement of NO concentration shall be by the chemiluminescent method in which the measure of the radiation intensity emitted during the reaction of the NO in the sample with added O_3 is the measure of the NO concentration. The NO_2 component shall be converted to NO in a converter of the requisite efficiency prior to measurement. The resultant NOx measurement system shall include all necessary flow, temperature and other controls and provide for routine zero and span calibration as well as for converter efficiency checks.

Note.—An overall specification is given in5.4.1of this Schedule.

5.4.1 Specification for NOx analyser

Note.—See 6.3.4 and 6.4.3 of this Schedule for information on calibration and test gases.

5.4.1.1. As indicated in 5.4 of this Schedule, the measurement of the oxides of nitrogen concentration shall be by the chemiluminescent technique in which radiation emitted by the reaction of NO and O_3 is measured. This method is not sensitive to NO_2 and therefore the sample shall be passed through a converter in which NO_2 is converted to NO before the measurement of total NOx is made. Both the original NO and the total NOx concentrations shall be recorded. Thus, by difference, a measure of the NO_2 concentration shall be obtained.

5.4.1.2. The instrument to be used shall be complete with all necessary flow control components, such as regulators, valves, flow meters, etc. Materials in contact with the sample gas shall be restricted to those which are resistant to attack by oxides of nitrogen, such as stainless steel, glass, etc. The temperature of the sample shall everywhere be maintained at values, consistent with the local pressures, which avoid condensation of water.

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

5.4.1.3. The principal performance specification, determined for the instrument operated in an ambient temperature stable to within 2°C, shall be as follows:

(a) *Total range:*0 to 2500 pp min appropriate ranges.

(b) *Resolution:* better than 0.5 percent of full scale of range used or 1ppm, whichever is greater.

(c) *Repeatability:* better than±1 percent of full scale of range used, or±1ppm, whichever is greater.

(d) *Stability:* better than±2 percent of full scale of range used or±1ppm, whichever is greater, in a period of 1hour.

(e) *Zero drift:* less than ±1 percent of full scale of range used or ±1ppm, whichever is greater, in a period of 1 hour.

(f) *Noise:* 0.5 Hz and greater, less than ±1.0 per cent of full scale of range used or ±1 ppm, whichever is greater, in a period of 2 hours.

(g) *Interference:* suppression for samples containing CO_2 and water vapour, shall be limited as follows:

- Less than 0.05 percent reading/percent CO_2 concentration;
- less than 0.1 percent reading/percent water vapour concentration.

If the interference limitation for CO_2 or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied.

Note.—It is recommended as consistent with good practice that such correction procedures be adopted in all cases.

(h) *Response time:* shall not exceed10 seconds from in let of the sample to the analysis system to the achievement of 90 per cent of the final reading.

(i) *Linearity:* better than ±2 percent of full scale of range used or ±2ppm, whichever is greater.

(j) *Converter:* this shall be designed and operated in such a matter as to reduce NO_2 present in the sample to NO. The converter shall not affect the NO originally in the sample.

The converter efficiency shall not be less than 90 percent.

This efficiency value shall be used to correct the measured sample NO_2value (i.e. [NOx] *c*– [NO]) to that which would have been obtained if the efficiency had not been 100 percent.

6. GENERAL TEST PROCEDURES

6.1 Engine operation

The engine shall be operated on an open air static test facility which is suitable and properly equipped for high accuracy performance testing, and which conforms to the requirements for sampling probe installation as specified in 5.1. The emissions tests shall be made at the power settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

6.2 Ambient air conditions

6.2.1 A check shall be made on the ambient concentrations of CO, HC, CO_2 and NOx, with the engine under test running at the test condition. Unusually high concentrations indicate abnormal conditions such as exhaust gas recirculation, fuel spillage or some other source of unwanted emissions in the test area and such situations shall be rectified or avoided as appropriate.

Note.—For guidance, the normal ambient concentration of CO_2 *is 0.03 percent, and ambient concentration levels for CO and HC of 5 ppm and NOx of 0.5 ppm are unlikely to be exceeded under normal conditions.*

6.2.2 Extreme climatic conditions, such as those involving precipitation or excessive wind speed shall also be avoided.

6.3 Major instrument calibration

Note.—The general objective of this calibration is to confirm stability and linearity.

6.3.1 The applicant shall satisfy the certificating authority that the calibration of the analytical system is valid at the time of the test.

6.3.2 For the hydrocarbon analyser this calibration shall include checks that the detector oxygen and differential hydrocarbon responses are within the limits specified in 5.2.1 of this Schedule. The efficiency of the NO_2/NO converter shall also be checked and verified to meet the requirements in 5.4.1 of this Schedule.

6.3.3 The procedure for checking the performance of each analyser shall be as follows (using the calibration and test gases as specified in 6.3.4 and 6.4.3 of this Schedule):

(a) Introduce zero gas and adjust instrument zero, recording setting as appropriate;
(b) for each range to be used operationally, introduce calibration gas of (nominally) 90 percent range full-scale deflection (FSD) concentration; adjust instrument gain accordingly and record its setting;
(c) introduce approximately 30, 60 and 90 percent range FSD concentrations and record analyser readings;
(d) fit a least squares straight line to the zero,30,60 and 90 percent concentration points. For the CO and/ or CO_2analyser used in its basic form without linearization of output, a least squares curve of appropriate mathematical formulation shall be fitted using additional calibration points if judged necessary. If any point deviates by more than 2 percent of the full scale value (or ±1 ppm*, whichever is greater) then a calibration curve shall be prepared for operational use.

6.3.4 Calibration gases

Table S5-1. Table of calibration gases

Analyser	*Gas*	*Accuracy**
HC	Propane in zero air	±2 per cent or ±0.05 ppm**
CO_2	CO_2 in zero air	±2 per cent or ±100 ppm**
CO	CO in zero air	±2 per cent or ±2 ppm**
NOx	NOx in zero nitrogen	±2 per cent or ±1 ppm**

* Taken over the 95 percent confidence interval.
** Whichever is greater.

The above gases are required to carry out the routine calibration of analysers during normal operational use.

6.3.4.1 Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

6.3.4.2 Zero gas as specified for the CO, CO_2 and HC analysers shall be zero air (which includes "artificial" air with 20 to 22 percent O_2 blended with N_2). For the NOx analyser zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following concentrations:

1ppm C
1ppm CO
100ppmCO_2
1ppm NOx

**Except for the CO_2analyse r, for which the value shall be±100ppm.*

6.3.4.3 The applicant shall ensure that commercial gases, as supplied, do in fact meet this specification, or are so specified by the vendor.

6.4 Operation

6.4.1 No measurements shall be made until all instruments and sample transfer lines are warmed up and stable and the following checks have been carried out:

(a) leakage check: prior to a series of tests the system shall be checked for leakage by isolating the probe and the analysers, connecting and operating a vacuum pump of equivalent performance to that used in the smoke measurement system to verify that the system leakage flow rate is less than 0.4L/min referred to normal temperature and pressure;

(b) clean lines check: isolate the gas sampling system from the probe and connect the end of the sampling line to a source of zero gas. Warm the system up to the operational temperature needed to perform hydrocarbon measurements. Operate the sample flow pump and set the flow rate to that used during engine emission testing. Record the hydrocarbon analyser reading. The reading shall not exceed 1 percent of the engine idle emission level or 1ppm (both expressed as methane), whichever is the greater.

Note 1. It is good practice to back-purge the sampling lines during engine running, while the probe is in the engine exhaust but emissions are not being measured, to ensure that no significant contamination occurs.

Note .2It is also good practice to monitor the inlet air quality at the start and end of testing and at least once per hour during a test. If levels are considered significant, then they should be taken into account.

6.4.2 The following procedure shall be adopted for operational measurements:

(a) Apply appropriate zero gas and make any necessary instrument adjustments;

(b) apply appropriate calibration gas at a nominal 90 per cent FSD concentration for the ranges to be used, adjust and record gain settings accordingly;

(c) when the engine has been stabilised at the requisite operating conditions and sampling location, continue to run it and observe pollutant concentrations until a stabilized reading is obtained, which shall be recorded. At the same engine operating condition repeat the measurement procedure for each of the remaining sampling locations;

(d) recheck zero and calibration points at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of full scale of range, the test shall be repeated after restoration of the instrument to within its specification.

6.4.3 Test gases

Table S 5-2. Table of test gases

Analyser	*Gas*	*Accuracy**
HC	Propane in 10±1 percent O_2 balance zero nitrogen	±1percent
HC	Propane in 21±1 percent O_2 balance zero nitrogen	±1percent
HC	Propylene in zero air	±1percent
HC	toluene in zero air	±1percent
HC	n-hexane in zero air	±1percent
HC	Propane in zero air	±1percent
CO_2	CO_2in zero air	±1percent
CO_2	CO_2 in zero nitrogen	±1percent
CO	CO in zero air	±1percent
NOx	NO in zero nitrogen	±1percent
*Taken over the 95 percent confidence interval.		
The above gases are required to carry out the tests of 5.2.1, 5.3.1 and 5.4.1 of this Schedule.		

6.4.3.1 Carbon monoxide and carbon dioxide calibration gases may be blended singly or as dual component mixtures. Three component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

6.4.3.2 Zero gas as specified for the CO, CO_2 and HC analysers shall be zero air (which includes "artificial" air with 20 to 22 percent O_2 blended with N_2). For the NOx analyser, zero nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following gas concentrations:

1ppm C
1ppm CO
100ppmCO_2
1ppm NOx

6.4.3.3 The applicant shall ensure that commercial gases, as supplied, do in fact meet this specification, or are so specified by the vendor.

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the concentrations of the various classes of pollutant, at the relevant afterburning mode(s) of the engine, at the various locations in the sampling plane. In addition to the recording of these basic parameters, other parameters shall be computed and reported, as follows.

7.1.2 Analysis and validation of measurements

(a) At each engine setting, the concentrations measured at different probe sampling positions must be averaged as follows:

$$C_{i\ moy} = \sum_{j=1}^{n} C_{i\ j}$$

Where:

$\sum_{j=1}^{n}$ Summation of the total number n of sampling positions used.

C_i Concentration of species i measured at the jth sampling position.
C_{imoy} average or mean concentration of species i.

All dry concentration measurements shall be converted in to real wet concentrations. (see Part B of this Schedule).

(b) The quality of the measurements for each pollutant will be determined through a comparison with measurements of CO_2 using the correlation coefficient:

$$r_i = \frac{n\sum_{j=1}^{n} \mathrm{C}_{ij}\mathrm{CO}_{2j} - \sum_{j=1}^{n} \mathrm{C}_{ij} \sum_{j=1}^{n} \mathrm{CO}_{2j}}{\sqrt{\left(\left\{n\sum_{j=1}^{n}(\mathrm{CO}_{2j})^2 - \left(\sum_{j=1}^{n}\mathrm{CO}_{2j}\right)^2\right\}\left\{n\sum_{j=1}^{n}\mathrm{C}_{ij^2} - \left(\sum_{j=1}^{n}\mathrm{C}_{ij}\right)^2\right\}\right)}}$$

Values of $r_i$which are near to1indicate that measurements taken over the entire sampling period are sufficiently stable and that the curves are Gaussian. In the event that $r_i$is less than 0.95, measurements must be repeated in a sampling plane located at a more remote distance from the air craft engine. The measurement process, perse is then followed by the same calculations and the same demonstration as previously.

7.1.3 Basic parameters

For the measurements a teach engine operating mode the average concentration for each gaseous species is estimated as shown in 7.1.2, any necessary corrections for dry sample measurement or interferences having been made as indicated in Part B of this Schedule. These average concentrations are used to compute the following basic parameters:

$$\mathrm{EI}_p\text{(emission index for component } p\text{)} = \frac{\text{mass of } p \text{ produce ding}}{\text{mass of fuel use dink g}}$$

$$\mathrm{EI(CO)} = \left(\frac{[\mathrm{CO}]}{[\mathrm{CO_2}]+[\mathrm{CO}]+[\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{CO}}}{M_{\mathrm{C}}+(n/m)M_{\mathrm{H}}}\right)(1+T(\mathrm{P}_0/m))$$

$$\mathrm{EI(HC)} = \left(\frac{[\mathrm{HC}]}{[\mathrm{CO_2}]+[\mathrm{CO}]+[\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{HC}}}{M_{\mathrm{C}}+(n/m)M_{\mathrm{H}}}\right)(1+T(\mathrm{P}_0/m))$$

$$\begin{matrix}\mathrm{EI(NO}_x)\\ (\mathrm{as\ NO_2})\end{matrix} = \left(\frac{[\mathrm{NO}_x]}{[\mathrm{CO_2}]+[\mathrm{CO}]+[\mathrm{HC}]}\right)\left(\frac{10^3 M_{\mathrm{NO_2}}}{M_{\mathrm{C}}+(n/m)M_{\mathrm{H}}}\right)(1+T(\mathrm{P}_0/m))$$

$$\text{Air/fuel ratio} = (\mathrm{P}_0/m)\left(\frac{M_{\mathrm{AIR}}}{M_{\mathrm{C}}+(n/m)M_{\mathrm{H}}}\right)$$

Where

$$P_0 / m = \frac{2Z - (n/m)}{4\left(1 + h_{vol} - [TZ/2]\right)}$$

and

$$Z = \frac{2 - [CO] - ([2/x] - [y/2x])[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}$$

M_{AIR}	molecular mass of dry air=28.966g or, Where appropriate, = ($32R+28.1564S+44.011\ T$)g
M_{HC}	molecular mass of exhaust hydrocarbons, taken as CH4=16.043g
M_{CO}	molecular mass of CO=28.011g
M_{NO_2}	molecular mass of NO_2=46.088g
M_C	atomic mass of carbon=12.011g
M_H	atomic mass of hydrogen=1.008g
R	concentration of O_2in dry air, by volume =0.2095 normally
S	concentration of N_2+rare gas sin dry air, by volume =0.7092 normally
T	concentration of CO_2 in dry air, by volume =0.0003 normally
[HC]	means concentration of exhaust hydrocarbons vol/ vol, wet, expressed as carbon
[CO]	means concentration of CO vol/vol, wet
[CO_2]	means concentration of CO_2 vol/vol, wet
[NO_x]	means concentration of NOx vol/vol, wet = [NO + NO_2]
[NO]	means concentration of NO in exhaust sample, vol/vol, wet
[NO_2]	means concentration of NO_2 in exhaust sample, vol/vol, wet $= \frac{([NO_x]_c - [NO])}{\eta}$
[NOx]$_c$	means concentration of NO in exhaust sample after passing through the NO_2/NO converter, vol/vol, wet
η	efficiency of NO_2 /NO converter

h_{vol}	humidity of ambient air, vol water/vol dry air
m	number of C atoms in characteristic fuel molecule
n	number of H atoms in characteristic fuel molecule
x	number of C atoms in characteristic exhaust hydrocarbon molecule
y	number of H atoms in characteristic exhaust hydrocarbon molecule

The value of n/m, the ratio of the atomic hydrogen to atomic carbon fuel used is evaluated by fuel type analysis. The ambient air humidity, h, shall be measured at each set condition. In the absence of contrary evidence as to the characterization (x,y) of the exhaust hydrocarbons, the values $x = 1$, $y = 4$ are to be used. If dry or semi-dry CO and CO_2 measurements are to be used then these shall first be converted to the equivalent wet concentrations as shown in Part B of this Schedule, which also contains interference correction formulas for use as required.

Note.—The procedure given in7.1.4 and 7.2 is only applicable to tests made when after burning is not used. For tests when after burning is used, a similar procedure could be used after approval by the certificating authority.

7.1.4 Correction of emission indices to reference conditions

Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine operating modes to account for deviations from the reference conditions (ISA at sea level) of the actual test in let air conditions of temperature and pressure. The reference value for humidity shall be 0.00634 kg water/kg dry air.

Thus, EI corrected=K×EI measured,

Where the generalized expression for $K$is:

$$K=(P_{B\text{ref}}/P_B)^a\square(FAR_{\text{ref}}/FAR_B)^b\square\exp([T_{B\text{ref}}-T_B]/c)\square\exp(d[h_{vol}-0.00634])$$

P_B	Combustor in let pressure, measured
T_B	Combustor in let temperature, measured
FAR_B	Fuel/air ratio in the combustor
h_{vol}	Ambient air humidity, vol water/vol dry air
P_{ref}	ISA sea level pressure
T_{ref}	ISA sea level temperature

$P_{B\text{ref}}$	Pressure at the combustor in let of the engine tested (or the reference engine if the data is corrected to a reference engine) associated with $T_B$under ISA sea level conditions.
$T_{B\text{ref}}$	Temperature at the combustor in let under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine). This temperature is the temperature associated with each thrust level specified for each mode.
FAR_{ref}	Fuel/air ratio in the combustor under ISA sea level conditions for the engine tested (or the reference engine if the data is to be corrected to a reference engine).
a,b,c,d	Specific constants which may vary for ach pollutant and each engine type.

The combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas.

7.1.5Using the recommended curve fitting technique to relate emission indices to combustor inlet temperature effectively eliminates the exp $([T_{B\text{ref}}-T_B]/c)$ term from the generalized equation and for most cases the(FAR_{ref}/FAR_B) term may be considered unity. For the emissions in dices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the $(P_{B\text{ref}}/P_B)$ term is close to unity.

Thus,
EI (CO) corrected=EI derived from $(P_B/P_{B\text{ref}})\cdot\text{EI(CO)}$v.$T_B$ curve
EI (HC) corrected=EI derived from $(P_B/P_{B\text{ref}})\cdot\text{EI(HC)}$v.$T_B$ curve
EI (NOx) corrected=EI derived from $\text{EI(NOx)}(P_{B\text{ref}}/P_B)^{0.5\exp}(19[h_{vol}-0.00634])$v.$T_B$curve

If this recommended method for the CO and HC emissions index correction does not provide a satisfactory correlation, an alternative method using parameters derived from component tests may be used.

Any other methods used for making corrections to CO, HC and NOx emissions in dices shall have the approval of the certificating authority.

7.2 Control parameter functions (D_p, F_{oo}, π)

7.2.1 Definitions

D_p	The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle.
F_{oo}	The maximum thrust available for take-off under normal operating conditions at ISA sea level static conditions, without the use of water injection, as approved by the applicable certificating authority.
π	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 at ISA sea level static conditions.

7.2.2 The emission indices (EI) for each pollutant, corrected for pressure and humidity (as appropriate) to the reference ambient atmospheric conditions as indicated in 7.1.4 and if necessary to the reference engine, shall be obtained for the required LTO engine operating mode settings (n) of idle, approach, climb-out and take-off, at each of the equivalent corrected thrust conditions. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined for each pollutant:

(a) Between EI and T_B; and

(b) between W_f (engine fuel mass flow rate) and T_B; and

(c) between F_n (corrected to ISA sea level conditions) and *TB* (corrected to ISA sea level conditions);

Note.—These are illustrated, for example, by Figure S 5-3 a), b) and c).

When the engine being tested is not a "reference" engine, the data may be corrected to "reference" engine conditions using the relationships b) and c) obtained from a reference engine. A reference engine is defined as an engine substantially configured to the description of the engine to be certificated and accepted by the certificating authority to be representative of the engine type for which certification is sought.

The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

(d) maximum rated thrust (F_{oo}); and
(e) engine pressure ratio (π) at maximum rated thrust.

Note.—These are illustrated by Figure S 5-3d).

7.2.3 The estimation of EI for each pollutant at each of the required engine mode settings, corrected to the reference ambient conditions, shall comply with the following general procedure:

a) A teach mode ISA thrust condition F_n, determine the equivalent combustor in let temperature (T_B)(FigureS5-3 c));

b) from the EI/T_B characteristic (Figure S 5-3a)), determine the EI_nvalue corresponding to T_B;

c) from the W_f/T_B characteristics (Figure S 5-3b)), determine the W_{f_n}value corresponding to T_B;

d) note the ISA maximum rated thrust and pressure ratio values. These are F_{oo} and π respectively (Figure S 5-3d));

e) calculate, for each pollutant $D_p=\Sigma(\mathrm{EI}_n)(W_{f_n})(t)$ where:
t time in LTO mode (minutes)

W_{f_n} fuel mass flow rate (kg/min)
Σ is the summation for the set of modes comprising the reference LTO cycle.

7.2.4 While the methodology described above is the recommended method, the certificating authority may accept equivalent mathematical procedures which utilise mathematical expressions representing the curves illustrated if the expressions have been derived using an accepted curve fitting technique.

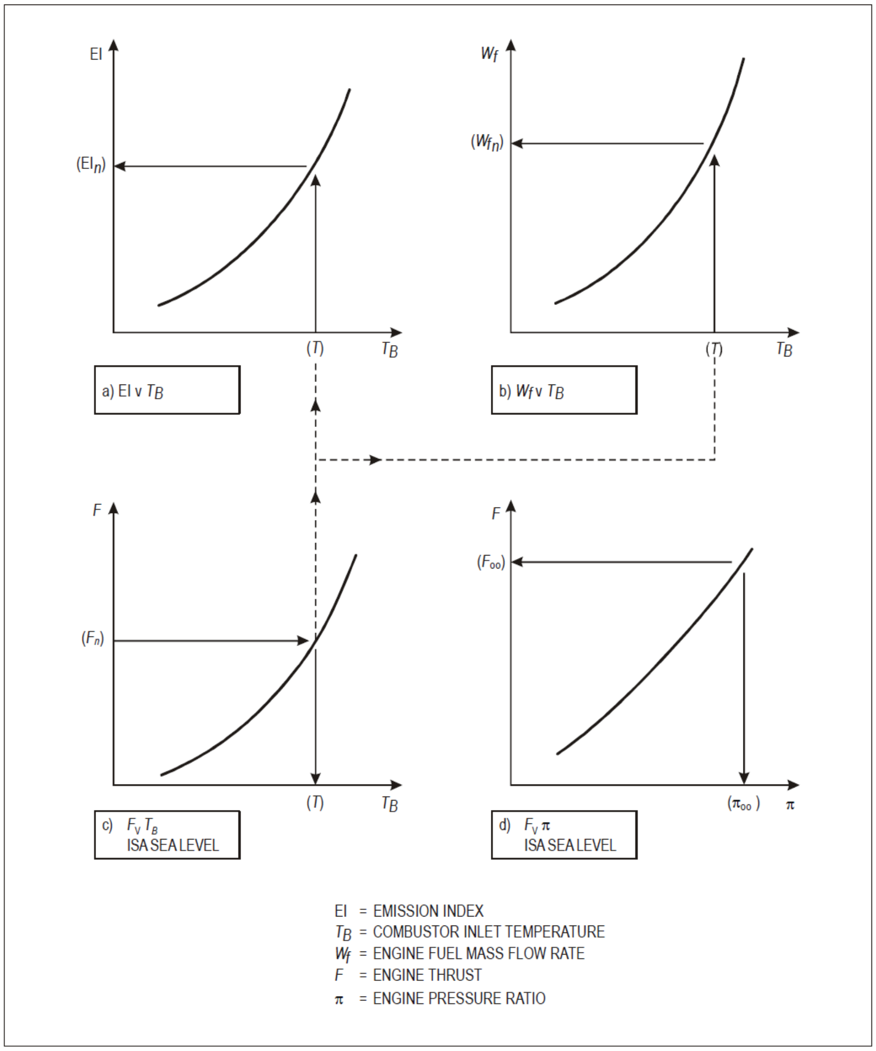


Figure S 5-3. Calculation procedure

PART B

THE CALCULATION OF THE GASEOUS EMISSIONS PARAMETERS FOR AFTERBURNING GAS TURBINE ENGINES — BASIS, MEASUREMENT CORRECTIONS AND ALTERNATIVE NUMERICAL METHOD

1. SYMBOLS

AFR	air/fuel ratio; the ratio of the mass flow rate of dry air to that of the fuel
EI	emission index; 10^3 × mass flow rate of gaseous emission product in exhaust per unit mass flow rate of fuel
K	ratio of concentration measured wet to that measured dry (after cold trap)
L, L'	analyser interference coefficient for interference by CO_2
M, M'	analyser interference coefficient for interference by H_2O
M_{AIR}	molecular mass of dry air = 28.966 g or, where appropriate, = $(32\ R + 28.156\ 4\ S + 44.011\ T)$ g
M_{CO}	molecular mass of CO = 28.011 g
M_{HC}	molecular mass of exhaust hydrocarbon, taken as CH_4 = 16.043 g
M_{NO_2}	molecular mass of NO_2 = 46.008 g
M_C	atomic mass of carbon = 12.011 g
M_H	atomic mass of hydrogen = 1.008 g
P_0	number of moles of air per mole of fuel in initial air/fuel mixture
P_1	number of moles of CO_2 in the exhaust sample per mole of fuel
P_2	number of moles of N_2 in the exhaust sample per mole of fuel
P_3	number of moles of O_2 in the exhaust sample per mole of fuel
P_4	number of moles of H_2O in the exhaust sample per mole of fuel
P_5	number of moles of CO in the exhaust sample per mole of fuel
P_6	number of moles of C_xH_y in the exhaust sample per mole of fuel
P_7	number of moles of NO_2 in the exhaust sample per mole of fuel
P_8	number of moles of NO in the exhaust sample per mole of fuel
P_T	$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8$

R	concentration of O_2 in dry air, by volume = 0.2095 normally
S	concentration of N_2 + rare gases in dry air, by volume = 0.7902 normally
T	concentration of CO_2 in dry air, by volume = 0.0003 normally
Z	symbol used and defined in 3.4
$[CO_2]$	mean concentration of CO_2 in exhaust sample, vol/vol
$[CO]$	mean concentration of CO in exhaust sample, vol/vol
$[HC]$	mean concentration of HC in exhaust sample, vol/vol
$[NO]$	mean concentration of NO in exhaust sample, vol/vol
$[NO_2]$	mean concentration of NO_2 in exhaust sample, vol/vol
$[NOx]$	mean concentration of NO and NO_2 in exhaust sample, vol/vol
$[NOx]_c$	mean concentration of NO in exhaust sample, after passing through the NO_2/NO converter, vol/vol
$[NO_2]$	mean $= \dfrac{([NO_x]_c - [NO])}{\eta}$
$[\ ]_d$	mean concentration in exhaust sample after cold trap, vol/vol
$[\ ]_m$	mean concentration measurement indicated before instrument correction applied, vol/vol
h_{vol}	humidity of ambient air, vol water/vol dry air
h_d	humidity of exhaust sample leaving “drier” or “cold trap”, vol water/vol dry sample
m	number of C atoms in characteristic fuel molecule
n	number of H atoms in characteristic fuel molecule
x	number of C atoms in characteristic exhaust hydrocarbon molecule
y	number of H atoms in characteristic exhaust hydrocarbon molecule
η	efficiency of NO_2/NO converter

2. BASIS OF CALCULATION OF EI AND AFR PARAMETERS

1.1 It is assumed that the balance between the original fuel and air mixture and the resultant state of the exhaust emissions as sampled can be represented by the following equation:

$$C_mH_n+P_0[R(O_2)+S(N_2)+T(CO_2)+h_{vol}(H_2O)]=P_1(CO_2)+P_2(N_2)+P_3(O_2)$$
$$+P_4(H_2O)+P_5(CO)+P_6(C_xH_y)+P_7(NO_2)+P_8(NO)$$

From which the required parameters can, by definition, be expressed as

$$\mathrm{EI(CO)} = P_5 \left(\frac{10^3 M_{CO}}{mM_C + nM_H} \right)$$

$$\mathrm{EI(HC)} = xP_6 \left(\frac{10^3 M_{HC}}{mM_C + nM_H} \right) \text{ expressed as methane equivalent}$$

$$\mathrm{EI(NO}_x) = (P_7 + P_8) \left(\frac{10^3 M_{NO_2}}{mM_C + nM_H} \right) \text{ expressed as } \mathrm{NO_2} \text{ equivalent}$$

$$\mathrm{AFR} = P_0 \left(\frac{M_{AIR}}{mM_C + nM_H} \right)$$

2.2 Values for fuel hydrocarbon composition (*m,n*) are assigned by fuel specification or analysis. If only the ratio*n/m*is so determined, the value *m*=12 may be assigned. The mole fractions of the dry air constituents (*R, S, T*) are normally taken to be the recommended standard values but alternative values may be assigned, subject to the restriction $R + S + T = 1$ and the approval of the certificating authority.

2.3 The ambient air humidity, h_{vol}, is as measured at each test condition. It is recommended that, in the absence of contrary evidence as to the characterization (*x, y*) of the exhaust hydrocarbon, values of $x = 1$ and $y = 4$ are assigned.

2.4 Determination of the remaining un known requires the solution of the following set of line a simultaneous equation, where (1) to (4) derive from the fundamental atomic conservation relationships and (5) to (9) represent the gaseous product concentration relationships.

$m+TP_0=P_1+P_5+xP_6$ ....……(1)

$n+2hP_0=2P4+yP6$ ....(2)

$(2R+2T+h_{vol})P_0=2P_1+2P_3+P_4+P_5+2P_7+P_8$..(3)

$2SP_0=2P_2+P_7+P_8$..(4)

$[CO_2]P_T=P_1$..(5)

$[CO]P_T=P_5$ ....(6)

$[HC]P_T=xP_6$..……………(7)

$[NO_x]_cP_T=\eta P_7+P_8$ (8)

$[NO]P_T=P_8$ (9)

$P_T=P_1+P_2+P_3+P_4+P_5+P_6+P_7+P_8$.. (10)

The above set of conditional equations is for the case where all measured concentrations are true ones, that is, not subject to interference effects or to the need to correct for sample drying. In practice, interference effects are usually present to a significant degree in the CO, NO_x and NO measurements, and the option to measure CO_2 and CO on a dry or partially dry basis is often used. The necessary modifications to the relevant equations are described in 2.5 and 2.6 of this schedule.

2.5 The interference effects are mainly caused by the presence of CO_2 and H_2O in the sample which can affect the CO and NO_x analysers in basically different ways. The CO analyser is prone to a zero-shifting effect and the NO_x analyser to a sensitivity change, represented thus:

$$[CO]=[CP]_m+L[CO_2]+M[H_2O]$$

and $$[NO_x]_c=[NO_x]_{cm}(1+L'[CO_2]+M'[H_2O])$$

which transform into the following alternative equations to(6),(8) and (9),when interference effects require to be corrected,

$[CO]_m P_T+LP_1+MP_4=P_5$..(6A)

$[NO_x]_{cm}(P_T+L'P_1+M'P_4)=\eta P_7+P_8$..(8A)

$[NO]m(PT+L'P1+M,P4)=P8$..(9A)

2.6 The option to measure $CO_2$and CO concentrations on a dry or partially dry sample basis, that is, with a sample humidity reduced to hd, requires the use of modified conditional equations as follows:

$[CO_2]_d(P_T- P_4)(1+h_d)=P_1$

....

(5A)

and

$$[CO]_d(P_T-P_4)(1+h_d)=P_5$$

However, the CO analyser may also be subject to interference effects as described in 2.5 and so the complete alternative CO measurement concentration equation becomes

$[CO]md(P_T-P_4)(1+h_d)+LP_1+Mh_d(P_T-P_4)=P_5$

....

(6B)

3. ANALYTICAL FORMULATIONS

3.1 General

Equations (1) to (10) can be reduced to yield the analytical formulations for the EI and AFR parameters, as given in 7.1 of Schedule 5. This reduction is a process of progressive elimination of the roots P_0,P_1 through P_8,P_T, making the assumptions

That all concentration measurements are of the "wet" sample and do not require interference corrections or the like. In practice the option is often chosen to make the CO_2 and CO concentration measurements on a "dry" or "semi-dry" basis; also it is often found necessary to make interference corrections. Formulations for use in these various circumstances are given in 3.2, 3.3 and 3.4 of this schedule.

$$[\,] = K[\,]_d$$

3.2 Equation for conversion of dry concentration measurements to wet basis

The following expression for K applies when CO and CO_2 are determined on a "dry" basis:

Concentration wet=K× concentration dry; that is,

$$K = \frac{\{4+(n/m)T+([n/m]T-2h_{vol})([NO_2]-(2[HC]/x))+(2+h_{vol})([y/x]-[n/m])[HC]\}(1+h_d)}{(2+h_{vol})\{2+(n/m)(1+h_d)([CO_2]_d+[CO]_d)\}-([n/m]T-2h_{vol})(1-[1+h_d][CO]_d)}$$

3.3 Interference corrections

The measurements of CO and/or NO_x and NO may require corrections for interference by the sample $CO_2$and water concentrations before use in the above analytical equations. Such corrections can normally be expressed in the following general ways:

$$[CO]=[CO]_m+L[_{CO2}]+M[H_2O]$$

$$[CO]_d=[CO]_{md}+L[CO_2]_d+M\left(\frac{h_d}{1+h_d}\right)$$

$$[NO]=[NO]_m(1+L'[CO_2]+M'[H_2O])$$

$$\eta[NO_2]=([NO_x]_{cm}-[NO]_m)(1+L'[CO_2]+M'[H_2O])$$

3.4 Equation for estimation of sample water content

Water concentration in sample

$$[H_2O]= \frac{[n/2m]+h_{vol}[P_0/m])([CO_2]+[CO]+[HC])}{1+[CO_2]_b\,(^{Po}/m)} -(y/2_x)[HC]$$

where

$$P_0/m = \frac{2Z-(n/m)}{4(1+h_{vol}-[[CO_2]_b Z/2])}$$

and

$$Z=\frac{2-[CO]-([2/x]-[y/2x])[HC]+[NO_2]}{[CO_2]+[CO]+[HC]}$$

It should be noted that this estimate is a function of the various analyses concentration readings, which may themselves require water interference correction. For better accuracy an iterative procedure is required in these cases with successive recalculation of the water concentration until the requisite stability is obtained. The use of the alternative, numerical solution methodology (4) avoids this difficulty.

4. ALTERNATIVE METHODOLOGY — NUMERICAL SOLUTION

4.1 As an alternative to the analytical procedures summarized in 3 above, it is possible to obtain readily the emissions indices, fuel/air ratio, corrected wet concentrations, etc., by a numerical solution of equations (1) to (10) for each set of measurements, using a digital computer.

4.2 In the equation set (1) to (10) the actual concentration measurements are substituted using whichever of the alternative equations (5A), (6A), etc. applies for the particular measuring system, to take account of interference corrections and/or dried sample measurements.

4.3 Suitable simple two-dimensional array equation-solving computer programmes are widely available and their use for this purpose is convenient and flexible, allowing ready incorporation and identification of any sample drying options and interference or other corrections.

SIXTH SCHEDULE

(Made under regulations 6(2)(b), 11(2), 13, 15, 22(2), 23, 24, 30(2), 32(1) and (2))

COMPLIANCE PROCEDURE FOR GASEOUS EMISSIONS, SMOKE AND PARTICULATE MATTER EMISSIONS

1. GENERAL

The following general principles shall be followed for compliance with the regulatory levels set forth in Part III, regulations 12, 14, 23, 24 and 31:

(a) The manufacturer shall be allowed to select for certification testing any number of engines, including a single engine if so desired;

(b) All the results obtained during the certification tests shall be taken into account by the certification authority;

(c) a total of at least 3 engine tests shall be conducted, so that if a single engine is presented for certification, it must be tested at least 3 times;

(d) if a given engine *(i)* is tested several times, the arithmetic mean value *(X_i)* of the tests shall be considered to be the mean value for that engine *(i)*. The certification result is then the arithmetic mean value of the values (X_i) obtained for each engine tested;

(e) the manufacturer shall provide to the certificating authority the information specified in Part III, regulation 16, 25, 31 or 34 as appropriate;

(f) the engines submitted for testing shall have emissions features representative of the engine type for which certification is sought. However, at least one of the engines shall be substantially configured to the production standard of the engine type and have fully representative operating and performance characteristics. One of these engines shall be declared to be the reference standard engine. The methods for correcting to this reference standard engine from any other engines tested shall have the approval of the national certificating authority. The methods for correcting test results for ambient effects shall be those outlined in 7.1.3 of Third Schedule, 7.1.4 of Fifth Schedule or 6 of Seventh Schedule, as applicable.

2. COMPLIANCE PROCEDURES

2.1 Gaseous Emissions and Smoke Number

The certificating authority shall award a certificate of compliance if the mean of the values measured and corrected (to the reference standard engine and reference atmospheric conditions) for all the engines tested, when converted to a characteristic level dividing by the appropriate factor which is determined by the number of engines tested (*i*) as shown in Table S 6-1, does not exceed the regulatory level.

Note.— The characteristic level of the Smoke Number or gaseous emissions is the mean of the values of all the engines tested, and, for gaseous emissions only, appropriately corrected to the reference standard engine and reference atmospheric conditions, divided by the factor corresponding to the number of engines tested, as shown in Table S6-1.

TableS6-1. Factors to determine characteristic levels

Number of Engines tested (i)	*CO*	*HC*	*NOx*	*SN*	*nvPM mass concentration*	*nvPM LTO mass*	*nvPM LTO number*
1	0.814 7	0.649 3	0.862 7	0.776 9	0.7769	0.7194	0.7194
2	0.877 7	0.768 5	0.909 4	0.852 7	0.8527	0.8148	0.8148
3	0.924 6	0.857 2	0.944 1	0.909 1	0.9091	0.8858	0.8858
4	0.934 7	0.876 4	0.951 6	0.921 3	0.9213	0.9011	0.9011
5	0.941 6	0.889 4	0.956 7	0.929 6	0.9296	0.9116	0.9116

6	0.946 7	0.899 0	0.960 5	0.935 8	0.9358	0.9193	0.919 3
7	0.950 6	0.906 5	0.963 4	0.940 5	0.9405	0.9252	0.925 2
8	0.953 8	0.912 6	0.965 8	0.944 4	0.9444	0.9301	0.930 1
9	0.956 5	0.917 6	0.967 7	0.947 6	0.9476	0.9341	0.934 1
10	0.958 7	0.921 8	0.969 4	0.950 2	0.9502	0.9375	0.937 5
more than10	$1-\frac{0.13059}{\sqrt{i}}$	$1-\frac{0.24724}{\sqrt{i}}$	$1-\frac{0.09678}{\sqrt{i}}$	$1-\frac{0.15736}{\sqrt{i}}$	$1-\frac{0.15736}{\sqrt{i}}$	$1-\frac{0.19778}{\sqrt{i}}$	$1-\frac{0.19778}{\sqrt{i}}$

2.2 Particulate matter emissions

2.2.1 The certificating authority shall award a certificate of compliance if the mean of the values of the maximum nvPM mass concentration for all the engines tested, when converted to a characteristic level dividing by the appropriate factor which is determined by the number of engines tested *(i)* as shown in Table S6-1, does not exceed the regulatory level.

Note.— The characteristic level of the maximum nvPM mass concentration is the mean of the maximum values of all the engines tested, divided by the factor corresponding to the number of engines tested, as shown in Table S6-1.

2.2.2 The certificating authority shall award a certificate of compliance if the mean of the values of the nvPM mass and the mean of the values of the nvPM number emissions for all the engines tested, when converted to a characteristic level dividing by the appropriate factor which is determined by the number of engines tested (i), as shown in Table S6-1, does not exceed the regulatory level.

Note.—The characteristic level of the nvPM mass and nvPM number emissions is the mean of the values of all the engines tested, divided by the factor corresponding to the number of engines tested, as shown in Table S6-1.

2.3 Characteristic level

The factors needed to determine the characteristic levels of engine emissions are given in TableS6-1.

3. PROCEDURE IN THE CASE OF FAILURE

3.1 When a certification test fails, it does not necessarily mean that the engine type does not comply with the requirements, but it may mean that the confidence given to the certificating authority in compliance is not sufficiently high, less than 90 percent. Consequently, the manufacturer should be allowed to present additional evidence of engine type compliance.

3.2 If an engine type fails a certification test, the certificating authority shall permit the manufacturer, if the manufacturer so wishes, to conduct additional tests on the certification engines. If the total results available still show that the engine type fails the certification requirements, the manufacturer shall be allowed to test as many additional engines as desired. The resulting test results shall then be considered with all previous data.

3.3 If the result is still failure, the manufacturer shall be allowed to select one or more engines for modification. The results of the tests already made on the selected engine(s) while unmodified shall be inspected, and further testing shall be done so that at least three tests are available. The mean of these tests shall be determined for each engine and described as the “unmodified mean”.

3.4 The engine(s) may then be modified, and at least three tests shall be conducted on the modified engine(s), the mean of which shall be described as the “modified mean” in each case. This “modified mean” shall be compared to the “unmodified mean” to give a proportional improvement which shall then be applied to the previous certification test result to determine if compliance has been achieved. It shall be determined before testing of any modified engine is begun that the modification(s) comply with the appropriate airworthiness requirements.

3.5 This procedure shall be repeated until compliance has been demonstrated or the engine type application is withdrawn.

SEVENTH SCHEDULE

(Made under regulations 6(10), 30(4), 32(1) and (2), 33, 34(4) and 35(1))

INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR NON-VOLATILE PARTICULATE MATTER EMISSIONS

1. INTRODUCTION

Note.— The procedures in this Schedule are concerned with the acquisition of representative turbine engine non-volatile particulate matter (nvPM) exhaust samples, and their transport to, and analysis by, the nvPM sampling and measurement system. The procedures do not apply to engines employing afterburning.

2. DEFINITIONS, ACRONYMS AND SYMBOLS

2.1 Definitions

Where the following expressions are used in this Schedule, they have the meanings as cribbed to them below:
Accuracy. The closeness with which a measurement approaches the true value established in dependently.
Aerodynamic diameter of a particle. The diameter of an equivalent sphere of unit density with the same terminal settling velocity as the particle in question, also referred to as "classical aerodynamic diameter".
Calibration gas. A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.
Catalytic stripper. A catalytic device that removes volatile species through oxidation.
Competent laboratory. A testing and calibration laboratory which establishes, implements and maintains a quality system appropriate to the scope of its activities, in compliance with ISO/IEC 17025:2005, as amended from time to time, or equivalent standard and for which the programme for calibration of equipment is designed and operated so as to ensure that calibrations and measurements made by the laboratory are traceable to the International System of Units (SI). Formal accreditation of the laboratory to ISO/IEC 17025:2005 is not required.
Cyclone separator. Separation of particles larger than a prescribed aero dynamic diameter via rotational and gravitational means. The specified cut-point aerodynamic diameter is associated with the percent of particles of a particular size that penetrate through the cyclone separator.
Diffusion flame combustion aerosol source. A device employing diffusion flame combustion using a given fuel that generates air borne particulate matter.
Electrical mobility diameter of a particle. The diameter of a sphere that moves with exactly the same mobility in an electrical field as the particle in question.
Elemental carbon (EC). Light absorbing carbon that is not removed from a filter sample heated to 870°C in an inert atmosphere during thermal optical transmittance (TOT) analysis, excluding char.
Gas concentration. The volume fraction of the component of interest in the gas mixture.
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.
Organic carbon (OC). Carbon volatilised in helium while heating a quartz fibre filter sample to 870°C during thermal optical transmittance (TOT) analysis. Includes char formed during pyrolysis of some materials.
Particle loss. The loss of particles during transport through a sampling system. This loss is due to various deposition mechanisms, some of which are size dependent.
Particle mass concentration. The mass of particles per unit volume of sample.
Particle mass emissions index. The mass of particles emitted per unit of fuel mass used.
Particle number concentration. The number of particles per unit volume of sample.
Particle number emissions index. The number of particles emitted per unit of fuel mass used.
Particle size distribution. A list of values or a mathematical function that represents

particle number concentration according to size.

Parts per million (ppm). The unit volume gas concentration of a gas per million-unit volume of the gas mixture of which it is part.

Penetration fraction. The ratio of particle concentration downstream and upstream of a sampling system element.

Quality system. A management system in which the competent laboratory documents its policies, systems, programmes, procedures and instructions to the extent necessary to assure the quality of the test or calibration results.

Repeatability. The closeness with which a measurement upon a given in variant sample can be reproduced in short-term repetitions of the measurement with no intervening instrument adjustment.

Resolution. The smallest change in a measurement which can be detected.

Response. The change in instrument output signal that occurs with change in sample concentration.

Rise time. The time required for the output signal to pass from 10 percent to 90 percent of the final change in the output signal when a reference material is abruptly applied to the automatic measuring system initially in the basic state. This term is only applicable for an online analyser.

Stability. The closeness with which repeated measurements upon a given in variant sample can be maintained over a given period of time.

2.2 Acronyms

CPC	Condensation particle counter
EC	Elemental Carbon
FS	Full scale range of the analyser
GL	Gas line
HEPA	High efficiency particle air filter, class H13, which removes at least 99.97 percent of Dioctyl Phthalate particles (0.3 µm in diameter)
ID	Internal diameter
ISA	International Standard Atmosphere (ISO2533:1975)
LOD	Limit of detection
NMI	National metrology institute
nvPM	Non-volatile particulate matter (see definition)
nvPMmi	Non-volatile particulate matter mass instrument
nvPMni	Non-volatile particulate matter number instrument
PTFE	Polytetra fluoroethylene
slpm	Standard litres per minute (litres per minute at STP)
STP	Instrument condition at standard temperature 0°C and pressure
101.325 kPa TOT	Thermal optical transmittance
VPR	Volatile particle remover
VRE	Volatile removal efficiency

2.3 Symbols

$[CO]$	Mean gas concentration of CO in exhaust sample, vol/ vol, wet
$[CO_2]$	Mean gas concentration of CO_2 in undiluted exhaust sample, vol/vol,
wet $[CO_2]_b$	Gas concentration of CO_2 in dry air, by volume = 0.000 3
$[CO_2]_{dil1}$	Mean gas concentration of CO_2 vol/vol after the first dilution stage,

wet $[CO_2]_{dil2}$	Mean gas concentration of CO_2 vol/vol after the second dilution stage, wet
$[CO_2]_S$	Mean gas concentration of CO_2 vol/vol in undiluted exhaust as sampled, wet, semi-dry or dry
DF	Dilution factor = (sample concentration before dilution)/(sample concentration after dilution) Volume of undiluted sample Volume of diluted sample
DF_1	First stage dilution factor $= \frac{[CO2]}{[CO2]dil1}$

DF_{1_S}	First stage dilution factor calculated using directly sampled $[CO_2]_S$ and $[CO_2]_{dil1}$
DF_2	Second stage (VPR) dilution factor as per calibration by a competent laboratory
D_m	nvPM electrical mobility diameter, nm
D_{xy}, at z nm	Aerodynamic diameter at which xy percent (detection efficiency) of z size particles are detected
EImass	nvPM mass emission index corrected for thermophoretic losses and for fuel composition, in milligrams/kg fuel
EInum	nvPM number emission index corrected for thermophoretic losses and for fuel composition, in number/kg fuel
F	Thrust for the given operating mode
H	Fuel hydrogen content (mass percentage)
[HC]	Mean gas concentration of hydrocarbons in exhaust sample, vol/vol, wet, expressed as carbon
K_{fuel_M}	Fuel composition correction factor for nvPM mass emissions index
K_{fuel_N}	Fuel composition correction factor for nvPM number emissions index
K_{thermo}	Collection Part thermophoretic loss correction factor
[NO]	Mean gas concentration of NO in exhaust sample, vol/vol, wet
$[NO_2]$	Mean gas concentration of NO_2 in exhaust sample, vol/vol, wet
$[NO_x]$	Mean gas concentration of NO and NO_2 in exhaust sample, vol/vol, wet = $[NO]+[NO_2]$
M_C	Atomic mass of carbon = 12. 011
M_H	Atomic mass of hydrogen = 1.008
m	Number of C atoms in characteristic fuel molecule
n	Number of H atoms in characteristic fuel molecule
$nvPM_{mass}$	nvPM mass concentration at instrument STP condition, corrected for dilution and thermophoretic losses in the Collection Part of the sampling system, $\mu g/m^3$
$nvPM_{mass\_STP}$	Diluted nvPM mass concentration at instrument STP condition, μg/m3
$nvPM_{num\_STP}$	Diluted nvPM number concentration at instrument STP condition, number/cm3
T_{line}	Sample line wall temperature
T_1	Diluter 1 inlet wall temperature °C
T_{EGT}	Engine measured or performance-derived engine exhaust nozzle exit plane gas temperature °C
t_{90}	90 per cent response time (time between change in inlet concentration and the detector reaching 90 per cent of its final signal)
α	Atomic hydrogen-carbon ratio of the fuel = n/m, where CmHn is the equivalent hydrocarbon representation of the fuel used in the test and evaluated by reference to the engine fuel type analysis.
$\eta_{VPR}(D_m)$	Particle penetration fraction of VPR for particles of D_m

3. DATA REQUIRED

3.2 nvPM emissions

3.2.1 In order to calculate the nvPM mass and number emissions, the following concentrations shall be determined:

(a) nvPM mass: $nvPM_{mass\_STP}$;
(b) nvPM number: $nvPM_{num\_STP}$;
(c) carbon dioxide (CO_2): $[CO_2]$and $[CO_2]_{dil1}$;
(d) carbon monoxide (CO): [CO];
(e) hydrocarbons (HC): [HC]; and
(f) oxides of Nitrogen (NO_x): $[NO_x]$, [NO], $[NO_2]$.

3.2.2 For system operability check purposes, the concentration of the following emission shall be determined:

Carbon dioxide (CO_2): $[CO_2]_S$

3.3 Other information

In order to normalize the emissions measurement data and to define the engine test characteristics, additional information listed in 3.2 of Third Schedule and the data in Tables S7-1 and S7-2 shall be provided.

Table S7-1. Ambient nvPM requirements

Data required	*Unit*
Ambient nvPM mass concentration ($nvPM_{mass\_STP}$)	µg/m^3
Ambient nvPM number concentration ($DF_2 \times nvPM_{num\_STP}$)	particles/cm^3

Table S7-2. nvPM sampling system and measurement parameter requirements

Parameter	*Unit*
Probe inlet temperature (T_{engine_exit}) (Equivalent to performance-predicted engine exit exhaust gas temperature T_{EGT})	°C
MeasuredDiluter1inlettemperature(T_1)	°C
Individual flow rates (Measured Module3 and Module4; practical estimation Module1, Module 2)	slpm
Individual pipe inner diameters for Modules1to 4	mm

Individual lengths for Modules1 to 4	m
Individual pipe wall temperatures for Modules 1 to 4	°C
Module 1total angle of sampling tube bend(s)	degrees
Cyclone separator D_{50} cut point (manufacturer specification)	nm
Cyclone separator sharpness (manufacturer specification)	Decimal fraction
Diluter1four penetration values (see7.2.5, Table S7-4)	Decimal fraction
VPR calibration four penetration values (see9.1.1.6, Table S7-9)	Decimal fraction
CPC calibration two counting efficiencies	Decimal fraction
First stage dilution factor, DF_1	
Second stage (VPR)dilution factor, DF_2	
Particle mass concentration corrected for DF_1:DF_1×nv PM_{mass_STP}	µg/m^3
Particle number concentration corrected for $DF_1$and DF_2:DF_1× DF_2×nvPM $_{num\_STP}$	particles/cm^3

Note.— Modules of then vPM sampling and measurement system are described in Figure S7-1andTableS7-3.

4. GENERAL ARRANGEMENT OF THE nvPM SAMPLING AND MEASUREMENT SYSTEM

4.1 nvPM sampling and measurement system

4.1.1 The nvPM sampling and measurement system shall consist of three parts, divided into five modules:

(a) collection part (Module1);
(b) transfer part (Modules 2, 3 and 4); and
(c) measurement part (Module 5).

Note1.—An over view description of the nvPM sampling and measurement system is provided in Figure S 7-1 and Table S 7 - 3.

Note2.—More detailed requirements and recommendations for each module of the system are provided in 7, 8, 9 and 10 of this Schedule.

4.1.2 Modules 1 to 4 shall meet the following requirements:

(a) The sample lines shall be as straight-through as possible.
(b) The total sample line length from probe tip to measurement instrument in let shall not exceed 35m. This total length is not equal to the sum of the individual sampling module’s maximum allowable lengths. Detailed length requirements are provided in 7 of this Schedule and shown in Figure S7-1.

4.1.3 The following is recommended for Modules 1 to 4:

(a) The number of fittings should be minimised and should be manufactured from stainless steel material with a smooth bore.
(b) The number of bulkhead union fittings should be minimised and should be thermally insulated to minimise thermal gradients.

Figure S7-1. Overview schematic of an nvPM sampling and measurement system

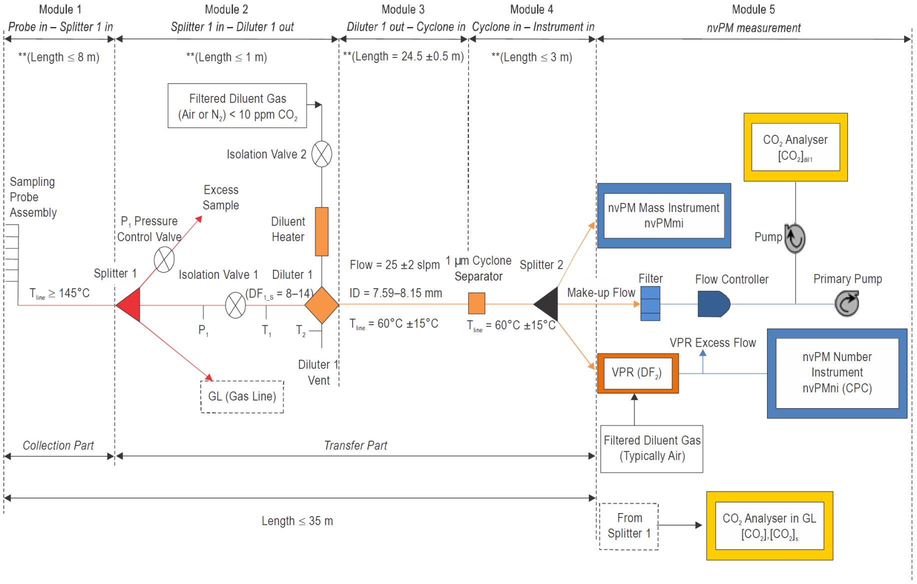


Table S7-3. nvPM sampling and measurement system terminology overview

Terminology		*Description*
Module1	Sampling probe assembly	Single or multi-point rake hardware used to obtain representative sample from aircraft engine exhaust.
	Connection line	Length of tubing to transport sample from probe to Splitter 1 inlet.
	Splitter1	Flow splitter assembly to allow controlled separation of samples to both particle and gas sampling systems. Also provides a flow path (excess sample) to relieve and control sample line pressure.
	P_1pressure control valve	Valve used to control pressure at Diluter 1 inlet.

Module2	P_1	Diluter 1 inlet pressure; regulated by the pressure control valve when P_1 is above ambient.
	T_1	Sample tube temperature at Diluter 1 inlet needed for thermophoretic particle loss calculation in Modules 1 and 2.
	Isolationvalve1	Allows isolation of the particle system from the GL sample and allows leakage checks of GL (including probe) and cleanliness check of transfer part.
	Isolationvalve2	Diluent shut-off valve for Diluter 1.
	Diluter1	Ejector-type diluter, which provides a near ambient pressure to the inlet of Module 3. Dilutes the nvPM sample early in the transfer Part (first stage dilution, DF1) to minimize particle coagulation and reduces sample temperature to minimise thermophoretic losses.
	Filtered diluent gas	Compressed gas (air or nitrogen) for Diluter 1.
	Diluent heater	Heats the diluent prior to entering the Diluter 1.
	Diluter1 vent	Allows venting of excess diluted sample to atmosphere to maintain near-ambient pressure at Diluter 1 exhaust and prevent over pressuring the transfer part.
	T_2	Temperature in vent flow to monitor Diluter 1 outlet temperature.
GL		Gas line. Heated section to transport the exhaust sample for gaseous emissions measurement.
Module3	Heated sample line	Standardised sampling section. Allows measurements at a safe distance from the engine.
Module4	1 µm cyclone separator	Removes large particles not generated by combustion and helps to prevent instrumentation blockage.
	Splitter2	Flow splitter assembly to provide sample flow paths for nvPM mass and number concentration measurement and a third flow path to ensure that the total system flow rate in Module 3 is maintained.
	Filter	Particle filter to prevent blockage and damage to the flow controller.
	Flow controller	Maintains constant flow rate in Module 3 by controlling make-up flow.
	Primary pump	Provides suction for the make-up flow.
	CO_2analyser	Measurement of $[CO_2]_{dil1}$ in the diluted sample.
	nvPMmi	nvPM mass instrument

Module5	VPR (DF$_2$)	Device that removes volatile species and dilutes further the sample (second stage dilution, DF$_2$) prior to the nvPMni.
	Filtered diluents gas	Diluent gas (air or nitrogen) for VPR.
	nvPMni(CPC)	nvPM number instrument that is a condensation particle counter.

4.1.4 Modules 2 to 4 shall meet the following requirements:

(a) Any necessary sampling line bends shall have radii greater than 10 times the ID of the line.
(b) There shall not be forward facing step-shoulders greater than 15 percent of the ID.
(c) Changes in sampling line ID greater than 15 percent shall only occur at a splitter flow path interface.
(d) Differences in ID of less than or equal to 15 percent shall be considered as no change.

4.1.5 For Modules 2 to 4 the sampling line should be actively heated across a fitting. If not practical, the sample line should be heated as close as possible to the next heated element and thermally insulated across the fitting.

4.2 Collection Part

4.2.1 Module 1 is comprised of the probe/rake hardware and the connection line. It shall meet the following requirements:
(a) The sampling probe material shall be stainless steel or any other non-reactive high temperature material.
(b) If a sampling probe with multiple sample or if ices is used:
    1) All sampling or if ices shall be of equal diameter; and
    2) the sampling probe design shall be such that at least 80 percent of the pressure drop through the sampling probe assembly is taken at the orifices.
(c) The number of locations sampled shall not be less than12.
(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 diameter 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.

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

4.3 Transfer part

4.3.1 At the inlet to Module 2, the Splitter 1 assembly shall split the sample into the transfer part line, the GL for the measurement of undiluted CO_2, CO, HC and NOx, and the excess sample line.

Note.— This arrangement also allows the GL to be used to measure Smoke Number, if required, as specified in Second Schedule.

4.3.2 The transfer part line shall be arranged such that the nvPM sample:

(a) Passes through Diluter 1, an ejector-type diluter, which draws, dilutes and cools the sample;
(b) Passes through Module 3; and
(c) Passes through a cyclone separator and Splitter 2 in Module 4 before entering the measurement part in Module 5.

4.4 Measurement part

4.4.1 nvPM mass measurement

4.4.1.1 The nvPM mi shall meet the requirements in 8.1of this Schedule.
4.4.1.2 Each make and model of the nvPM mi shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that the make and model of the nvPMmi meets the performance specifications listed in Table S7-5 of this Schedule.

4.4.2 nvPM number measurement

4.4.2.1 The VPR and the nvPMni (CPC) shall meet the requirement sin 9.1 of this Schedule.

4.4.2.2 The nvPM number concentration shall be determined using a system consisting of a volatile particle remover (VPR) and a condensation particle counter (CPC) (nvPMni) in series. The VPR includes a dilution system (DF_2) and a device for the removal of volatile species.

4.4.2.3 Each make and model of the VPR and CPC shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that the make and model of each device meets the performance specifications listed in 9.1 of this Schedule.

4.4.3 Make-up flow path

(a) The make-up flow path shall be used to maintain a constant sample flow rate through Module 3 and provide a diluted sample CO_2 concentration measurement.

(b) The make-up flow path shall contain a pump, flow controller and CO_2 analyser.

(c) A particle filter should be placed upstream of the flow controller to prevent damage to components.

5. GENERAL TEST PROCEDURE

5.1 Calibration and maintenance

5.1.1 All instruments shall be maintained conforming to the manufacturer's guidelines.

5.1.2 The nvPM sampling and measurement system

Calibration and maintenance of the nvPM sampling and measurement system shall be performed as follows at least on an annual basis or as recommended by the manufacturer:

(a) The cyclone separator collection reservoir shall be emptied and cleaned
(b) The Diluter 1 or if ice nozzle shall be cleaned.
(c) The make-up flow controller and in let flow rates for nvPM mi, nvPMni and VPR shall be calibrated by a NMI-traceable flow meter.
(d) All calibrated flow rates should be within 5 percent FS.
(e) Pressure transducers shall be calibrated by a NMI-trace able pressure transducer.
(f) All calibrated pressure measurements should be within 2 percent FS.

5.1.3 nvPMmi

(a) The nvPMmi shall be annually calibrated by a competent laboratory to meet the calibration requirements prescribed in 8.5 of this Schedule.
(b) The nvPMmi shall meet the requirements in 8.1 of this Schedule after hardware or software changes to the nvPMmi which affect data acquisition and processing.

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

5.1.4 VPR

(a) TheVPRshallbeannuallycalibratedbyacompetentlaboratorytomeetthecalibrationrequirementsprescribedin 9.2.1 of this Schedule.
(b) If the VPR contains a catalytic stripper, its replacement interval shall meet the manufacturer guidelines.
(c) The VPR shall meet the requirements in 9.1.1 of this Schedule after hardware or software changes to the VPR which affect data acquisition and processing.

5.1.5 nvPMni (CPC)

(a) The nvPMni shall be annually calibrated by a competent laboratory to meet the calibration requirements prescribed in 9.2.2 of this Schedule.

(b) The nvPMni working fluid shall be n-butanol and shall be replaced following the manufacturer guidelines.

(c) The nvPMni shall meet the requirements in 9.1.3 of this Schedule after hardware or software changes to the nvPMni which affect data acquisition and processing.

Note.— Guidance material is provided in the *Environmental Technical Manual* (Doc 9501), Volume II — *Procedures for the Emissions Certification of Aircraft Engines.*

5.1.6 Gas analysers

(a) Calibration of the CO_2, CO, HC and NOx analysers shall be in accordance with the procedures of Third Schedule.

(b) The CO_2 impurity of the zero calibration gas for the CO_2 analyser downstream of Diluter 1 shall be less than 10 ppm.

Note.— The CO_2 *impurity specification for the* CO_2 *analyser downstream of Diluter 1 is different from 6.2 of Third Schedule.*

(c) The diluent for Diluter 1 should be the same as the zero calibration gas used for the CO_2 analyser.

5.2 Engine operation

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

5.2.2 The nvPM emissions tests shall be made at the thrust settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

5.3 Carbon balance

Each test shall include a check that the air/fuel ratio as estimated from the integrated sample total carbon concentration exclusive of smoke agrees with the estimate based on engine air/fuel ratio with an accuracy of ± 15 percent for the taxi or ground idle mode, and with an accuracy of ±10 percent for all other operating modes.

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

5.4 Operation of nvPM sampling and measurement system

5.4.1 Prior to an engine test series, the following requirements shall be met:

(a) Collection part leakage and cleanliness checks shall be performed using the procedures described in 10.1 and 10.2 of this Schedule.

(b) A VPR dilution factor (DF_2) check shall be performed as described in 10.3 of this Schedule.

(c) A transfer part cleanliness check shall be performed using the procedures described in 10.3 of this Schedule.

Note.—The transfer part cleanliness check also serves as an operational nvPM instrumentation zero check.

5.4.2 The following procedure shall be adopted for gaseous measurements on the GL and downstream of Diluter 1:

(a) Apply appropriate zero calibration gas and make any necessary instrument adjustments.

(b) Apply appropriate calibration gas at a nominal 90 per cent FS concentration to span the ranges to be used, adjust and record gain settings accordingly.

5.4.3 During an engine test series, the following requirements shall be met:

(a) The nvPM measurements shall only be taken after all instruments and sample transfer lines are warmed up and stable.

(b) If any component or module of the nvPM sampling system is new, cleaned since last use or used previously for a purpose other than sampling engine exhaust, then the nvPM sampling system shall sample aircraft engine exhaust for a minimum of 30 minutes at any engine power condition prior to obtaining nvPM measurements. *Note.— Removal of soot blockage in the Diluter 1 orifice does not constitute a cleaning process as defined in (b).*

(c) The nvPMmi manufacturer recommended operability checks shall be performed.

(d) For nvPM number measurements, the following requirements shall be met:

1) The VPR heated stage is at350°C±15°C.
2) If a catalytic tripper is used in the VPR, the diluents shall contain atleast10 percent of O_2.
3) The nvPMni working fluid is at the level required by the manufacturer.
4) The nvPMni saturator and the condenser have reached correct operating temperatures.

(e) The nvPMni manufacturer recommended operability checks shall be performed.

(f) Ambient nvPM measurements shall be performed at the beginning and end of an engine test using the procedures described in 10 of this Schedule.

Note: The ambient measurement also serves as an operational nvPMni response check.

(g) Gaseous analyser zero and calibration points shall be rechecked at the end of the test and also at intervals not greater than 1 hour during tests. If either has changed by more than ±2 per cent of FS range, the test shall be repeated after restoration of the instrument to within its specification.

5.4.3.1 Back-purging of Module 1 should occur during engine start-up and shutdown with the measurement analysers isolated.

Note.—Back- purging ensures that no significant fuel contamination occurs in the sampling system.

5.4.4 During engine nvPM measurements, the following requirements shall be met:

(a) If P_1 is at sub-atmospheric pressure, the P_1 pressure control valve shall be closed; and if installed, the optional shut-off valve shall be closed.

(b) Both the GL CO_2 concentration and the CO_2 concentration downstream of Diluter 1, $[CO_2]_{dil1}$, shall be continuously measured and used for validating and controlling DF_1 in real time (DF_{1_s}) to within the range 8 to 14. DF_{1_s} is defined as:

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

Note.—The calculation of DF_{1_S} *does not require the* CO_2 *concentration on a wet basis.*

(c) The sample flow rate of 25 slp m ±2slp min Module 3 shall be monitored by summation of the make-up flow and the inlet flow rates of the nvPMmi and the VPR.

(d) When the engine operation and measured nvPM and $[CO_2]_{dil1}$ concentrations are stable at the required thrust setting, a minimum of 30 seconds of data shall be averaged and recorded.

(e) If the nvPMmi lacks a sample pressure measurement, the pressure shall be measured at a location between the Splitter 2 outlet and the make-up flow inlet, and recorded.

(f) If the nvPMni lacks a sample pressure measurement, the pressure shall be measured at a location between the VPR outlet and nvPMni inlet, and recorded.

6. CALCULATIONS

6.1 nvPM mass concentration and nvPM mass and number emissions indices equations

This procedure is used to calculate nvPM mass concentration and nvPM mass and number emission in dices (EIs) from aircraft gas turbine engines burning hydrocarbon fuel in air. All equations utilize the nvPM mass concentration and nvPM number concentration at instrument STP conditions. If this is not the case, the user shall follow recommended procedures per the instrument manufacturer to correct the reported concentrations to STP conditions for the instrument.2

6.1.1 nvPM mass concentration

The nvPM mass concentration ($nvPM_{mass}$) represents the mass of particles per unit volume of engine exhaust sample corrected for the first stage dilution factor (DF_1) and the Collection Part thermophoretic particle losses. It shall be calculated using the following equation:

$$nvPM_{mass} = DF1 \times nvPM_{mass\_STP} \times k_{thermo}$$

6.1.2 nvPM mass and number emission in dices

The nvPM mass and nvPM number emission indices (EI_{mass} and EI_{num}) represent the mass (in milligrams) and number of engine exhaust particles per mass of fuel burned (in kilograms) corrected for their respective dilution factors, the Collection Part thermophoretic particle losses and their respective fuel composition correction factors. They shall be calculated using the following equations:

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

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

$[CO_2]$, [CO] and [HC] shall be calculated.

Note1.—Methods for calculating $[CO_2]$, [CO] and [HC are contained in Part B of the Third Schedule.
Note 2.— The constant 22.4 used in the EI equations above is the volume of one mole of air in litres at STP conditions rounded to one decimal place.

6.2 Correction factors for nvPM emissions

6.2.1 Correction forn Vpm thermophoretic losses in the Collection Part
The correction for nvPM thermophoretic losses in the collection part shall be determined using:

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

If $T_{EGT} < T_1$, then $k_{thermo} = 1$

6.2.2 Correction for fuel composition
The correction for fuel composition shall be determined using:

$$k_{fuel\_M} = \exp\left\{\left(1.08\frac{F}{F_{00}} - 1.31\right)(13.8 - H)\right\}$$

$$k_{fuel\_N} = \exp\left\{\left(0.99\frac{F}{F_{00}} - 1.05\right)(13.8 - H)\right\}$$

6.3 Control parameter functions

The EI shall be normalised to the combust or inlet temperature of the reference standard engine at ISA sea level conditions.

6.3.1 Definitions

Reference standard engine: An engine substantially configured to the production standard of the engine type, with fully representative operating and performance characteristics

F_{oo}	Rated thrust
F_n	Thrust at operating mode *n* for reported nvPM emissions (kN)
Wf	Fuel mass flow rate of the reference standard engine under ISA sea level

conditions (kg/s)

W_{fn} Fuel mass flow rate of the reference standard engine under ISA sea level conditions at LTO operating mode *n*

T_B Combustor inlet temperature

6.3.2 The nvPM mass and number EIs shall be obtained for each LTO operating mode at T_B of the reference standard engine. A minimum of three test points shall be required to define the idle mode. For each LTO operating mode, the corresponding fuel flow under ISA conditions shall be obtained. The following relationships shall be determined under ISA reference conditions for nvPM mass and number EIs:

(a) Between EI and T_B; and
(b) between W_f and T_B; and
(c) between F_n and T_B.

Note1.—These relationships are illustrated, for example, by Figure S7-2 (a), (b)and (c).

Note2.—The relationships (b) and (c) may be established directly from engine test data, or may be derived from a validated engine performance model.

6.4 Calculation procedure

The estimation of EI (referenced to T_B) for nvPM mass and number emissions at the reported operating modes shall comply with the following general procedure:

(a) Determine the combustor inlet temperature (T_B) (Figure S7-2 c)) at the values of F_n corresponding to the reported operating modes, *n* under reference atmospheric conditions.

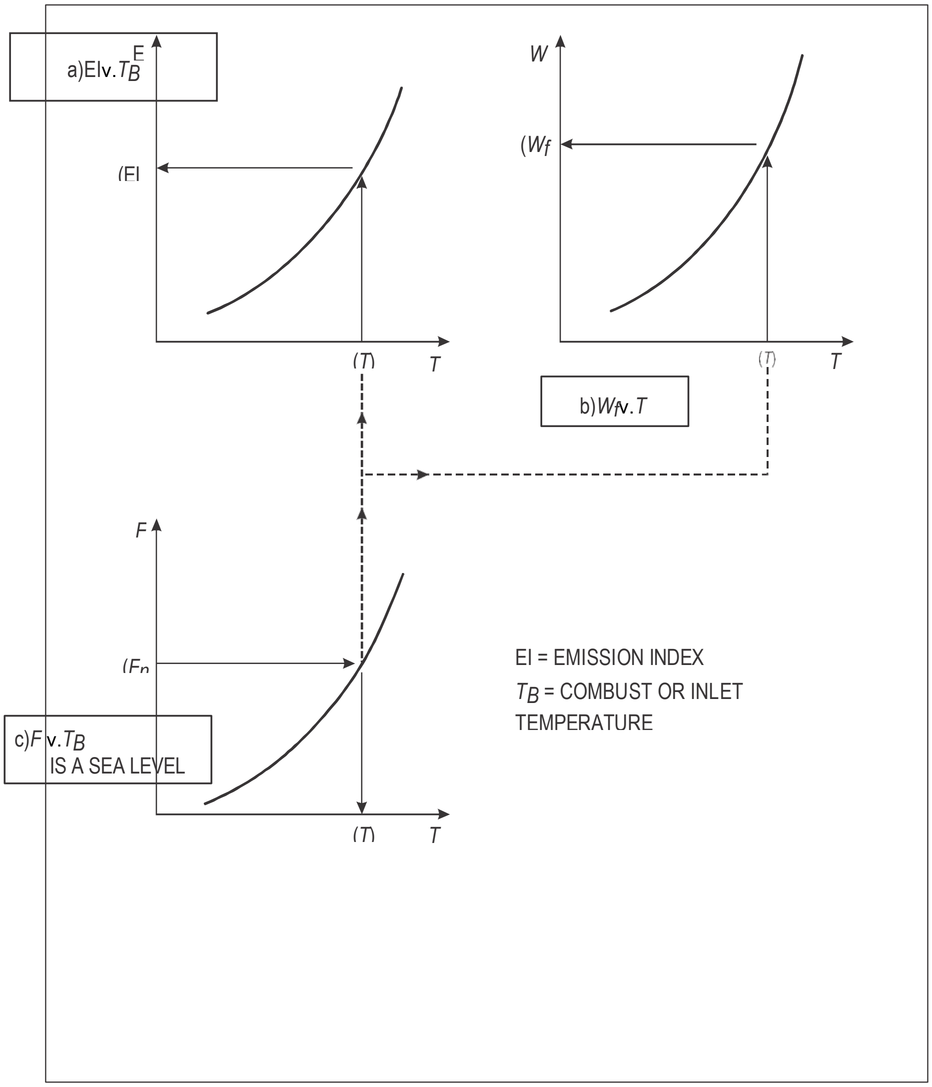
(b) From the EI/T_B characteristic (FigureS7-2a), determine the EI$_n$ value corresponding to T_B.

(c) From the W_f/T_B characteristic (FigureS7-2b)), determine the W_{f_n} value corresponding to T_B.

(d) Calculate, for $\text{LTO}_{\text{mass}}=\sum(\text{EI}_{\text{mass}_n})\ (W_{f_n})\ (t)$, where: t is the time in mode (minutes);
W_{fn} is the fuel mass flow rate (kg/min); and
$\sum$ is the summation for these to f modes comprising the reference LTO cycle.

(e) Calculate, for $\text{LTO}_{\text{num}}=\sum(\text{EI}_{\text{num}_n})(W_{f_n})(t)$, where: t is the time in mode (minutes);
W_{f_n} is the fuel mass flow rate (kg/min); and
$\sum$ is the summation for these to f modes comprising the reference LTO cycle.

Note.—While the methodology described above is the required method, the certificating authority may accept equivalent mathematical procedures which utilize mathematical expressions representing the curves illustrated if the expressions have been derived using an accepted curve fitting technique.



FigureS7-2. Turbine engine nvPMEI as a function of several engine parameters

7. REQUIREMENTS AND RECOMMENDATIONS FOR nv PM SAMPLING SYSTEM

7.1 Module 1: probe inlet — splitter 1 inlet

7.1.1 Module1shall meet the following requirements:

(a) The sample shall be transferred from the probe to Module 2 via a line of 4.0 to 8.5 mm ID, taking the shortest route practicable.

(b) The sampling line shall be maintained at a temperature greater than or equal to 145°C.

(c) The length from probe in let to the Splitter 1in let shall be less than or equal to 8m.

7.2 Module 2: splitter 1 inlet — diluter 1 outlet

7.2.1 Module 2 shall meet the following requirements:

(a) Module 2 shall contain Splitter 1and Diluter1.

(b) The material of the sample line shall be such as to minimize build-up of particulate matter or static electricity.

Note.— Stain less steel or carbon-loaded electrically grounded PTFE meets these requirements.

(c) The length of Module 2 from the Splitter 1in let to the Diluter1outlet shall not exceed1m.

(d) Module 2 shall contain Isolation Valve1in order to perform the leakage check on the GL.

7.2.2 Splitter1shall meet the following requirements:

(a) Splitter1shall be made of stainless steel.

(b) Splitter1body temperature shall be maintained at greater than or equal to145°C.

(c) Splitter1shall separate the engine exhaust sample in to three flow paths.

(d) The split angles relative to the incoming flow shall be as a cute as practical but not exceeding 35°.

(e) The nvPM sample flow path shall be as straight-through and short as practical.

(f) Splitter 1internalgeometry shall meet the following requirements:

- no forward facing step-shoulders on the inner wall;

(i). no change in ID from Splitter 1outlet to Diluter1 in let;
(ii). GLID=4to8.5mm; and

(iii). excess sample line internal cross sectional area greater than or equal to the total in let area of the probe tips.

7.2.3 Isolation Valve 1 shall meet the following requirements:

(a) Isolation Valve 1 shall be placed between Splitter 1 outlet and Diluter 1 inlet.

(b) Isolation Valve 1 shall be full bore with no forward facing step-shoulders greater than 15 percent of the ID.

(c) The sea ls of Isolation Valve1 shall be dry and heat resistant to175°C.

7.2.4 The nvPM Module 2 line wall temperature(T_1), to within 5cm of the Diluter1mixing plane, shall be maintained at greater than or equal to 145°C as shown in Figure S7-3.

7.2.5 Diluter 1shall meet the following requirements:

(a) Diluter 1 shall be an ejector – type diluter.

(b) The ID of Diluter 1 inlet shall be greater than or equal to 7.59 mm.

(c) The diluents flow shall be controlled as specified by the manufacturer.

(d) The real-time Diluter 1 DF shall be controlled within the range of 8to 14.

Note1.—The minimum DF is necessary to minimize nvPM coagulation, while the maximum is necessary to maintain the diluted sample within the measurement range of the instruments.

Note2.—DF1may be adjusted by controllingP1with the pressure control valve on the excess sample flow path or by adjusting the diluent gas flow.

(e) The Diluter 1 vent shall be open to ambient (equal to engine in let pressure).

(f) The Diluter 1 body shall be heated to 60°C±15°C as shown in Figure S 7-3.

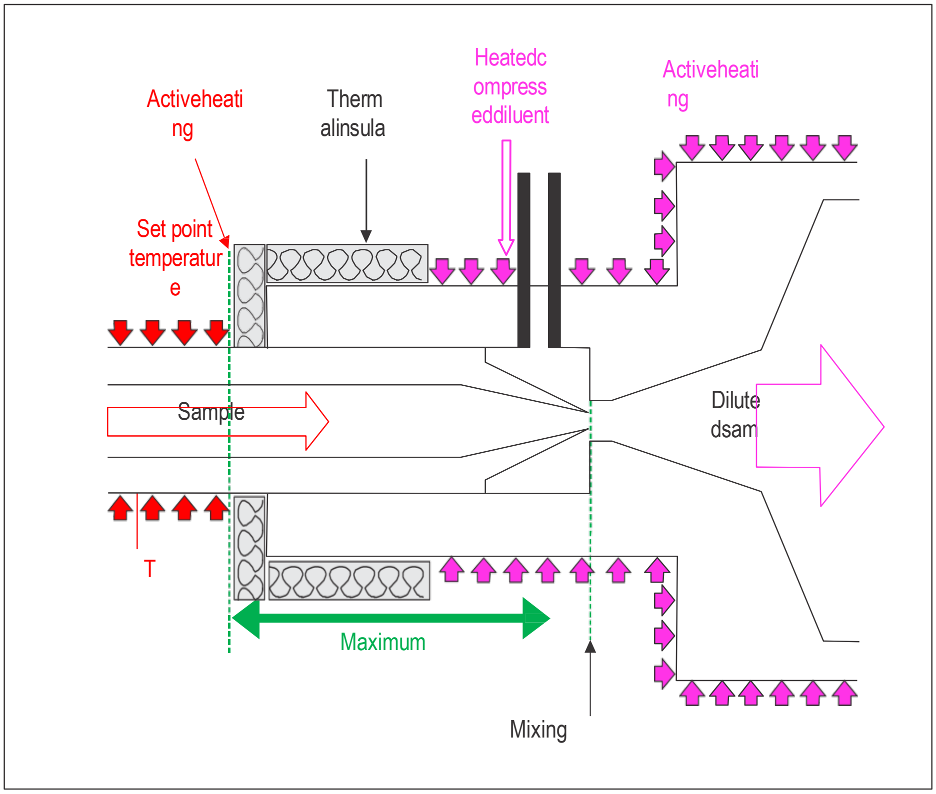
(g) The diluents shall be air or nitrogen be HEPA filtered and contain less than 10ppm CO_2.

(h) The diluents shall be heated to provide a diluted nvPM sample temperature of 60°C±15°C at the Diluter 1 vent (T_2).

(i) The particle penetrations of Diluter 1 shall meet the minimum requirements as shown in Table S 7-2.

Table S7-4: Minimum requirements for particle penetration fractions (transmission efficiencies) of Diluter 1

Particle electrical mobility size (diameter)	15 nm	30 nm	50 nm	100 nm
Minimum particle penetration fraction	80percent	90percent	90percent	90percent



FigureS 7-3. Cross section of example ejector-type Diluter 1 inlet with heating interface

7.2.5.1 To minimise impact on the operable DF_1 range, the Diluter 1 vent line pressure drop should be kept to a minimum, as practically possible.

7.2.5.2 A safety feature should be implemented to prevent the diluent heater from overheating when the diluent is not flowing.

7.2.6 Gas line

7.2.6.1 The GL and gaseous emissions analysers shall meet the specifications in Third Schedule.

Note.—The collection part (Module1) of the nvPM sampling and measurement system meets the specifications in Third Schedule.

7.2.6.2 For nvPM EI determination, GL measurements of CO, HC and NO_x gaseous concentrations shall be performed simultaneously.

Note.— Guidance material is provided in the Environmental Technical Manual *(Doc 9501), Volume II* — Procedures for the Emissions Certification of Aircraft Engines.

7.2.6.3 For determination of DF_{1_S}, a GL measurement of CO_2 concentration (dry, semi-dry or wet) shall be performed simultaneously with the nvPM measurements.

7.2.7 Excess sample line

7.2.7.1 The sample line pressure at Diluter1 inlet (P_1) shall be maintained near local ambient air pressure using a suitable pressure control valve with sufficient internal area. When fully closed, the valve shall be capable of holding a vacuum pressure of –75 kPa relative to ambient.

7.2.7.2 An optional shut-off valve, with sufficient internal area to avoid system back pressure, should be added downstream of the pressure control valve to prevent leakage at sub-atmospheric conditions inside Splitter 1.

7.3 Module 3: diluter 1 outlet — cyclone separator inlet

7.3.1 The sampling line shall meet the following requirements:

(a) The sampling line material shall be carbon-loaded electrically grounded PTFE.

(b) The sampling line should meet the anti-static specification in ISO8031.

(c) The sampling line ID shall be between7.59mmand8.15mm.

Note.— Accounting for manufacturing tolerances, the sampling line ID specification corresponds to commercially available line outer diameter dimensions of 3/8 inch and 7/16 inch, both with 0.035 inch wall thickness; and 10 mm with a 1 mm wall thickness.

(d) The line shall be of length 24.5m±0.5m, have no unnecessary fittings and consist of a maximum of three segments.

(e) The coiled sample line bendrdii shall be greater 0.5m.

(f) The sampling line temperature shall be maintained at 60°C±15°C through active heating.

(g) The sample flow shall be maintained at 25 slpm ± 2 slpm.

7.4 Module 4: cyclone separator inlet — instrument inlet

7.4.1. Cyclone separator The cyclone separator shall meet following requirements:

(a) The cyclone separator material shall be stainless steel.

(b) The cyclone separator shall be heated to 60°C±15°C.

(c) The cyclone separator inlet and out let IDs shall be less than a 15 percent difference to the inlet and outlet sample line ID.

(d) The performances of the cyclone separator at a sample flow rate of 25 slpm shall meet the following specifications:

1) cut-point: D_{50}=1.0µm±0.1µm;

2) sharpness: $(D_{16}/D_{84})^{0.5}$ less than or equal to 1.25; and

3) pressure drop: ΔP less than or equal to 2kPa.

7.4.2 Splitter 2 Splitter 2 shall meet the following requirements:

(a) Splitter 2 body material shall be stainless steel.

(b) Splitter 2 shall be heated to 60°C±15°C.

(c) Splitter 2 shall separate the sample into three flow paths to deliver the diluted nvPM sample to:

1) nvPMmi;

2) VPR; and

3) make-up flow.

(d) The split angles relative to the incoming flow shall be as a cute as practical not exceeding 35°.

(e) All nvPM flow paths shall be as short as practical.

(f) The Splitter 2geometry shall meet the following requirements:

1) no forward facing shoulders on the inner wall;

2) no change in ID from Splitter 2 outlet to nvPMmi inlet; and

3) no change in ID from Splitter 2 outlet to VPR inlet.

7.4.3 Measurement system interface, The sampling lines to the nvPMmi and VPR shall meet the following requirements:

(a) The sampling line material shall be of stainless steel or carbon loaded electrically grounded PTFE.

(b) If the sampling line is carbon-loaded electrically grounded PTFE, it should meet the anti-static specification in ISO 8031.

(c) The sampling line shall be heated to60°C±15°C.

(d) No change in ID between the sampling line and the instrument inlets.

(e) Each total line length from cyclone separator inlet to the inlet of the nvPMmi and VPR shall be kept as short as practical and shall not exceed 3 m.

7.5 Module 5: nvPM measurement

7.5.1 Make-up flow

7.5.1.1 The make-up flow path components shall meet the following requirements:

(a) The primary pump and flow controller to maintain a constant total sample flow rate (flow rate sum of make-up flow, nvPMmi and VPR) of 25 slpm ±2 slpm up to 10 kPa below ambient, through Module 3.

(b) The CO_2 analyser to measure continuously CO_2 concentration downstream of Diluter 1, $[CO_2]$ dil1, during the nvPM measurement.

Note1.—Depending on the sampling configuration, there may be multiple flow controller sand pumps.

Note2.—Guidance material is provided in the Environmental Technical Manual *(Doc9501), Volume II*—Procedures for the Emissions Certification of Aircraft Engines.

7.5.1.1.1 Particle filters should be placed up stream of flow controllers to prevent damage to components.

7.5.1.2 If the nvPMmi lacks a sample pressure measurement, the pressure shall be measured at the Splitter 2 outlet to the make-up flow path.

7.5.1.3 The CO_2 analyser shall meet the following requirements:

a) The CO_2 analyser shall be located after a flow controller.

b) The CO_2analyser shall meet the performance specifications given in 5.3 of Third Schedule under the headings *CO and CO_2 analysers* and *CO_2 analyser* with the exception of a).

7.5.1.3.1 The CO_2 analyser total range should be approximately ten times lower than the CO_2 analyser used on the GL.

8. SPECIFICATION FOR nvPM MASS INSTRUMENT AND CALIBRATION

Note1.—In this section of Seventh Schedule, element al carbon (EC) mass is being used as surrogate for nvPM mass. Guidance is provided in the Environmental Technical Manual *(Doc 9501), Volume II —* Procedures for the Emissions Certification of Aircraft Engines.

Note2.—A full descriptive text for the thermal optical transmittance (TOT) measurement reference method is provided in 8.2of this Schedule. This method is commonly performed by calibration laboratories; it is not expected that the aircraft engine manufacturer would perform this method.

Note 3.— The following ISO reference is used in this section of Seventh Schedule: International Standards Organization, Air quality — Definition and determination of performance characteristics of an automatic measuring system *(ISO 9169: 2006).*

8.1 Specifications

Each make and model of the nvPMmi shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that it:

(a) shall have a measurement range of 0µg/m^{3}to1000µg/m^{3}or greater;

(b) shall have a resolution of 1µg/m^3 or better;

(c) shall be insensitive to volatile particulate matter; and

Note1.—Volatile particulate matter is combustion exhaust material that volatilizes at temperatures less than or equal to 350°C.

Note2.—This specification is met when the nvPMmi meets the verification performance specification in Table S 7-5.

(d) Meets the performance specifications listed in Table S7-5.

Note 1.— While all references are to ISO 9169 in Table S7-5, those that are denoted by an asterisk refer to performance specifications for which modifications are applied as described in 8.4 of this Schedule.

Note 2.— The performance specifications reflect the limits of the quantities that can be verified using thermal optical transmittance (TOT) as the measurement reference method. The TOT method is described in 8.2 of this Schedule.

Note 3.— Only the accuracy performance specification from Table S 7-5 is needed and applied in the annual calibration procedure described in 8.5 of this Schedule.

Table S 7-5. Performance specifications for nvPM mass instruments (nvPMmi)

Performance specification	*Value (equal to or less than)*	*Determination method*
Repeatability	10µg/m^3	ISO*6.4.5.3 asdescribedin8.4
Zero drift	10µg/m^3/hr	ISO 6.6 (for CO only) as described in 8.4
Linearity	15µg/m^3	ISO*6.4.5.4 asdescribedin8.4
Limit of detection (LOD)	1µg/m^3	ISO*6.4.5.5 asdescribedin8.4
Rise time	2seconds	ISO6.3 asdescribedin8.4
Sampling interval	1second	ISO2.1.7asdescribed in8.4
Accuracy	±10per cent	Slope of the line arregression between nvPMmi mass concentration and EC mass concentration as described in 8.3.2.8
Verification	±16per cent	Verification of the instrument and calibration source on an aircraft turbine exhaust (as described in 8.3)

8.2 Thermal optical transmittance (TOT) method

Thermal optical transmittance (TOT) shall be the measurement reference method to demonstrate conformity with the performance specifications of each make and model of the nvPMmi and to calibrate the nvPMmi. This method permits the determination of EC and organic carbon (OC) in the nvPM samples.

8.2.1 General

8.2.1.1 The TOT analyser shall be either a laboratory instrument (with a flame ionization detector (FID)) or semi-continuous instrument (with a non-dispersive infrared detector (NDIR)).

8.2.1.2 The TOT method shall use the temperature profile specified inTableS7-6.

Note.—Guidance material on the TOT method is provided in the Environmental Technical Manual *(Doc9501), Volume II —* Procedures for the Emissions Certification of Aircraft Engines.

8.2.2 Reagents and materials

8.2.2.1 The following reagents shall be used:
(a) aqueous solutions of reagent grade (99 percent or greater) sucrose, diluted with ultra pure H_2O Type I, or equivalent, to produce 0.1 to 3 mg C per millilitre solution;
(b) He—purity 5.0 (greater than 99.999 percent);
(c) H_2—purity 4.5 (greater than 99.995 percent);
(d) zero air (with less than 0.2 ppm hydrocarbons);
(e) a certified mixture of 10 percent O_2 in He; and
(f) a certified mixture of 5 percent CH_4 in He.

8.2.2.2 The following material shall be used:

(a) for the laboratory instrument, a metal punch provided with the instrument for removal of 1.0 cm^2 or 1.5 cm^2 rectangular portion of filter;

(b) for the semi-continuous instrument, a metal punch provided with the instrument for removal of two 2.0 cm^2 circular filters;

(c) Pa llT is suquartz™ quartz fibre filters, or equivalent; and

(d) Syringe of 10 microlitres.

8.2.2.3 Filter preparation

Depending on the instrument used, the filters shall be prepared as follows:

(a) for manual sampling and analysis, all quartz fibre filters shall be pre-fired in a muffle furnace at or greater than 550°C for12 hours, or greater than or equal to 800°C for 1 hour to 2 hours before sampling and stored in a sealed container; or

(b) for the semi-continuous analyser, the filters for measurement shall be conditioned by performing at least one complete measurement cycle as described in Table S7-6.

Table S 7-6. Required temperature profile for the TOT method analysis cycle

Carrier gas	*Temperature (°C)*	*Time at temperature (seconds)*
100 percent He	310	80
	475	80
	615	80
	870	110
	550	45
10 percent O_2 in He	550	45
	625	45
	700	45
	775	45
	850	45
	870	60
	930	120
5 percent CH_4 in He	0	120

8.2.3 Sample preparation

8.2.3.1 The sample filter shall be placed on a clean aluminium foil surface.

Note.—Is opropyl alcohol race tone can be used to clean the foil surface. In this case, allow residual solvent to vaporize from the surface prior to use. Alternatively, the foil can be cleaned by baking in a muffle furnace prior to use.

8.2.3.2 A representative portion of the filter shall be punched out. Good laboratory practice shall be used in filter handling.

8.2.4 Calibration and quality control

8.2.4.1 The temperature sensor controlling the oven temperature shall be calibrated using a traceable transfer standard within 1 year prior to any TOT analyses being conducted.

8.2.4.2 If the laboratory instrument is used, the FID response shall be calibrated. The calibration shall meet the following procedure:

(a) Prepare external calibration standard comprised of a sucrose solution in organic-free water.

(b) Disperse10 micro litres of the solution on to punches from anew and clean pre- baked quartz filter.

(c) Analyse a minimum of three method blank samples and three sucrose solution samples to ensure that instrument calibration shows a percent recovery of 95 per cent to 105 per cent of the theoretical mass of C (µgC measured/µgC dispersed).

8.2.4.3 If the semi-continuous instrument is used, the NDIR response shall be calibrated. The calibration shall meet the following procedure:

(a) Prepare external calibration standard comprised of a sucrose solution in organic-free water.

(b) Disperse 10 micro litres of the solution on to punches from a separate pre-conditioned “boat” filter inserted into the bottom of the quartz semi-tube.

(c) Analyse a minimum of three method blank samples and three sucrose solution samples to ensure that instrument calibration shows a percent recovery of 95 per cent to 105 per cent of the theoretical mass of C (µgC measured/µgC dispersed).

8.2.4.4 If the filter analyses require more than one day, each day a single quality control check, generally using the stock sucrose solution, shall be dispersed to the filter and analysed accordingly. The results shall be within 95 to 105 percent of the theoretical mass of C.

Note.—The method blank is a pre-fired quart filter without addition of sucrose but handled in the same manner.

8.2.5 Measurement

The measurement shall be obtained using the following procedures;

(a) The TOT analyser shall be operated in accordance with manufacturer’s recommendations.
(b) Place sample portion into sample oven.
(c) Determine EC and OC mass in µg.

Note.— TOT analyser results are reported in µg/cm2 of C.

(d) Final sample results shall always be blank-corrected:

(i). For the laboratory instrument, the field blank consists of pre-fired quartz fibre filters handled in the same manner as the samples, except that no air is passed through the filter. EC mass loading per unit area greater than or equal to 0.3 μg/cm^2 in the blank samples represents contamination;

(ii). for the semi-continuous analyser, a measurement of the internal filter set shall be performed without any sample gas being passed through the filters.

(e) Final sample results shall always be corrected for gas phase OC arte facts. For this correction, the operating conditions (duration and flow rate) shall be identical to those used for sample collection. Depending on the instrument used, the procedure shall be as follows:

(i). For the laboratory analyses, a sampling configuration consisting of a Teflon filter followed by a pre-fired back-up quartz filter, or a pre-fired quartz filter followed by a pre-fired back-up quartz filter, shall be employed with the backup filter analysed asprescribedinTableS7-6. Any OC found on the backup filters shall be subtracted from the OC found on sample filters;

(ii). for the semi-continuous analyses, a Teflon filter shall be inserted in the sampling configuration prior to the analyser. Any OC found during this measurement shall be subtracted from the OC found during sample measurement.

8.2.6 Calculations

For the laboratory instrument:

(a) multiply the reported EC loading result (μg/cm^2) by the filter deposit area (cm^2) to calculate total mass of EC (μg) on each filter sample (W_{EC});

(b) do the same calculation as in a) for the blanks and calculate the mass found in the average blank (W_b); and

(c) calculate the EC mass concentration (C_{EC}) in the air volume sampled at STP conditions, V(inm^3):

$$C_{EC} = \frac{W_{EC} - W_b}{V} \quad (\mu g/m^{3)}$$

Note 1.—The semi-continuous instrument provides the EC mass concentration as a reported result.

Note2.—Guidance material on the principle of the TOT method is provided in the Environmental Technical Manual
(Doc9501), Volume II—Procedures for the Emissions Certification of Aircraft Engines.

8.3 Procedure to demonstrate conformity to performance specifications

Note.—The procedure escribed in this section is used to demonstrate the conformity to the performance specifications of each make and model of the nvPMmi.

The performance specifications listed in Table S7-5 shall be demonstrated using the TOT method as described in 8.2 of this Schedule. The measurements shall be performed using the two following sources: a diffusion flame combustion aerosol source and a gas turbine engine exhaust nvPM source.

8.3.1 Diffusion flame combustion aerosol source

Note.— Guidance material on a diffusion flame combustion aerosol source is provided in the Environmental Technical Manual *(Doc 9501), Volume II* — Procedures for the Emissions Certification of Aircraft Engines.

8.3.1.1 Diffusion flame combustion aerosol source

For demonstrating nvPMmi conformity and annual calibration, the diffusion flame combustion aerosol source shall be defined by the model of device used to produce the diffusion flame, the fuel used and the operating settings.

8.3.1.2

a) care should be taken when selecting and operating different diffusion flame combustion aerosol sources as the nvPMmi calibration factor (the relationship between instrument response and TOT reference) can potentially change for different diffusion flame combustion aerosol source devices.

b) A single diffusion flame combustion aerosol source should be used to show nvPMmi conformity to the repeatability, zero drift, linearity, rise time and accuracy performance specifications in Table S7-5.

8.3.1.3 Diffusion flame combustion aerosol sources used for nvPMmi calibration

Each diffusion flame combustion aerosol source used for calibration of a nvPMmi shall demonstrate conformity to the verification performance specifications in Table S7-5 applying 8.3.2 and 8.3.3.

8.3.2 Measurement using a diffusion flame combustion aerosol source

8.3.2.1 The measurement system shall contain:

(a) a diffusion flame combustion aerosol source;

(b) a dilution system using HEPA filtered diluents to control target EC mass concentrations;

(c) a1µmcut-point cyclone separator upstream of the TOT instrumentation and nvPMmi;

(d) a splitter assembly meeting requirements in7.4.2d) and f) of this Schedule;

Note.—An equivalent procedure is provided in the Environmental Technical Manual *(Doc9501), Volume II—*
Procedures for the Emissions Certification of Aircraft Engines.

(e) stainless steel or anti-static tubing to connect the manual quartz filter sampler, or a semi-continuous EC/OC analyser, and the nvPMmi. All tubing shall be of the same material, length and temperature from the split point to the instrument inlets; and

(f) *If anti-static tubing is used, the tubing should meet the anti-static specification in ISO8031.*

8.3.2.2 Depending on the instrument used for the TOT measurement, the following requirements shall be met:

(a) If manual sampling and laboratory analyser are used, one pre-fired, quartz filter in a stainless steel filter holder having at a pered inlet section with a≤12.5°half-angle operated at a filter face velocity less than or equal to0.5m/s at actual operating conditions shall be used. The diameter of the filter deposit shall be large enough to allow at lea stone punch to be collected from each filter. At least one punch shall be analysed from each quartz filter sample collected; or

(b) if a semi-continuous TOT analyser is used, it shall be operated at a filter face velocity of less than or equalto0.5m/s.

8.3.2.3 Measurements shall be made at tiered levels of target EC mass concentration specified in Table S 7-7. Achieved EC mass concentrations shall be within 20 percent of the target mass concentrations specified.

8.3.2.4 At each concentration tier level, samples shall be taken for a similar time period to establish are pea table EC filter loading. The EC filter loading shall be 12 ±5 $\mu g/cm^2$.

8.3.2.5 The averaging time as defined in ISO9169 shall be the same as the filter collection time.

8.3.2.6 The average EC content determined by the TOT method shall be greater than or equal to 80percent of total C.

8.3.2.7 EC mass concentrations from the TOT method and the nvPMmi mass concentrations shall be used to determine parameters as specified in 8.4 of this Schedule that demonstrate conformity to the repeatability and linearity performance specifications in Table S7-5.

8.3.2.8 The nvPMmi is calibrated using the number of tests in Table S7-7 and procedure as specified in 8.5.5 of this Schedule. The resulting slope of the linear regression between nvPMmi mass concentration and EC mass concentration determined from TOT shall be used to determine the accuracy performance specifications in Table S7-5.

Table S7-7. EC mass loading parameters for nvPMmi conformity and diffusion flame combustion aerosol source verification

Target concentration ($\mu g/m^3$)	*Instrument (number of tests)*	*Calibration with a new diffusion flame combustion aerosol source (number of tests)*
0(blank run)	6	3
50	6	0
100	6	3
250	0	3
500	6	3

8.3.3 Measurement using an air craft engine exhaust nvPM source

8.3.3.1 This measurement is used to demonstrate the nvPMmi verification performance specification in Table S7-5 to verify the combination of instrument and diffusion flame combustion aerosol source for nvPM mi calibration. 8.3.2.4 to 8.3.2.5 shall be repeated for a gas turbine engine exhaust nvPM source using the measurement system specified in 8.3.2.1c), d), e) and

8.3.2.2 with a dilution system using HEPA filtered diluent.

8.3.3.2 Sufficient dilution should be used to prevent water condensation in the sample line.

8.3.3.3 A minimum of four data points shall be obtained for a minimum of three different thrust levels with duplicate measurements made at one of the thrust levels using the nvPM sampling system specified above. The measurements shall be conducted at a minimum of three target concentrations, each at least a factor of 1.5 apart from the next, at least one concentration shall be above 120 $\mu g/m^3$, and at least one concentration shall be below 120 $\mu g/m^3$. The EC filter loading for these four data points shall be between 2.5 $\mu g/cm^2$ and 17 $\mu g/cm^2$.

8.3.3.4 EC mass concentrations from the TOT method and the nvPMmi mass concentrations shall be used to demonstrate conformity to the verification performance specification as specified in Table S7-5.

8.3.3.5 The engine test fuel shall be one of the aviation turbine engine fuels listed in the *Manual on Civil Aviation Jet Fuel Supply* (Doc 9977) and regulation 23 of these Regulations. The same fuel shall be used for the minimum four data points.

8.4 Calculation of instrument performance

8.4.1 The nvPMmi performance parameters zero drift, rise time and sample rate shall be determined as specified in ISO 9169, paragraphs 6.6, 6.3 and 2.1.7, respectively.

8.4.2 Repeatability parameter of the nvPMmi at 95 percent confidence interval shall be determined using 6 consecutive measurements at each concentration level as:

$$s_{r_i}^2 = s_{Y_i}^2 - \Delta^2 \cdot s_{C_i}^2$$

where

$$s_{Y_i}^2 = \frac{\sum_{j=1}^{n}\left(Y_{i,j} - \overline{Y}_i\right)^2}{(n-1)}$$

s_{C_i}	the standard deviation over j of the $C_{i,j}$ for level i
$Y_{i,j}$	the result of measurement by the instrument of the reference material $C_{i,j}$
$C_{i,j}$	the jth instance of the reference material concentration at level i
Y_i	the average over j of the $Y_{i,j}$
n	number of consecutive measurements at each concentration level (6 minimum)
Δ	the slope of the regression function applied in the lack of fit test determined from the following equations:

$$E_{i,j} = Y_{i,j} - \left(\Gamma + \Delta \times C_{i,j}\right)$$

$$E_i = \frac{\sum_{j=1}^{n} E_{i,j}}{n}$$

where

$E_{i,j}$ is the difference between $C_{i,j}$ and $Y_{i,j}$;

E_i is the average over j of the $E_{i,j}$; and

Γ is the intercept of the regression function applied in the lack of fit test.

8.4.3 *If the repeatability so determined is negative, the repeatability should reported as "significantly better than* $\Delta \cdot s_{C_i}^2$ *".*

Note.— If the repeatability so determined is negative, indicating that the variance of the measurement could not be discriminated from the variability of the reference material, the test may be repeated with additional attention given to the stability of the reference material source (diffusion flame combustion aerosol source flow and pressure settings) and the accuracy of the determination of the reference material level (TOT method loadings and procedures).

8.4.4 LinearityofthenvPMmishallbedeterminedasspecifiedinISO9169,paragraph6.4.5.4,howeverwiththe residual determined by the following:

$$E_i = \frac{\sum_{j=1}^{n} E_{i,j}}{n}$$

8.4.5 The LOD of the nvPM mi shall be determined as specified in ISO 9169, paragraph 6.4.5.5. If the instrument does not make a measurement when there are no particles in the sample, then a higher nvPM mass concentration, C_{LOD}, just above zero shall be used such that the instrument produces regular readings. The LOD in this case shall be determined as:

$$Y_{LOD,0.95} = \overline{Y}_{LOD} - C_{LOD} + 2 \times t_{\nu,0.95} \times s_{LOD}$$

where

$Y_{LOD,0.95}$ is the limit of detection at 95 per cent confidence interval;

$\overline{Y}_{LOD}$ is the average of the values $Y_{LOD,j}$;

C_{LOD} is the average of the values $C_{LOD,j}$;

$t_{\nu,0.95}$ is the two sided Student's factor at 95 per cent confidence, degree $\nu = n-1$;

s_{LOD} is the standard deviation associated with the average Y_{LOD}.

Note.— The reference material may not be the same in consecutive measurements taken over the averaging time. Thus, each determination of the reference material's value may be different, albeit well known as determined by the TOT method. ISO 9169 definitions are modified to accommodate such variability.

8.5 Calibration

8.5.1 The nvPMmi shall be calibrated annually using a verified diffusion flame combustion aerosol source as specified by 8.3.1.3, the TOT method specified in 8.2 and a system setup specified in 8.3.2.1 and 8.3.2.2 of this Schedule.

8.5.2 Measurements shall be made at tiered levels of target EC mass concentration specified inTableS7-8. Achieved EC mass concentrations shall be within ±20 per cent of target mass concentrations specified.

Table S7-8. EC mass loading parameters for calibration samples

Target concentration (μg/m^3)	*Annual calibration (number of tests)*
0(blank run)	3
50	0
100	3
250	3
500	3

8.5.2.1 Three points at 50µg/m3 for annual calibration should be tested.

8.5.3 At each concentration tier level, samples shall be taken for a similar time period to establish a repeatable EC filter loading. The EC filter loading shall be 12 ±5 µg/ cm2.

8.5.4 The averaging time as define din ISO9169 shall be the same as the filter collection time.

8.5.5 EC mass concentrations from the TOT method and the nvPMmi mass concentrations shall be used to establish the best fit for the data points collected from the calibration of the instruments. A linear least squares method shall be used to determine the scale factor b to adjust the nvPM mass concentrations reported by the nvPMmi as follows:

$$b = \frac{\sum \frac{y_i}{x_i}}{n}$$

where

x_i is the i^th^ nvPMmi measurement;

y_ii is the i^th^ TOT EC mass concentration; and

b is the slope of the best fit line.

Note1.—Once the b scaling factor is applied to the nvPMi, the slope of the adjusted instrument readings against the TOT results for EC is mathematically equal to 1.0, and the requirement on the slope in Table S7-5 will be met by definition.

Note2.—Because of the expected un certainties in the repeatability of the TOTEC as says, are peat of the above process at the same or at a different laboratory may produce a different slope without any change in the response of the instrument. The accuracy performance specifications of Table S 7-5 are intended to account for such variability.

8.5.6 Prior to each annual calibration, the performance of each mass instrument should be assessed in the "as found" condition at an EC mass concentration of 100 µg/m^3 for the number of tests listed in Table S7-8. This assessment will allow traceability to prior calibrations of the instrument and allow comparison of existing and new calibration constants.

9. SPECIFICATIONS AND CALIBRATION FOR THE VOLATILE PARTICLE REMOVER AND THE nvPM NUMBER INSTRUMENT

9.1 Specifications

9.1.1 VPR specifications

9.1.1.1 Each make and model of the volatile particle remover (VPR) shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that it meets the performance specifications listed below.

9.1.1.2 The VPR dilution factor (DF_2) shall meet the following requirements:

(a) DF_2 shall be adjusted to maintain particle number concentration within condensation particle counter (CPC) single count mode and to reduce sample temperature to between 10°C and 35°C at the CPC inlet.

(b) DF_2variability shall be less than10percent.

9.1.1.3 The heated section which evaporates volatile species shall be maintained at a temperature of 350°C±15°C

9.1.1.4 If the VPR contains multiple heated stages, the additional temperature controls shall be ±15°C of operating temperatures specified by the VPR manufacturer.

9.1.1.5 The sample pressure control shall meet the following requirements:

a) A pressure control device shall permit delivery of a diluted sample to the CPC within ±15k Pa of ambient (CPC exhaust) pressure.

b) The pressure shall not exceed 105k Pa.

9.1.1.6 The minimum allowed particle penetration fractions of the VPR for each dilution setting shall meet the specifications listed in Table S7-9.

Table S7-9. Minimum allowed penetration fractions of the VPR at four particle diameters

Electrical mobility particle diameter, D_m	15 nm	30 nm	50 nm	100 nm
Minimum penetration fraction, $\eta_{VPR}(D_m)$	0.30	0.55	0.65	0.70

9.1.1.7 The VPR volatile removal efficiency (VRE) shall be such that more than 99.5 per cent of tetracontane ($CH_3(CH_2)_{38}CH_3$, greater than 95 percent purity) particles with an inlet concentration of at least 10 000 particles/cm^3 at 30nm electrical mobility diameter are removed. This VRE shall be demonstrated when the VPR is operated at it is minimum dilution setting and manufacturer's recommended operating temperature.

9.1.1.8 If a catalytic tripper is used in the VPR, the diluents shall contain at least 10 percent of O_2.

9.1.2 VPR to CPC interface

The tube connecting the VPR outlet to the inlet of the CPC shall meet the following requirements:

(a) The material shall be electrically conductive.

(b) The tube shall have n internal diameter greater than ore qual to 4mm.

(c) The sample in the tube shall have a residence time less than or equal to 0.8 seconds.

9.1.3 CPC specifications

9.1.3.1 Each make and model of the CPC shall receive a certificate from the instrument manufacturer or from another competent testing and calibration laboratory confirming that it meets the performance specifications listed below.

9.1.3.2 A coincidence correction function up to a maximum of 10 percent correction shall be allowed. The coincidence correction function shall not use any algorithm to correct for or define the counting efficiency.

9.1.3.3 The counting of the particles shall meet the following requirements:

(a) The counting mode shall be a single count mode. CPC use in the photometric mode is not allowed. Thus, to ensure single count mode, DF_2shall be increased as necessary.

(b) The counting accuracy shall be of ±10 per cent from 2 000 particles/cm^3 to the upper threshold of the single particle count mode against a traceable standard (ISO 27891).

(c) The counting efficiency shall be greater than or equal to 50 percent at 10 nm electrical mobility diameter and greater than or equal to 90 per cent at 15 nm electrical mobility diameter.

(d) The counting efficiency shall be established using an Emery oil aerosol.

9.1.3.4 The data acquisition rate shall be greater than or equal to 1.0 Hz for a minimum interval of 30 seconds once the engine is stabilized.

9.1.3.5 The particle number concentration shall be reported as particles/cm^3 at STP conditions. If the reported value is not at STP conditions, the CPC absolute inlet pressure shall be measured with an accuracy better than 2 percent so that the number concentration can be corrected to STP conditions, following manufacturer's guidelines.

9.1.3.6 The resolution shall be better than 0.1 particles/cm^3 at concentrations below 100 particles/cm^3.

9.1.3.7 The rise time shall be less than 4 seconds.

9.1.3.8 The sample flow shall be full flow. No internal flow splitting is allowed.

9.1.3.9 The working fluid shall be in-but a no l.

9.1.3.10 The response shall be linear.

9.1.4 System requirement

The t_{90} from the inlet of the VPR through the CPC shall be equal to or less than 10 seconds.

9.2 Calibration

9.2.1 VPR

Prior to each VPR calibration, the VPR should be validated "as found" at a single DF_2 setting, typical of that used for measurements on aircraft turbine engines. This validation should include the VPR dilution factor at the selected DF_2 setting, the determination of the penetration fractions and VRE.

9.2.1.1 The DF_2 calibration shall meet the following requirements:

a) The DF_2 shall be calibrated at each dilution setting of the VPR, as defined by the VPR manufacturer.

b) *The DF_2 calibration should be performed by a competent laboratory, using either trace gases such as CO_2, or flow measurements.*

9.2.1.2 VPR particle penetration fractions calibration shall meet the following requirements:

a) The VPR particle penetration fractions shall be measured at 350°C with solid particles of 15 nm, 30 nm, 50 nm and 100 nm electrical mobility diameters for each dilution setting of the VPR. A minimum of 5 000 particles/cm^3 across the four particle sizes shall be delivered to the VPR. If soot is used for particle generation, then a thermal pre-treatment device heated to 350°C may be needed to deliver only nvPM to the VPR.

b) Particle concentrations shall be measured upstream and downstream of the VPR with a CPC that has a counting efficiency greater than or equal to 90 percent 15 nm.

c) The VPR penetration fractions shall be determined as follows:

$$\eta_{VPR}(D_m) = \frac{DF_2 \times N_{out}(D_m)}{N_{in}(D_m)}$$

where

$N_{in}(D_m)$ is the upstream particle number concentration for particles of D_m; and

$N_{out}(D_m)$ is the downstream particle number concentration for particles of D_m.

d) $N_{in}(D_m)$ and $N_{out}(D_m)$ shall be referenced to the same T and P conditions.

e) *The VPR should be calibrated as a complete unit.*

9.2.1.3 VPR VRE

a) The VRE shall be determined with a CPC that has accounting efficiency greater than or equal to 90 percent at 30nm, as follows:

$$\text{VRE }(D_{30})=100\times\left[1-\frac{DF_2 \times N_{out}(D_{30})}{N_{in}(D_{30})}\right]$$

where

$VRE(D_{30})$ is the VRE for particles of D_{30};

$N_{in}(D_{30})$ is the upstream particle number concentration for particles of D_{30};

$N_{out}(D_{30})$ is the downstream particle number concentration for particles of D_{30}; and

D_{30} are particles with an electrical mobility diameter of 30 nm.

b) $N_{in}(D_{30})$ and $N_{out}(D_{30})$ shall be referenced to the same T and P conditions.

9.2.2 CPC calibration

9.2.2.1 The CPC calibration shall be traceable to a standard calibration method (ISO27891): by comparison the response of the CPC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electro statically classified calibration particles.

9.2.2.2 *Prior to each CPC calibration, the CPC should be validated ("as found").*

9.2.2.3 The calibration and validation shall be performed using the procedures described below:

a) The CPC's detection efficiency shall be calibrated with particles of 10 and 15 nm electrical mobility diameter. The CPC shall have a counting efficiency of greater than or equal to 50 percent at 10nm and greater than or equal to 90 per cent at 15 nm.

b) The calibration aerosol shall be Emery oil.

10. PROCEDURES FOR SYSTEM OPERATION

10.1 Collection part and gas line leakage check

10.1.1 Leakage check procedure

Prior to an engine test series, the Collection Part and the GL shall be checked for leakage using the following procedure:

a) Isolate the GL from then vPM measurement part using Isolation Valve 1, the P_1 pressure control valve and, if installed, the optional shut-off valve.

b) Isolate the probe and the analysers.

c) Connect and operate a vacuum pump to verify the leakage flow rate.

d) The vacuum pump shall have an o-flow vacuum capability of–75kP a with respect to atmospheric pressure; its full-flow rate shall not be less than 26 L/min at standard temperature and pressure.

10.1.2 Leakage check requirement
The leakage flow rate shall be less than 0.4 slpm.

10.2 Collection part and gas line cleanliness check

This check is only performed if using the full gaseous nv PM EI calculation method.

10.2.1 Cleanliness check procedure

The Collection Part and GL shall be checked for cleanliness using the following procedure:

a) Isolate the GL from the nvPM measurement part using Isolation Valve1and the P1pressure control valve.
b) Isolate the GL from the probe and connect that end of the sampling line to a source of zero gas.
c) Warm the system up to the operational temperature needed to perform HC measurements.
d) Operate the sample flow pump and set the flow rate to that used during engine emissions testing.
e) Record the HC analyser reading.

10.2.2 Clean lines check requirement

10.2.2.1 The HC reading shall not exceed1percent of the engine idle emissions levelor1ppm (both expressed as carbon), whichever is the greater.

Note.— If there are significant levels of emission species present in the background air at the engine inlet due to various other sources, there may be an impact on the levels of engine exhaust emission species. In this situation, monitoring those species and accounting for this background air quality in reported emissions levels may be warranted.

10.2.2.2 If a procedure accounting for the background air quality on the reported emissions levels is warranted, then this procedure should be used, subject to the approval of the certificating authority

10.3 Transfer part cleanliness/leakage check

Note 1.— Cleanliness checks can fail due to contaminated transfer part components or leaks in either the transfer or measurement parts, or both.

Note2.—A system leakage will result in ambient air particles drawn into the system.

10.3.1 Cleanliness/leakage check procedure

10.3.1.1 Prior to an engine test series, the transfer part shall be checked for cleanliness and leaks using the following procedure:

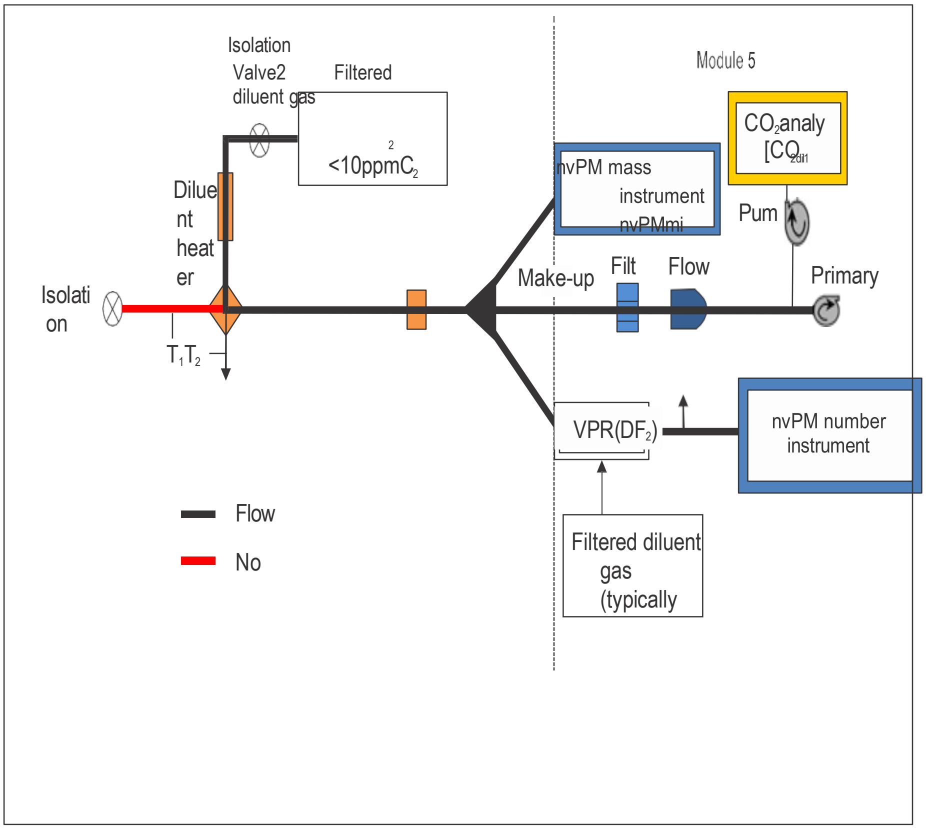
a) Flow filtered diluents through Diluter 1 with Isolation Valve 1 closed.

b) The flow rates in each Splitter 2 path shall be equal to those used during engine testing.

c) Set the DF_2 to the lowest setting of the VPR.

10.3.1.2 When the measured nvPM mass and number concentrations are stable, record data for a minimum of 30 seconds.

Note.—The flow schematic for the transfer part cleanliness check is shown in Figure S7-4



FigureS7-4. Flow schematic for the transfer part cleanliness check

10.3.2 Cleanliness/leakage check requirement

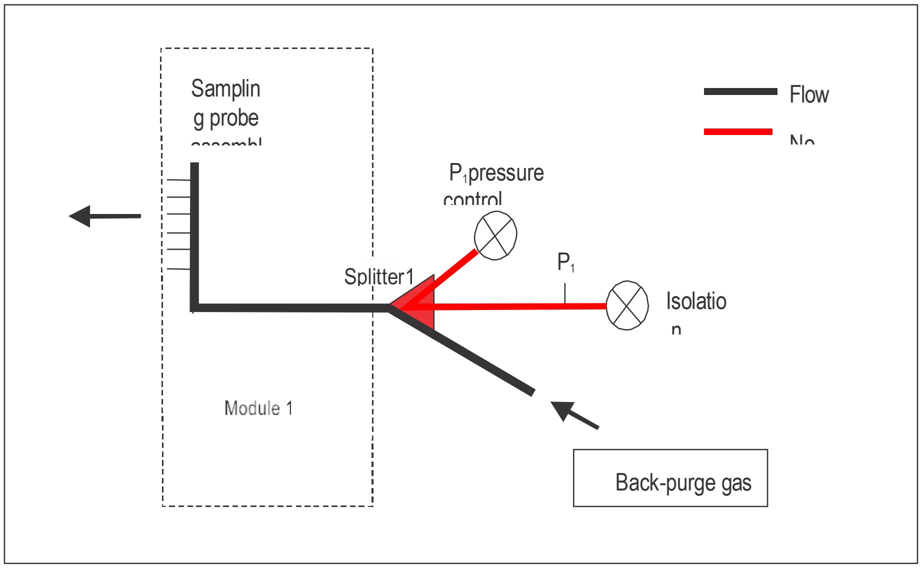
10.3.2.1 The 30 seconds average dnvPM mass concentration (nvPM$_{mass}$_STP) shall be lessthan1 µg/m^3.

10.3.2.2 The 30 seconds average dnvPM number concentration (nvPM$_{num}$_STP) shall be less than 2.0particles/cm^3.

10.3.2.3 If the clean lines check fails, the system should be first inspected for leakage. If no leaks are detected, the cyclone separator collection reservoir should be inspected and cleaned. If the cleanliness check still fails, segments of the sampling system may need cleaning or replacement.

10.4 Collection part back-purging

In order to maintain the Module 1 sampling probes and lines clear of unburned fuel, Module 1 should be back-purged during engine start-up and shutdown as depicted in Figure S7-5.



FigureS7-5. Flow schematic for Module 1 back-purge

10.5 Ambient nvPM measurement

10.5.1 General

10.5.1.1 Ambient nvPM mass and number concentrations representative of engine air in let shall be obtained before and after an engine test and reported as the average of these two measurements.

Note 1.— For an enclosed test cell, elevated levels of nvPM within the test cell may occur due to the presence of other nvPM sources prior to engine start. In this situation, obtaining representative ambient nvPM measurements may require flushing the test cell with ambient air.

Note2.—Guidance material is provided in the Environmental Technical Manual *(Doc9501), Volume II—*Procedures for the Emissions Certification of Aircraft Engines.

10.5.2 Ambient nvPM sampling procedure

The ambient nvPM mass and number concentrations representative of engine air inlet shall be sampled by either:
Method 1: Sampling through Diluter 1 vent

The nvPM sampling and measurement system shall be used to sample through the Diluter 1 vent. When sampling through the Diluter 1 vent the following procedure shall be used:

a) Turn off the diluent flows up ply to Diluter 1 by closing Isolation Valve 2 and ensure that Isolation Valve 1 is closed.

b) *The diluent heater should be protected from overheating when the diluent flow is turned off.*

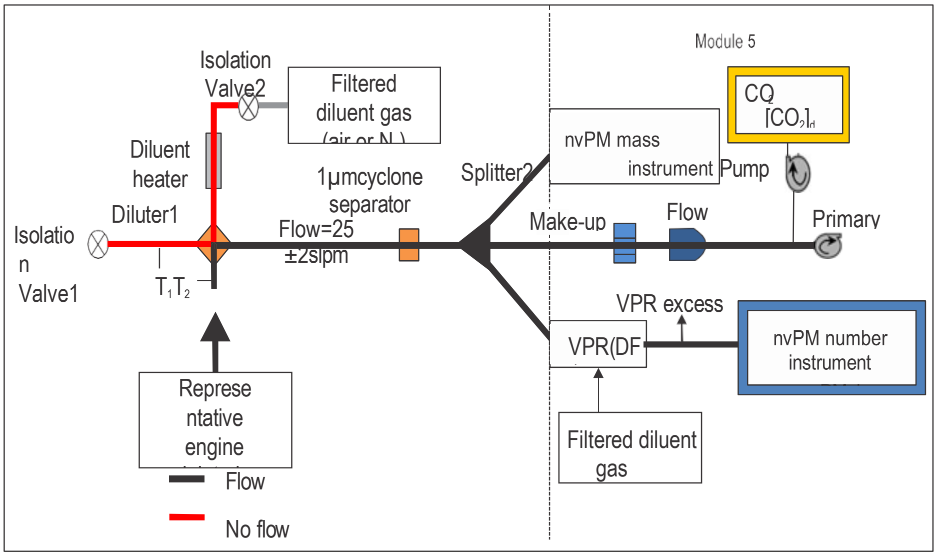
c) Ensure flow rates in each Splitter 2flow path are equal to those to be used during engine testing.

d) When the measure dnvPM mass and number concentrations are stable, record data for a minimum of three minutes.

Note.—The flow schematic for the Method 1 ambient nvPM measurement in shown in Figure S 7-6.

This setup shall only be used if the vent exhaust location is representative of engine inlet air.

Figure S 7-6. Flow schematic for ambient particle air measurement



Method 2: An additional nvPM measurement system:

a) The ambient nvPM sampling system shall conform to Module 3 and Module 4 sampling system requirements in 7.3 of this Schedule.

b) The nvPM mi, VPR and nvPM ni shall comply with 8 and 9 of this Schedule.

c) The ambient nvPM sampling system in let shall be located within 50 m of the engine in take plane.

10.5.2.1.1 When sampling with an additional nvPM sampling and measurement system, the following procedure shall be used:

a) Ensure flow rates in each Splitter 2 path are equal to those to be used during engine testing.

b) When the measured nvPM mass and number concentrations are stable, record data for a minimum of three minutes.

10.5.3 Ambient particle measurement requirement

10.5.3.1 The three minutes averaged nvPM mass concentration ($nvPM_{mass}$ STP) and nvPM number concentration corrected for DF_2(DF_2× $nvPM_{num}$_STP) shall be reported.

Note.—The ambient level of nvPM mass concentration may be below the LOD of then vPMmi.

10.5.3.2 *The average nvPMni concentration value corrected for* DF_2*should be greater than 10 times the value measured for the cleanliness scheck. If this check fails, the system operation should be verified (valve positions, flow rates, pressures and temperatures) and the measurement should be repeated.*

Note.—If there are significant levels of emissions species present at engine in let in the background air due to various other sources, there may be an impact on the levels of engine exhaust emission species. In this situation, accounting for ambient nvPM in reported nvPM emissions levels may be warranted.

10.5.3.2.1 *If a procedure accounting for the background air quality on the reported emissions levels is warranted, then this procedure should be used, subject to the approval of the certificating authority.*

10.6VPR dilution factor calibration check

10.6.1 The VPR dilution factor (DF_2) anticipated during the engine test shall be checked using the following setup:

a) a CO_2 gas analyser compliant with 5.3 to Third Schedule;

b) a certified, high concentration CO_2 gas with purity 2.0 (greater than 99.0 percent) CO_2 or a blended CO_2 gas with either nitrogen or zero air as acceptable diluents;

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

c) Connect the CO_2 gas analyser to the outlet of the VPR with a tee fitting to prevent over pressurisation of CO_2 sample;

d) connect the high concentration CO_2 gas to the inlet of the VPR using a tee fitting and flow control valve to provide a VPR inlet pressure as on engine test;

e) allow the sample at the inlet of the VPR to have the same flow rate and pressure as used during an engine test.

Note.—The flow schematic for the VPR dilution factor check is shown in Figure S 7-7.

10.6.2 The VPR dilution factor (DF_2) shall be checked using the following procedure:

a) Warm up the VPR and ensure operating temperatures are reached.

b) Check that the VPR in let is pulling a sample flow.

c) Warm-up the CO_2 analyser accordingly and prepare for data logging.

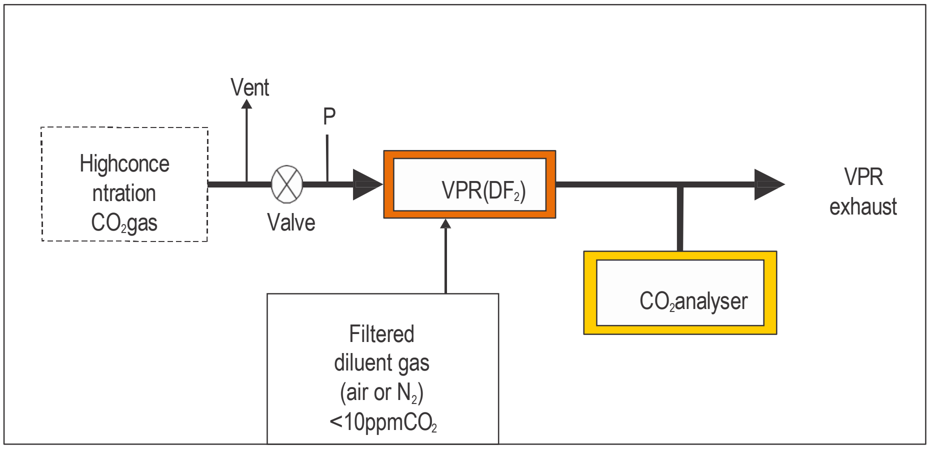
d) Apply appropriate zero calibration gas to the CO_2 analyser and make any necessary instrument adjustments.

e) Apply appropriate calibration gas at a nominal 90 percent FS concentration to the CO_2 analyser to span the ranges to be used, and adjust and record gain settings accordingly.

f) Ensure the sample flow to the CO_2 analyser is adequate (a pump may be required up stream of the CO_2 analyser).

g) Flow the high concentration CO_2 gas to the inlet of the VPR, ensuring that there is excess flow at the vent up stream of the VPR inlet.

h) Set the VPR to a dilution factor setting.
i) Adjust the flow control valve at the VPR in let, creating a pressure drop to simulate the sub-ambient sample pressure at the VPR inlet during an engine test nvPMni measurement operation.



FigureS7-7.VPR dilution factor check setup

j) Sample the VPR exhaust flow with the CO_2 gas analyser.

k) When the CO_2 gas analyser readings stable, record a minimum of seven CO_2 concentration data points within a three-minute period and calculate the mean.

l) Calculate the mean DF_2 value as a ratio of the mean of CO_2 measurements and the certified CO_2 gas concentration.

m) Repeat 10.6.2h) to 10.6.2l) to above for each VPR dilution setting to be used during engine testing.

10.6.3 Calculated DF_2mean values shall be compared against the results of a competent laboratory calibration. If the difference is:

b) Less than or equal to ±10 percent, DF_2 values from a competent laboratory calibration shall be used.

c) Greater than±10percent, the VPRDF_2 values shall be determined from calibration by a competent laboratory.

Note.—Guidance material on the use of an equivalent procedure is provided in the Environmental Technical Manual *(Doc9501), Volume II—*Procedures for the Emissions Certification of Aircraft Engines.

EIGHTH SCHEDULE

(Made under regulation 35(2))

PROCEDURES FOR ESTIMATING NON-VOLATILE PARTICULATE MATTER SYSTEM LOSS CORRECTIONS

Note 1.— The procedures specified in this Schedule are concerned with the determination of non-volatile particulate matter (nvPM) sampling and measurement system loss correction factors, excluding the Collection Part thermophoretic losses which are included in Schedule 7 data reporting.

Note 2.— Implementation of the nvPM sampling and measurement system requires a long sample line of up to 35 m and includes several sampling and measurement system components, which can result in significant particle loss on the order of 50 per cent for nvPM mass and 90 per cent for nvPM number. The particle losses are size dependent and hence are dependent on engine operating condition, combustor technology and possibly other factors. The procedures specified in this Schedule allow for an estimation of the particle losses.

Note 3.— The method in this Schedule uses data and measurements as specified in Schedule 7 and attachments to Schedule 7. Symbols and definitions not defined in this Schedule are defined in Schedule 7 and attachments.

1. GENERAL

1.1 Within the nvPM sampling and measurement system, particles are lost to the sampling system walls by deposition mechanisms. These losses are both size dependent and independent. The size independent Collection Part thermophoretic loss is specified in Schedule 7, 6.2.1.

1.2 The overall nvPM sampling and measurement system particle loss excluding the Collection Part thermophoretic loss is referred to as system loss.

1.3 The nvPM size distribution needs to be taken into consideration because the particle loss mechanisms are particle size dependent. These particle size dependent losses are quantified in terms of the fraction of particles of a given size that penetrate through the sampling and measurement system.

2. DEFINITIONS, ACRONYMS, AND SYMBOLS

2.1 Definitions

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

Aerodynamic diameter of a particle. The diameter of an equivalent sphere of unit density (1 g/cm^3) with the same settling velocity as the particle in question, also referred to as "aerodynamic diameter".

Competent laboratory. A testing and calibration laboratory which establishes, implements and maintains a quality system appropriate to the scope of its activities, in compliance with the International Organization for Standardization standard ISO/IEC 17025:2005, as amended from time to time, or equivalent standard and for which the programme for calibration of equipment is designed and operated so as to ensure that calibrations and measurements made by the laboratory are traceable to the International System of Units (SI). Formal accreditation of the laboratory to ISO/IEC 17025:2005 is not required.

Cyclone separator. Separation of particles larger than a prescribed aerodynamic diameter via rotational and gravitational means. The specified cut-point aerodynamic diameter is associated with the percent of particles that penetrate through the cyclone separator.

Electrical mobility diameter of a particle. The diameter of a sphere that moves with exactly the same mobility in an electrical field as the particle in question.

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.

Particle loss. The loss of particles during transport through a sampling or measurement system component or due to instrument performance. Sampling and measurement system loss is due to various deposition mechanisms, some of which are particle size dependent.

Particle mass concentration. The mass of particles per unit volume of sample.

Particle mass emission index. The mass of particles emitted per unit of fuel mass used.

Particle number concentration. The number of particles per unit volume of sample.

Particle number emission index. The number of particles emitted per unit of fuel mass used.

Particle size distribution. A list of values or a mathematical function that represents particle number concentration according to size.

Penetration fraction. The ratio of particle concentration downstream and upstream of a sampling system element.

2.2 Acronyms

CPC	Condensation particle counter
EENEP	Engine exhaust nozzle exit plane
nvPMmi	Non-volatile particulate matter mass instrument
nvPMni	Non-volatile particulate matter number instrument
nvPM	Non-volatile particulate matter (*see* definition)
slpm	Standard litres per minute (litres per minute at STP)
STP	Instrument condition at standard temperature 0°C and pressure 101.325 kPa
VPR	Volatile particle remover

2.3 Symbols

C_c	$1 + \frac{2\lambda}{D_m} \times (1.165 + 0.483 \times e^{-\frac{0.997 D_m}{2\lambda}})$, dimensionless Cunningham slip correction factor
D	$\frac{k_B \times (273.15 + T_i) \times C_c}{3 \times \pi \times \mu \times D_m \times 10^{-4}} \times 10^7$, the particle diffusion coefficient, cm^2/s
DF_1	First stage dilution factor
DF_2	Second stage (VPR) dilution factor as per calibration
D_m	nvPM electrical mobility diameter, nm
D_{mg}	Geometric mean diameter of nvPM electrical mobility size distribution, nm
D_{xy}, at z nm	Aerodynamic diameter at which *xy* per cent (detection efficiency) of *z* size particles are detected
EI_{mass}	nvPM mass emissions index corrected for Collection Part thermophoretic losses and for fuel composition, in milligrams/kg fuel
EI_{num}	nvPM number emissions index corrected for Collection Part thermophoretic losses and for fuel composition, in number/kg fuel
$f_{lgn}(D_m)$	Lognormal distribution function with parameters of geometric standard deviation, σ_g, and geometric mean diameter, D_{mg}

$f_N(D_m)$	The EENEP particle number lognormal distribution function
ID_{ti}	Inner diameter of the ith segment of the sampling line, mm
k_B	1.3806×10^{-16}, Boltzmann constant, $(g \cdot cm^2)/(s^2 \cdot K)$
k_{SL_mass}	EI_{mass} correction factor for system loss without Collection Part thermophoretic loss correction
k_{SL_num}	EI_{num} correction factor for system loss without Collection Part thermophoretic loss correction
k_{thermo}	Collection Part thermophoretic loss correction factor, specified in Appendix 7, 6.2.1
$nvPM_{num\_EP}$	Estimated engine exhaust nozzle exit plane nvPM number concentration not corrected for Collection Part thermophoretic losses
$nvPM_{mass\_EP10}$	Estimated engine nozzle exit plane nvPM mass concentration for particles with diameters between 10 nm and 1000 nm, micrograms/m^3
$nvPM_{num\_EP10}$	Estimated engine nozzle exit plane nvPM number concentration for particles with diameters between 10 nm and 1000 nm, number/cm^3
$nvPM_{mass\_STP}$	Diluted nvPM mass concentration at instrument STP condition, micrograms/m^3
$nvPM_{num\_STP}$	Diluted nvPM number concentration at instrument STP condition, number/cm^3

P_i	Carrier gas pressure in the i^{th} segment of the sampling line, kPa
Q_i	Carrier gas flow in the i^{th} segment of the sampling line, slpm
Re	$\frac{2 \times \rho_{gas} \times Q_i}{3 \times \pi \times \mu \times ID_{ti}}$, the Carrier gas Reynolds number
$R_{MN}(D_m)$	Calculated ratio of the estimated nvPM mass concentration to the estimated nvPM number concentration
T_i	Carrier gas temperature in the i^{th} segment of the sampling line, °C
δ	Sum of the square of relative differences between measured and calculated dilution corrected nvPM mass and number concentrations
$\eta_{mass}(D_m)$	Overall sampling and measurement system penetration fraction for the nvPMmi without Collection Part thermophoretic losses at electrical mobility particle size D_m
$\eta_{num}(D_m)$	Overall sampling and measurement system penetration fraction for the nvPMni without Collection Part thermophoretic losses at electrical mobility particle size D_m
$\eta i(D_m)$	Penetration fraction for the i^{th} component of the sampling and measurement system at electrical mobility particle size D_m
$\eta bi(D_m)$	Penetration fraction for the sampling line bend for i^{th} component of the sampling and measurement system at electrical mobility particle size D_m
λ	$67.3 \times \left(\frac{273.15+T_i}{296.15}\right)^2 \times \left(\frac{101.325}{P_i}\right) \times \left(\frac{406.55}{T_i+383.55}\right)$, the carrier gas mean free path, nm
μ	Carrier gas viscosity, $(g/cm \cdot s)$
ρ	Assumed nvPM effective density, g/cm^3
ρ_{gas}	$\frac{29 \times P_i}{8314 \times (273.15 + T_i)}$, Carrier gas density, g/cm^3
σ_g	Assumed geometric standard deviation of lognormal distribution

3. DATA REQUIRED

3.1 nvPM emissions

In order to calculate the system loss correction factors, the following concentrations as specified in Schedule 7 are needed:

a) nvPM mass concentration: $nvPM_{mass\_STP}$;

b) nvPM number concentration: $nvPM_{num\_STP}$.

3.2 Other information

Additional information listed in 3.2 of this Schedule is required to perform the calculation procedure.

4. nvPM SYSTEM LOSS CORRECTION METHODOLOGY AND CALCULATION PROCEDURE

4.1 Overview

Note.— An overview diagram of the methodology for estimating the system loss correction factors is shown in Figure S 8-1.

4.1.1 The system loss correction factors shall be estimated based on the following assumptions: EENEP nvPM is represented by a constant value of nvPM effective density, a lognormal distribution, a fixed value of geometric standard deviation, no coagulation, limiting the nvPM mass and number concentrations as described in the calculation method limitations section, and a minimum summation particle size cut-off of 10 nm.

4.1.1.1 The system loss correction methodology shall use a particle effective density of 1 g/cm^3.

4.1.1.2 A mono-modal lognormal distribution with a geometric standard deviation of 1.8 shall be used in the system loss correction methodology.

4.1.1.3 The system loss correction methodology does not consider reduction in nvPM number concentration due to coagulation.

4.1.1.4 If the EENEP nvPM number concentration calculated using:

$$k_{SL\_num} \times k_{thermo} \times DF_1 \times DF_2 \times nvPM_{num\_STP}$$

is greater than 10^8 particles/cm^3, coagulation may occur and shall be reported to the certificating authority.

Note 1.— The system loss correction methodology does not consider penetration drift. This is not considered significant for Schedule 7-compliant nvPM measurement systems.

Note 2.— An illustration of the iterative calculation procedure is shown in Figure S 8-2.

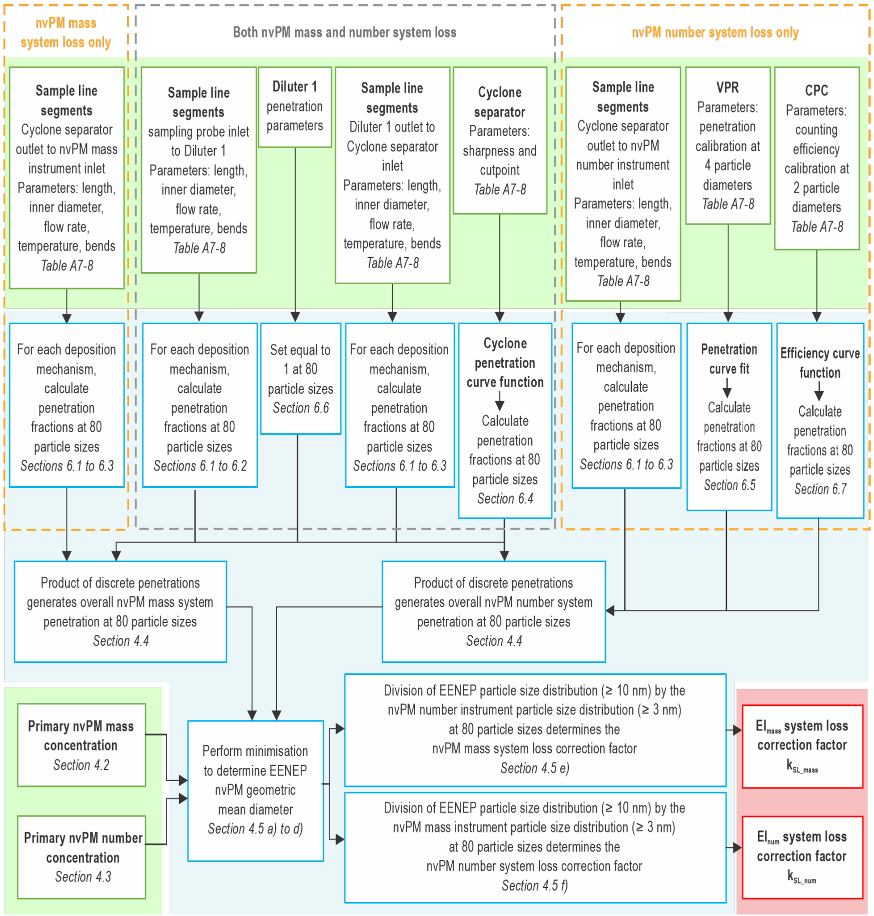


Figure S8-1. Flow block diagram of the nvPM system loss correction methodology. The green blocks show model input parameters, the blue blocks shows model calculations and the red outline blocks shows calculation output system loss correction factors.

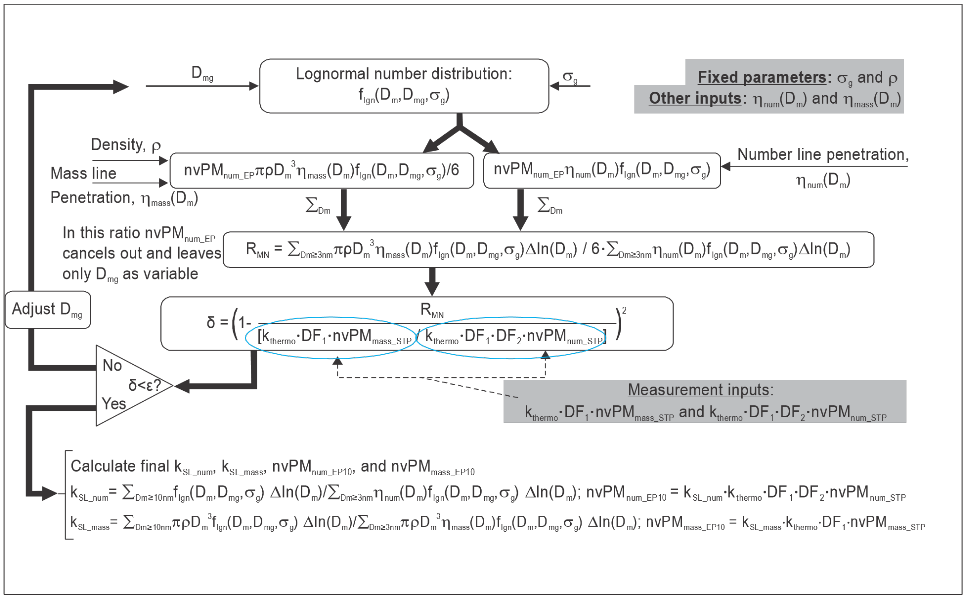


Figure S8-2. Iterative calculation procedure diagram for determination of system loss correction factors

4.2 Primary nvPM mass concentration

The primary nvPM mass concentration ($nvPM_{mass}$) is calculated using the following equation as defined in Schedule 7:

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

4.3 Primary nvPM number concentration

The primary nvPM number concentration ($nvPM_{num}$) represents the number of particles per unit volume of engine exhaust sample corrected for the first stage dilution factor (DF_1) and second stage dilution factor (DF_2) and the Collection Part thermophoretic particle loss. It is calculated using the following equation:

$$nvPM_{num} = k_{thermo} \times DF_1 \times DF_2 \times nvPM_{num\_STP}$$

4.4 nvPM penetration functions

4.4.1 The sampling system penetration fraction is a product of the individual penetration and counting efficiency functions. Table A8-1 provides the required nvPM penetration and counting efficiency functions and shall be calculated using the procedures described in Section 6.

4.4.2 The sampling system penetration for nvPMmi for a particle of diameter D_m is:

$$\eta_{mass}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \ldots \times \eta_{dil} \times \eta_{cyc}$$

4.4.3 The sampling system penetration for nvPMni for a particle of diameter D_m is:

$$\eta_{num}(D_m) = \eta_1 \times \eta_{b1} \times \eta_2 \times \eta_{b2} \times \eta_3 \times \eta_{b3} \times \ldots \times \eta_{dil} \times \eta_{cyc} \times \eta_{VPR} \times \eta_{CPC}$$

4.4.4 The size independent nvPM mass and number sampling system thermophoretic penetration is:

$$\eta_{thermo} = \eta_{th1} \times \eta_{th2} \times \eta_{th3} \times \ldots$$

Note.—
The Collection Part thermophoretic loss, k_{thermo}, is specified in Schedule 7, 6.2.1 and is not included in this calculation.

Table A8-1. Required nvPM Sampling and Measurement system component penetration fractions

Symbol	*Description of nvPM Sampling and Measurement system particle transport functions*
$\eta_i(D_m)$	Diffusional penetration fraction of ith segment of sampling system
$\eta_{bi}(\Theta_i)$	Penetration fraction due to bends in ith segment of sampling system
η_{thi}	Penetration fraction due to thermophoresis in ith segment of sampling system
$\eta dil(D_m)$	Diluter 1 penetration fraction
$\eta cyc(D_m)$	Cyclone separator penetration fraction
$\eta VPR(D_m)$	VPR penetration fraction
$\eta CPC(D_m)$	CPC counting efficiency

4.5 Calculation of system loss correction factors

System loss correction factors for nvPM mass (k_{SL_mass}) and nvPM number (k_{SL_num}) shall be calculated using the iterative procedure:

a) Estimate an initial value of the geometric mean diameter using the equation:

$$D_{mg} = \sqrt[3]{\frac{6 \times DF_1 \times nvPM_{mass\_STP}}{\pi \times \rho \times DF_1 \times DF_2 \times nvPM_{num\_STP}}} \times 10^3$$

Note.— The arithmetic mean diameter calculated by the equation above provides the initial value of the geometric mean diameter, D_{mg}, for the iterative procedure. Using the units defined for the inputs, the calculated particle diameter will be in nm.

b) Using the value of D_{mg} from step a), calculate the estimated nvPM mass to nvPM number ratio, $R_{MN}(D_{mg})$, using the equation:

$$R_{MN}(D_{mg}) = \frac{\sum_{D_m>3nm}^{1000nm} \eta_{mass}(D_m) \times \frac{\pi\rho D_m^3}{6} \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}{\sum_{D_m>3nm}^{1000nm} \eta_{num}(D_m) \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}$$

where the exponential functions come from the lognormal distribution function,

$$f_{lgn}(D_m) = \frac{1}{\sqrt{2\pi}\,\ln(\sigma_g)} \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2}$$

$\Delta\ln(D_m) = \frac{1}{n} \times \frac{1}{\log_{10}(e)}$, is the width of a size bin in base natural logarithm; *e* is the Euler's number, and n is the number of particle size bins per decade.

c) Determine the squared relative difference, δ between the measured and estimated nvPM mass to number ratio using:

$$\delta = \left\{1 - \frac{R_{MN}(D_{mg}) \times 10^{-9}}{\left[(k_{thermo} \times DF_1 \times nvPM_{mass\_STP})/(k_{thermo} \times DF_1 \times DF_2 \times nvPM_{num\_STP})\right]}\right\}^2$$

d) Repeat steps b) and c) by varying D_{mg} until reduces to less than 1×10^{-9}. The D_{mg} associated with this minimized value of shall be used to calculate the system loss correction factors.

e) Calculate the nvPM mass system loss correction factor using the equation:

$$k_{SL\_mass} = \frac{\sum_{D_m>10nm}^{1000nm} D_m^3 \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}{\sum_{D_m>3nm}^{1000nm} \eta_{mass}(D_m) \times D_m^3 \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}$$

Multiplying EI_{mass} by k_{SL_mass} yields nvPM emission index corrected for system loss.

f) Calculate the nvPM number system loss correction factor using the equation:

$$k_{SL\_num} = \frac{\sum_{D_m>10nm}^{1000nm} e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}{\sum_{D_m>3nm}^{1000nm} \eta_{num}(D_m) \times e^{-\frac{1}{2}\left\{\frac{\ln(D_m)-\ln(D_{mg})}{\ln(\sigma_g)}\right\}^2} \times \Delta\ln(D_m)}$$

Multiplying EI_{num} by k_{SL_num} yields nvPM emission index corrected for system loss.

g) A minimum of 80 discrete sizes in the particle size range from 3 to 1 000 nm or a minimum number of bins that will produce equivalent results as agreed by the certificating authority shall be used in this calculation.

Note 1.— For 80 discrete sizes, the number of size bins per decade, n, is 32 (see the definition for $\Delta\ln(D_m)$ above).

Note 2.— The summations to compute the system loss correction factors start at 10 nm in the numerator and 3 nm in the denominator.

Note 3.— The calculation procedure can be implemented using commercially available software programmes.

5. REPORTING AND LIMITATIONS

Note 1.— The system loss correction factor calculation method described in Schedule 8, section 4 has been shown to give acceptable results over a wide range of nvPM mass and number concentrations observed in aircraft turbine engine nvPM emissions. There are, however, ranges of nvPM mass and number concentrations that have been identified where the inputs to the analysis may lack the fidelity for the calculation method to yield quality results.

Note 2.— Any variations from the assumptions used by the calculation method as required in section 4.1.1 of this Schedule can lead to variation in the system loss correction factors. Similarly, variations in the data supplied to the calculation method will result in variation in system loss correction factors. The variation in the data could be due to particle size distributions, sampling system, or instruments. In addition, sampling and measurement system artifacts, such as possible shedding from the walls when concentrations are low, may provide invalid system loss correction factor. Method limitations are due to variation within the input data rather than the calculation method.

5.1 Applicable mass concentration ranges

Note.— When raw nvPM mass concentrations at the nvPMmi (not dilution corrected) are below 3 micrograms/m^3, use of this method to estimate system loss correction factors is cautioned because of the possible uncertainties with the nvPM mass concentration determination at such low values.

5.1.1 If the $nvPM_{mass\_STP}$ is below 3 micrograms/m^3, the applicant shall confirm that the predicted EENEP D_{mg} falls within the applicable range in 5.3.

5.1.2 For cases where calculations from this Schedule or other equivalent methods do not provide reasonable values as noted in 5.3 (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7 nm or greater than 100 nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes should be used, subject to the approval of the certificating authority.

Note.— There are no currently known limitations regarding high nvPM mass concentrations as long as it is verified that the nvPM mass concentration readings are within the range of the nvPMmi used.

5.2 Applicable number concentration ranges

5.2.1 If the nvPM number concentration measured at the nvPMni, corrected for dilution (both DF_1 and DF_2) and Collection Part thermophoretic loss is found to be less than or equal to the measured ambient number concentration[1], the applicant shall confirm that the predicted EENEP D_{mg} falls within the applicable range in 5.3.

5.2.2 For cases where calculations from this Schedule or other equivalent methods do not provide reasonable values as noted in 5.3 (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7 nm or greater than 100 nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes should be used, subject to the approval of the certificating authority.

Note.— For the nvPMni, there are no currently known limitations on low nvPM number concentrations. CPC manufacturers report the CPC LOD to be about 1 particle/cm^3*. High number concentration measurements are limited by the requirement for the CPC to stay in the single count mode. If the EENEP nvPM number concentrations are above* 10^8 *particles/cm*^{3}*, particle coagulation may be occurring. Coagulation is not considered in the system loss calculation method.*

5.3 Applicable predicted geometric mean diameters

Note.— The geometric mean diameter of nvPM at EENEP from aircraft gas turbines is anticipated to be in the range of 7 to 100 nm.

5.3.1 If the system loss calculation method predicts an EENEP geometric mean diameter that is smaller than 7 nm or larger than 100 nm, and/or if the system loss calculation method predicts an EENEP geometric mean diameter whereby the convergence criterion is not met (δ is greater than 1×10^{-9}), results for k_{SL_mass} and k_{SL_num} shall be reviewed with the certificating authority.

5.3.2 For cases where calculations from this Schedule or other equivalent methods do not provide reasonable values (e.g. when the system loss methodology calculates EENEP geometric mean diameters less than 7 nm or greater than 100 nm), or when the system loss methodology does not converge, alternate means of estimating system loss correction factors for the LTO operating modes should be used, subject to the approval of the certificating authority.

Note.— Calculated EENEP geometric mean diameters < 20 nm will result in underestimation of system loss factors due to the minimum summation particle size cut-off. The underestimation can be significant for k_{SL_num} *when EENEP* $D_{mg} \leq 10$ *nm.*

6. PROCEDURE TO DETERMINE PENETRATION FRACTIONS OF INDIVIDUAL COMPONENTS OF THE nvPM SAMPLING AND MEASUREMENT SYSTEM

To estimate the nvPM transport efficiency for particles over a range of sizes, penetration fractions shall be calculated for each component of the nvPM sampling and measurement system, for a minimum of 80 discrete particle sizes or a minimum number of discrete particle sizes that will produce an equivalent result, as agreed by the certificating authority in the range from 3 to 1 000 nm.

Note 1.— Where continuous functions are calculated to estimate penetration fractions, these functions are not to go below zero.

Note 2.— The nvPM measurement and sampling system parameters required to perform the penetration fraction calculations are contained in 3.2 of the Seventh Schedule.

6.1 Segment diffusional penetration fractions

Penetration values, $\eta_i(D_m)$, for diffusional losses in sampling system segments at electrical mobility particle size D_m are calculated with the expression:

$$\eta_i(D_m) = e^{\frac{-\pi \times ID_{ti} \times L_i \times V_{d,diff}}{Q_i}}$$

where:

L_i	length of the ith segment of the sampling line, m
$V_{d,diff}$	$0.0118 \times Re^{\frac{7}{8}} \times Sc^{\frac{1}{3}} \times D/ID_{ti}$, the deposition speed, cm/s
Sc	$\frac{\mu}{\rho_{gas}D} \times 10^3$, the carrier gas Schmidt number
ID_{ti}	inner diameter of the i^{th} segment of the sampling line, mm
Q_i	the carrier gas flow in the i^{th} segment of the sampling line, slpm

6.2 Segment bend penetration fractions

The bend penetration fractions are distinguished for turbulent flow, Re is greater than 5 000, and for laminar flow, Re is less than or equal to 5 000 where Re is the Reynolds number. For laminar flow (including the transition regime) the penetration due to bends in the sample transport lines for each segment at electrical mobility particle size D_m is calculated as:

$$\eta_{bi}(D_m) = 1 - 0.01745 \times Stk \times \theta_{bi}$$

For turbulent flow, the penetration due to bends in the sample transport lines shall be calculated as

$$\eta_{bi}(D_m) = e^{-0.04927 \times Stk \times \theta_{bi}}$$

where

$Stk = \frac{Q_i \times C_c \times \rho \times D_m^2 \times 10^{-3}}{27 \times \pi \times \mu \times ID_{ti}^3}$, the dimensionless Stokes number

θ_{bi}	total angle of bends in the of the i^{th} segment of the sampling line, degrees

6.3 Segment thermophoretic losses

Thermal gradients occurring because sample line wall temperatures are lower than gas temperatures cause additional particle deposition, thermophoretic losses, onto the sampling line surfaces. The thermophoretic losses, except for those in the Collection Part, are calculated using:

$$\eta_{thi} = \left[\frac{T_{linei} + 273.15}{T_{gasi} + 273.15}\right]^{Pr \times K_{th}} \times \left[1 + \left(\frac{T_{gasi} + 273.15}{T_{linei} + 273.15} - 1\right) \times e^{-\frac{\pi \times ID_i \times h_{gas} \times L_i}{\rho_{gas} \times Q_i \times C_p}}\right]^{Pr \times K_{th}}$$

Where:

T_{gasi}	sample gas temperature in °C
T_{linei}	line wall temperature in °C

h_{gas}	carrier gas convective heat transfer coefficient ($W/(m^2\ K)$)
C_p	constant pressure carrier gas specific heat ($J/(kg\ K)$)
Pr	Prandtl number
K_{th}	$\frac{2\times C_s\times C_c}{1+3\times C_m\times K_n}\left[2+\frac{1}{\left(k_{gas}/k_p\right)+C_t\times K_n}\right]^{-1}$, the thermophoretic coefficient
C_s	1.17, slip coefficient
C_m	1.14, soot momentum
C_t	2.18, thermal coefficient
k_{gas}	thermal conductivity of the carrier gas ($Wm^{-1}K^{-1}$)
K_n	$2\lambda/D_m$, Knudsen number
k_p	0.2 $Wm^{-1}K^{-1}$, particle thermal conductivity

Note.— The Collection Part and VPR thermophoretic losses are taken into account as specified in Schedule 7, 6.2.1 and 6.5 of this attachment. A system compliant with specifications in Schedule 7 uses instruments and segments that currently do not need to be corrected for thermophoretic losses and therefore $\square_{thi}$ *will effectively be equal to 1.0.*

6.4 Cyclone separator penetration function

The penetration function of the cyclone separator shall be estimated using the following expression:

$$\eta_{cyc}(D_m) = 1 - \int_{x>0}^{D_m} \frac{e^{-\frac{(\ln x-\mu_{cyc})^2}{2\sigma_{cyc}^2}}}{x\sigma_{cyc}\sqrt{2\pi}}\,dx$$

where

μ_{cyc}	$\ln(D_{50})$; and
σ_{cyc}	$\ln(D_{16}/D_{84})^{0.5}$

Note 1.— Modern computer spreadsheet applications have the cumulative lognormal distribution built into the function library that could be used to generate the penetration function of the cyclone separator.

Note 2.— For most gas turbine engine applications D_m *will be less than 300 nm. In such cases the cyclone separator penetration function will be effectively equal to 1.0.*

6.5 VPR penetration function

Note.— A smooth function provided by the calibration laboratory that has goodness of fit results (R^2 greater than 0.95) for the four VPR calibration penetration points could be used in place of the function determined from the calculation procedure outlined below.

Particle losses in the VPR are due to both diffusion and thermophoresis. The thermophoretic factor, η_{VPRth}, is a constant. The diffusion factor, η_{VPRdi}, is determined from standard particle losses due to diffusion in a laminar flow. The total VPR penetration function shall be estimated using the expression:

$$\eta_{VPR} = \eta_{VPRth} \times \begin{cases} 1 - 5.5 \times \psi^{\frac{2}{3}} + 3.77 \times \psi & \psi < 0.007 \\ 0.819 \times e^{-11.5\psi} + 0.0975 \times e^{-70.1\psi} + 0.0325 \times e^{-179\psi} & \psi > 0.007 \end{cases}$$

where

$\Psi \quad \frac{D \times L_{VPR} \times 100}{Q_{VPR}}$, deposition parameter

L_{VPR} effective length of the VPR, m

Q_{VPR} carrier gas flow in the VPR, slpm

T_{VPR} VPR temperature, °C

η_{VPRth} VPR thermophoretic loss

The VPR penetration function (η_{VPR}) shall be fitted to the four measured penetration points by varying the VPR effective length (L_{VPR}) and the thermophoretic loss factor (η_{VPRth}). The fit shall be calculated by minimizing δ_{VPR}, the relative sum of squares difference between the measured VPR penetration, $\eta_{VPRmeas}$, and the calculated penetration function.

$$\delta_{VPR} = \sqrt{\sum_{D_m} \left(\frac{\eta_{VPRmeas}(D_m) - \eta_{VPR}(D_m)}{\eta_{VPRmeas}(D_m)} \right)^2}$$

A value of δ_{VPR} less than 0.08 has been shown to provide a good fit to the measured penetrations.

6.6 Diluter 1 penetration function

A constant Diluter 1 penetration, $\eta_{dil}(D_m) = 1$ shall be used for all particle sizes.

6.7 CPC counting efficiency

A continuous function for the CPC counting efficiency shall be determined using the two CPC counting efficiencies specified with a two-parameter sigmoid function using the expression:

$$\eta_{CPC} = 1 - e^{-\ln(2)\times\left[\frac{D_m - D_0}{D_{50} - D_0}\right]}$$

where

$$D_0 = \frac{\alpha_{10}D_{15} - \alpha_{15}D_{10}}{\alpha_{10} - \alpha_{15}}$$

$$D_{50} = \frac{(\alpha_{15}+1)D_{10} - (\alpha_{10}+1)D_{15}}{\alpha_{15} - \alpha_{10}}$$

$$\alpha_i = \frac{\ln(1 - \eta_{CPC,i})}{\ln(2)}, i = 10 \text{ nm or } 15 \text{ nm}$$

D_{10} = 10 nm;
D_{15} = 15 nm;

$\eta_{CPC,10}$, the counting efficiency at 10 nm; and

$\eta_{CPC,15}$, the counting efficiency at 15 nm.

Dodoma,
22nd December, 2025

MAKAME M. MBARAWA,
Minister for Transport