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GOVERNMENT OF INDIA

OFFICE OF DIRECTOR GENERAL OF CIVIL AVIATION

TECHNICAL CENTRE, OPP SAFDARJANG AIRPORT, NEW DELHI

CIVIL AVIATION REQUIREMENTS
SECTION 6 – DESIGN STANDARDS AND TYPE CERTIFICATION
SERIES 'C' PART I

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F. No. 5-8/2009-R&D

Subject: CERTIFICATION OF AIRCRAFT – ENGINE EMISSION

1. Purpose

Rule 49 of the Aircraft Rules, 1937 stipulates requirements for a Type Certificate (TC) in respect of aircraft, aircraft engine and propeller designed and manufactured in India, as a pre-requisite to the issue/renewal of a Certificate of Airworthiness (C of A). The Type Certificate Data Sheet (TCDS), which forms the part of the TC, contains the certification basis in respect of that aircraft including emission requirements as mentioned in CAR 21.16 (A). This Civil Aviation Requirement (CAR) is issued under the provisions of Rule 133A of the Aircraft Rules, 1937 for information, guidance and compliance of all concerned. The requirements contained in this CAR are in compliance to the requirements as mentioned in ICAO Annex 16, Vol. II on aircraft engine emissions.

2. Applicability

The provision of this CAR shall apply to all turbine engine powered aircraft intended for operation on domestic or international routes at subsonic speed only, which are manufactured after 1st June, 2010.

3. Requirements

3.1 Aircraft designed and developed in India shall have a valid engine emission certificate for issuance of Certificate of Airworthiness (C of A) for which type certificate has been issued by DGCA.

3.2 Aircraft imported in India either by type acceptance or by validation shall meet the design standards of CS-E/FAR-33 for engine type certificate and FAR-34 for emission certificate in accordance with the provisions of CAR 21.16 (A).

4. Definitions

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.
Bypass Ratio	The ratio of the air mass flow through the bypass ducts of a gas turbine engine to the air mass flow through the combustion chambers calculated at maximum thrust when the engine is stationary in an international standard atmosphere at sea level.
Calibration Gas	A high accuracy reference gas to be used for alignment, adjustment and periodic checks of instruments.
Exhaust Nozzle	In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.
Fuel Venting Emissions	Means raw fuel, exclusive of hydrocarbons in the exhaust emissions, discharged from aircraft gas turbine engines during all normal ground and flight operations.
Oxides of Nitrogen	The sum of the amounts of the nitric oxide and nitrogen dioxide contained in a gas sample calculated as if the nitric oxide were in the form of nitrogen dioxide.
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 carbon (ppmC)	The mole fraction of hydrocarbon multiplied by 106 measured 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 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.
Rated Thrust	For engine emissions purposes, the maximum take-off thrust approved by the DGCA for use under normal operating conditions at ISA sea level static conditions, and without the use of water injection. Thrust is expressed in kilo newtons.
Reference Engine	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.
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.
Reference Pressure Ratio	The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating in ISA sea level static conditions.
Smoke	The carbonaceous materials in exhaust emissions which obscure the transmission of light.
Smoke Number	The dimensionless term quantifying smoke emissions.
SN	Smoke Number; Dimension less term quantifying smoke emission level based upon the staining of a filter by the reference mass of exhaust gas sample, and rated on a scale of 0 to 100.
SN'	Smoke Number obtained from an individual

smoke sample, not necessarily of the reference size.

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

W Mass of individual exhaust gas smoke sample, in kilograms, calculated from the measurements of sample volume, pressure and temperature.

5. Prevention of Intentional Fuel Venting

5.1 Aircraft engine shall be designed and constructed so as to prevent the intentional discharge of liquid fuel into the atmosphere from the fuel nozzle manifolds as a result of engine shutdown after flight or ground operations.

5.2 Certification related to prevention of intentional fuel venting shall be granted by DGCA on the basis of satisfactory evidence that either the aircraft or the aircraft engine complies with requirements of this CAR.

6. Emissions Certification

6.1 Requirements for Aircraft manufactured in India:

The engine emission certificate shall contain at least the following information:

a) Name of Engine Certificating Authority from where the engine is originally imported;
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.

6.2 Emissions certification shall be part of the Type Certificate/Data Sheet granted by DGCA on the basis of compliance with applicable requirements contained in CAR 21. The same shall be satisfactorily demonstrated as per procedure contained in Appendices of this CAR.

6.3 The Indian manufacturer will submit Compliance Report to DGCA showing compliance with the requirements as stipulated in this CAR.

a) Requirements for Imported Aircraft:

6.4 The engine emission certificate shall contain at least the following information:

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.

6.5 Emissions certification shall be part of the documents submitted to DGCA for Type Validation/Acceptance granted by DGCA on the basis of compliance with applicable requirements contained in CAR 21. The same shall be satisfactorily demonstrated as per procedure contained in Appendix of this CAR.

6.6 The company engaged in importing the aircraft must submitted the Compliance Report to DGCA showing compliance with the requirements.

(Dr. Nasim Zaidi)
Director General of Civil Aviation

PROCEDURE FOR SHOWING COMPLIANCE TOWARDS ENGINE EMISSION CERTIFICATION

1. Applicability

The provisions of this guidance material shall apply to all turbojet and turbofan engines intended for operation at subsonic speeds only.

2. Emissions Involved

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

i) Smoke
ii) Gaseous emissions

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

3. Units of Measurement

The smoke emission shall be measured and reported in terms of Smoke Number (SN). The mass (D_p) of the gaseous pollutant i.e. HC, CO, or NO_x emitted during landing and take-off (LTO) cycle shall be measured and reported in grams.

4. Reference Conditions

4.1 Atmospheric Conditions

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

4.2 Test Conditions

The tests shall be made with the engine on its test bed. The engine shall be representative of the certificated configuration (Appendix 1). Any loads other than those necessary for the engine's basic operation shall not be simulated. In case the test conditions differ from the reference atmospheric conditions, Appendix 2 shall be applied for the correction of the results.

4.3 Thrust Settings

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

Operating Mode	**Thrust Setting**
Take-off	100 per cent F_∞
Climb	85 per cent F_∞
Approach	30 per cent F_∞
Taxi/ground idle	7 per cent F_∞

4.4 Reference Emissions Landing and Take-off (LTO) Cycle

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

Phase	**Time in Operating Mode (in Minutes)**
Take-off	0.7
Climb	2.2
Approach	4.0
Taxi/ground idle	26.0

4.5 Fuel Specifications

While carrying out the tests, the fuel shall conform to the specifications given in the Table below. No additives shall be used for the purpose of smoke suppression.

Property	**Allowable range of values**
Density at 15°C (kg/m^3)	780 – 820
Distillation temperature, °C	
i) 10% boiling point	155 – 201
ii) Final boiling point	235 – 285
Net heat of combustion (MJ/kg)	42.86 – 43.50
Aromatics (volume %)	15 – 23
Naphthalene (volume %)	1.0 – 3.5
Smoke point (mm)	20 – 28
Hydrogen (mass %)	13.4 – 14.3
Sulphur (mass %)	less than 0.3%
Kinematic viscosity at –20°C (mm^2/s)	2.5 – 6.5

5. Smoke

5.1 Regulatory Smoke Number

The Smoke Number at any of the four LTO operating mode thrust settings, when determined in accordance with Appendix 2 and converted to a characteristic level in accordance with the procedures contained in Appendix 1, shall not exceed the level determined from the following formula:
Regulatory Smoke Number = $83.6\ (F_\infty)^{-0.274}$ or a value of 50, whichever is lower.

6. Gaseous Emissions

This paragraph shall apply to engines whose rated thrust is greater than 26.7 kN and as further specified for oxides of nitrogen.

6.1 Regulatory Levels

Gaseous emission levels given in Appendix 3 shall not exceed the regulatory levels determined from the following formulae:

Hydrocarbons (HC): $D_p / F_\infty = 19.6$
Carbon monoxide (CO): $D_p / F_\infty = 118$

Oxides of nitrogen (NO_x):

a) For engines with a pressure ratio ≤ 30:

i) $D_p / F_\infty = 16.72 + (1.4080 * \pi_\infty)$ (for Maximum rated thrust > 89.0 kN)

ii) $D_p / F_\infty = 38.5486 + (1.6823 * \pi_\infty) - (0.2453 * F_\infty) - (0.00308 * \pi_\infty * F_\infty)$ (for Maximum rated thrust > 26.7 kN and < 89.0 kN)

b) For engines with a pressure ratio >30 and <82.6:

i) $D_p / F_\infty = -1.04 + (2.0 * \pi_\infty)$ (for Maximum rated thrust > 89.0 kN)

ii) $D_p / F_\infty = 46.1600 + (1.4286 * \pi_\infty) - (0.5303 * F_\infty) + (0.00642 * \pi_\infty * F_\infty)$ (for Maximum rated thrust > 26.7 kN and < 89.0 kN)

c) For engines with a pressure ratio ≥82.6:

$D_p / F_\infty = 32 + (1.6 * \pi_\infty)$

7. General Information

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

a) Engine identification;
b) Rated thrust (kN);
c) Reference pressure ratio;
d) Fuel specification reference;
e) Fuel hydrogen/carbon ratio;
f) Methods of data acquisition;
g) Method of making corrections for ambient conditions; and
h) Method of data analysis.

8. Test Information

The following information on engine tests carried out at different thrust settings as mentioned in paragraph 2.2 (c), shall be provided for certification purposes after correction to the reference ambient conditions, wherever applicable:

a) Fuel flow (kg/s);
b) Emission index (gm/kg) for each gaseous pollutant; and
c) Measured Smoke Number.

9. Derived Information

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

a) Emission rate i.e. (emission index) x (fuel flow), (gm/s) for each gaseous pollutant;
b) Total gross emission of each gaseous pollutant measured over the LTO cycle (gm);
c) Values of D_p / F_∞ for each gaseous pollutant (gm/kN); and
d) Maximum Smoke Number.

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

APPENDIX 1

Compliance Procedure for Gaseous Emissions and Smoke

1. General

The following principles shall be followed:

i. Manufacturer shall have the freedom to select the number of engines to be tested for certification purposes;
ii. DGCA shall consider all the test results obtained from engine certification tests;
iii. Test shall be carried out on minimum three engines, so as to ensure that the engine has been tested at least three times before it is presented for certification;
iv. The arithmetic mean value of all test results obtained shall be considered for certification purposes, in case a given engine is tested several times;
v. The information specified in this CAR shall be provided by the manufacturer;
vi. In case more than one engine are submitted for testing, the engines shall have emissions features similar to the engine type for which certification is sought and one of these engines shall be identified as the reference standard engine. The methods for correcting to this reference standard engine from any other engines tested shall have the prior approval of DGCA.
vii. At least one of the engines shall be substantially configured to the production standard and shall have similar operating and performance characteristics.

2. Compliance Procedure

2.1 On being satisfied that the final emission values do not exceed the values given in Table 1, Certificate of Compliance shall be issued by the DGCA.

Number of Engines Tested (i)	CO	HC	NO_x	SN
1	0.8147	0.6493	0.8627	0.7769
2	0.8777	0.7685	0.9094	0.8527
3	0.9246	0.8572	0.9441	0.9091
4	0.9347	0.8764	0.9516	0.9213
5	0.9416	0.8894	0.9567	0.9296
6	0.9467	0.8990	0.9605	0.9358
7	0.9506	0.9065	0.9634	0.9405
8	0.9538	0.9126	0.9658	0.9444
9	0.9565	0.9176	0.9677	0.9476
10	0.9587	0.9218	0.9694	0.9502

More than 10

Table 1

3. Procedure in Case of Failure

3.1 In case an engine type fails during certification tests, manufacturer shall be asked to conduct additional tests on the certification engines. The final test results shall then be considered with all previous results. In case of unsatisfactory results, the manufacturer shall be asked to perform engine modification on one or more engines complying with the appropriate airworthiness requirements. The mean of tests on unmodified engines shall be determined for each engine and shall be described as the "unmodified mean".

3.2 The engine(s) may then be modified and at least three tests shall be conducted on the modified engine(s). The mean of these tests shall be described as the "modified mean". This "modified mean" shall be compared to the "unmodified mean" to give a proportional improvement, which shall be applied to the previous certification test result to determine if compliance has been achieved.

3.3 The aforesaid procedure shall be repeated until compliance has been demonstrated or the engine type application is withdrawn by the manufacturer.

APPENDIX 2

Smoke Emission Evaluation

1. Measurement of Smoke Emissions

1.1 Sampling Probe for Smoke Emissions

The sampling probe shall be made up of either stainless steel or other non-reactive materials so as to avoid reaction with the exhaust. In case of multiple sampling, the sample shall be taken within 0.5 nozzle diameters of the engine exhaust nozzle exit plane at minimum 12 locations. The diameters of all these probes shall be same. It shall be ensured that at least 80% of the pressure drop through the probe assembly is taken at the orifices. The applicant shall provide evidence to DGCA that the proposed probe design and position does provide a representative sample for each prescribed thrust settings.

1.2 Sampling line for smoke emissions

The sample shall be transferred from the probe to the sample collection system through a line of 4.0 to 8.5 mm inner diameter with a maximum length not exceeding 25 m. Sampling lines shall be as straight as possible. However, if required the bend shall not have radius more than 10 times the inner diameter of the lines and maintained at a temperature between 60°C and 175°C with a stability of ±15°C. Deposition of particulate matter or static electricity shall not be allowed on sampling lines.

1.3 Smoke Analysis System

The arrangement of the various components of the system for acquiring the necessary stained filter samples is shown in Figure 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%. The pressure and temperature at entry to this meter shall also be measured to accuracies of 0.2% 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. The flowmeter for this purpose shall be able to make this measurement with an accuracy of ±5%.

c) Filter and Holder: The filter holder shall be constructed in corrosion-resistant material. The filter material shall be Whatman type No. 4, or any equivalent material as approved by DGCA.

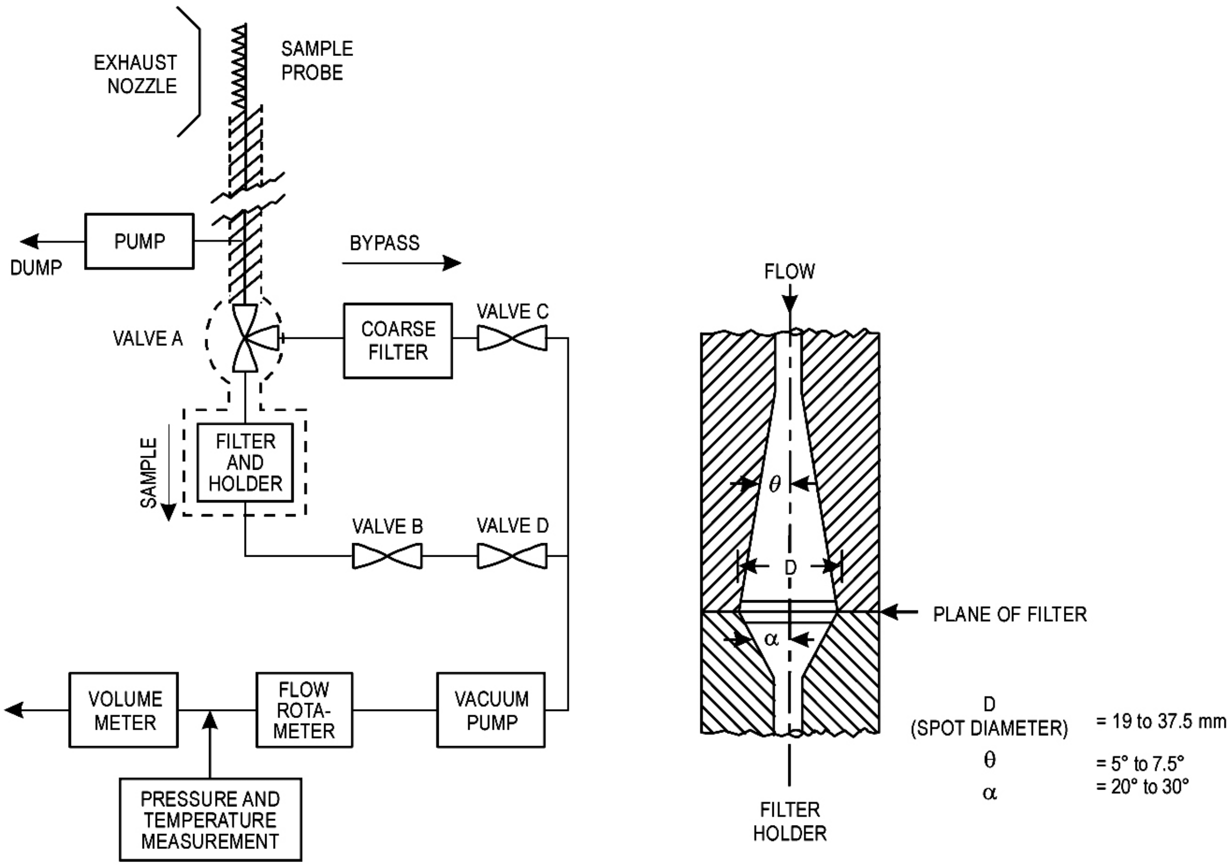

Figure 1

d) Valves: Four valve elements made of corrosion-resistant material shall be provided.

- 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.
- Valves B and C shall be throttling valves used to establish the system flow rate.
- Valve D shall be a shut-off valve to enable the filter holder to be isolated.

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

f) Temperature Control: The analyzer 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, so as to prevent water condensation prior to reaching the filter holder and within it.

g) If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and Valve A so as to dump excess flow. The dump line shall be as close as possible to probe off-take. It shall not affect the ability of the sampling system to maintain the required 80% pressure drop across the probe assembly. The dump flow may also be sent to the CO_2 analyzer or complete emissions analysis system.

h) If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

i) Leak Performance: The subsystem shall meet the requirements of the following test:

- Clean filter material be clamped into the holder.
- Valve A to be shut-off and Valves B, C and D in fully open position.
- Vacuum pump be operated for one minute to reach equilibrium conditions.
- The pump may continue to operate and the volume flow measured through the meter over a period of five minutes. This volume shall not exceed 5 L (referred to normal temperature and pressure). The system shall not be used until this standard has been achieved.

j) Reflectometer: The measurements of the diffuse reflection density of the filter material shall be by an instrument conforming to the international standards meeting ISO 5-41 requirements. 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.

1.4 Smoke Measurement Procedures

1.4.1 Engine Operation

The engine shall be operated on a static test facility, properly equipped for high accuracy performance testing. The tests shall be made by stabilizing the engine at different thrust settings as approved by DGCA. Prior to tests, all sample transfer lines and valves shall be warmed up and the system be checked for any leakage.

1.4.2 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.

2. Calculation of Smoke Number from Measured Data

The stained filter specimens obtained shall be analyzed using a reflectometer. The backing material used shall be black with an absolute reflectance of less than 3%. The absolute reflectance reading R_S of each stained filter shall be used to calculate the reduction in reflectance by $SN' = 100(1 - R_S/R_W)$ where R_W is the absolute reflectance of clean filter material.

The masses of the various samples shall be calculated by $W = 0.348\ PV/T \times 10^{-2}$ (kg), where P and T are the sample pressure (in Pascal) and the temperature (in Kelvin) respectively, measured immediately upstream of the volume meter. V is the measured sample volume (in cubic meters).

For each engine condition, where the sample size 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 reference size value is employed, the reported SN shall be the arithmetic average of the various individual values of SN′.

3. Reporting of Data

For each test, the measured data shall be reported to DGCA along with the following information:

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.

APPENDIX 3

Instrumentation and Measurement Techniques For Gaseous Emissions

1. Introduction

The procedures specified in this Appendix deal with the acquisition of representative exhaust samples and their transmission to the emissions measuring system. The methods proposed are representative of the best readily available and most established practice. Variations in the procedure contained in this Appendix shall only be allowed after prior approval by DGCA.

2. Data Required

2.1 Gaseous Emissions

Concentrations of the following emissions shall be determined:

a) Hydrocarbons (HC)
b) Carbon monoxide (CO)
c) Carbon dioxide (CO_2)
d) Oxides of nitrogen (NO_x) - Nitric oxide (NO) and nitrogen dioxide (NO_2)

2.2 Other Information

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

a) Inlet temperature
b) Inlet humidity
c) Atmospheric pressure
d) Hydrogen/carbon ratio of fuel
e) Other required engine parameters (for example, thrust, rotor speeds, turbine temperatures and gas-generator air flow).

3. 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.

4. General Test Procedures

4.1 Engine Operation

The engine shall be operated on a static test facility, which is suitable and properly equipped for high accuracy performance testing. The emissions tests shall be made at the thrust settings prescribed by DGCA. The engine shall be stabilized at each setting.

4.2 Major Instrument Calibrations

All instruments shall be properly calibrated prior to the tests and the applicant shall ensure that calibrations are valid at the time of the test.

4.3 Operation

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: The system shall be checked for leakage by isolating the probe and the analyzers, 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 0.4 L/min referred to normal temperature and pressure,

b) Cleanliness Check: The gas sampling system shall be isolated from the probe. The end of the sampling line shall be connected to a source of zero gas. The system shall be warmed up to the operational temperature needed to perform hydrocarbon measurements. The sample flow pump shall be operated and the flow rate adjusted to that used during engine emission testing. The hydrocarbon analyzer reading shall not exceed 1% of the engine idle emission level or 1 ppm (both expressed as methane), whichever is the greater.

4.4 Carbon Balance Check

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 within ±15% for the taxi/ground idle mode, and within 10% for all other modes.

5. Calculations

5.1 Gaseous Emissions

5.1.1 General

The analytical measurements made shall be the concentrations of the various gaseous emissions, as detected at their respective analyzers for a range of combustor inlet temperatures (T_B) encompassing the four LTO operating modes. Using these calculations or the alternative methods defined in this Appendix, the measured emissions indices (EI) for each gaseous emission shall be established. To account for deviations from reference atmospheric conditions, the necessary corrections shall be applied. These corrections may also be used to account for deviations of the tested engine from the reference standard engine, where appropriate. 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 appropriate procedures.

5.1.2 Basic Parameters

Where,

and

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 any evidence as to the characterization (x,y) of the exhaust hydrocarbons, the values of x=1 and y=4 may 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 concentration as indicated in this Appendix.

5.1.3 Correction of Emission Indices to Reference Conditions

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. The reference value for humidity shall be taken as 0.00634 kg water/kg dry air.

Thus, EI corrected = K * EI measured, where the generalized expression for K is:

$$K = (P_{Bref}/P_B)^a * (FAR_{ref}/FAR_B)^b * \exp([T_{Bref} - T_B]/c) * \exp(d[h_{mass} - 0.00634])$$

5.1.4 Using the recommended curve fitting technique of Para 5.2 to relate emission indices to combustor inlet temperature effectively eliminates the exp $((T_{Bref} - T_B)/c)$ 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 test results have shown that the humidity term approaches close to unity to be eliminated from the expression and that the exponent of the (P_{Bref}/P_B) term is close to unity.

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 NO_x emission indices shall have the prior approval of DGCA.

5.2 Control Parameter Functions

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 emission:

a) Between EI (corrected) and T_B

b) Between W_f and T_B

c) Between F and T_B

The manufacturer shall supply to DGCA all necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

d) Rated thrust (F_∞)

f) Engine pressure ratio (π) at maximum rated thrust.

The control parameter calculation procedure is shown in Figure 2. The estimation of EI (corrected) for each gaseous emission at four LTO operating modes shall comply with the following general procedure:

a) Determine the combustor inlet temperature (T_B) (Figure 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 2a)), determine the EI_n value corresponding to T_B.

c) From the W_f/T_B characteristic (Figure 2b)), determine the W_{fn} value corresponding to T_B.

d) Note the ISA maximum rated thrust and pressure ratio values. These are F_∞ and π respectively (Figure 2d)).

e) Calculate, for each pollutant $D_p = \Sigma\ (EI_n)\ (Wf_n)\ (t)$, where't' is time in LTO mode (minutes), W_{fn} is fuel mass flow rate (kg/min) and Σ is the summation for the set of modes comprising the reference LTO cycle.

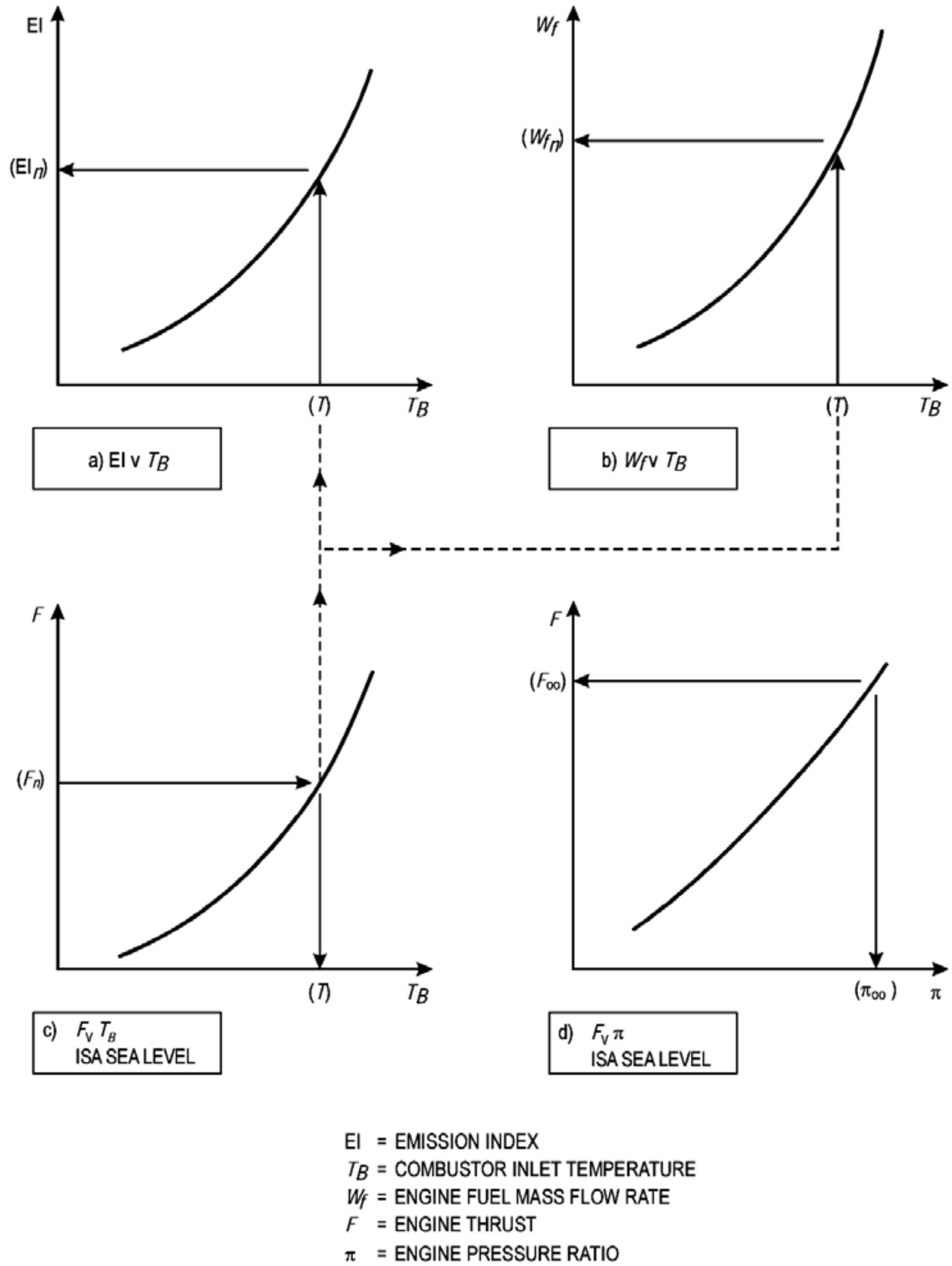

Figure 2

While the methodology described above is a recommended method, DGCA may accept any other equivalent procedures which utilize mathematical modeling.

6.3 Exceptions to the Proposed Procedures

In those cases where the configuration of the engine or other extenuating conditions exist which would prohibit the use of this procedure, DGCA, after receiving satisfactory technical evidence of equivalent results obtained by an alternative procedure, may approve an alternative procedure.

Calibration and Test Gases

Table of Calibration Gases

Analyzer	Gas	Accuracy*
HC	Propane in zero air	± 2% or ± 0.05 ppm **
CO_2	CO2 in zero air	± 2% or ± 100 ppm **
CO	CO in zero air	± 2% or ± 2 ppm *
NO_x	NOx in zero nitrogen	± 2% or ± 1 ppm **
* Taken over the 95% confidence interval ** Whichever is greater		

The above gases are required to carry out the routine calibration of analyzers during normal operation.

Table of Test Gases

Analyzer	Gas	Accuracy*
HC	Propane in 10±1% O_2 balance zero nitrogen	± 1%
HC	Propane in 21±1% O_2 balance zero nitrogen	± 1%
HC	Propylene in zero air	± 1%
HC	Toluene in zero air	± 1%
HC	n-hexane in zero air	± 1%
HC	Propane in zero air	± 1%
CO_2	CO2 in zero air	± 1%
CO_2	CO2 in zero nitrogen	± 1%
CO	CO in zero air	± 1%
NO_x	NO in zero nitrogen	± 1%
* Taken over the 95% confidence interval		

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

Zero gas as specified for the CO, CO_2 and HC analyzers shall be zero air (which includes "artificial" air with 20-22% O_2 blended with N_2). For the NO_x analyzer 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:

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

The applicant shall ensure that commercial gases, as supplied, do in fact meet this specification.

Basis of Calculation of 'EI' and 'AFR' Parameters

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:

$$C_mH_n+P_0[R(O_2)+S(N_2)+T(CO_2)+h_{vol}(H_2O)] = P_1(CO_2)+P_2(N_2)+P_3(O_2)+P_4(H2O)+P_5(CO)+P_6(C_xH_y)+P_7(NO_2)+P_8(NO)$$

from which the required parameters can be expressed as:

Values for fuel hydrocarbon composition (m, n) are assigned by fuel specification or analysis. The mole fractions of the dry air constituents (R, S, T) are normally taken to be the standard values. However, alternative values may be assigned subject to the restriction R+S+T = 1 and approval of the DGCA. The ambient air humidity (h_{vol}) is as measured at each test condition. It is recommended that, in the absence of any evidence as to the characterization (x, y) of the exhaust hydrocarbon, values of x = 1 and y = 4 may be taken.

Determination of the remaining unknowns requires the solution of the following set of linear simultaneous equations, where equations from (1) to (4) are derived from the fundamental atomic conservation relationships and equations from (5) to (9) represent the gaseous product concentration relationships.

$$m + TP_0 = P_1 + P_5 + xP_6 \qquad (1)$$

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

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

$2SP_0 = 2P_2 + P_7 + P_8$ (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 equations is for the case where all measured concentrations are true. 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 interference effects are mainly caused by the presence of CO_2 and H_2O in the sample which can affect the CO and the NO_x analyzers in basically different ways. The CO analyzer is prone to a zero-shifting effect and the NO_x analyzer to a sensitivity change, represented thus:

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

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,

$[CO]_mPT + LP_1 + MP_4 = P_5$ (6A)

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

$[NO]_m\ (PT + L'P_1 + M'P_4) = P_8$ (9A)

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

$[CO_2]_d\ (P_T – P_4)\ (1 + h_d) = P_1$ (5A)

and $[CO]_d\ (P_T – P_4)\ (1 + h_d) = P_5$

However, the CO analyzer may also be subject to interference effects and so the complete alternative CO measurement concentration equation becomes

$$[CO]_{md} (P_i – P_4) (1 + h_d) + LP_1 + M_{hd} (P_T – P_4) = P_5 \qquad (6B)$$

Analytical Formulations

Equations (1) to (10) can be reduced to yield the analytical formulations for the EI and AFR parameters, as given in this appendix. 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 below.

Equation for Conversion of Dry Concentration Measurements to Wet Basis

Concentration wet = K × concentration dry; that is,

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

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

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:

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

Equation for Estimation of Sample Water Content

Water concentration in sample

Where

and

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, given below, avoids this difficulty.

Alternative Methodology – Numerical Solution

As an alternative to the analytical procedures, 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.

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.

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.

Specification for Additional Data

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 intake 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% of reading,

c) Atmospheric pressure: measured within one 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%,

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% at take-off power and ±5% 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%,
iii. Gas generator airflow: determined to an accuracy of ±2% by reference to engine performance calibration.

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

Symbols

Following symbols are used in this CAR:

CO	Carbon monoxide
CO_2	Carbon dioxide
[CO]	Mean concentration of CO vol/vol, wet
$[CO_2]$	Mean concentration of CO_2 vol/vol, wet
D_p	The mass of any gaseous pollutant emitted during the reference emissions landing and take-off cycle
F_n	Thrust in International Standard Atmosphere (ISA), sea level conditions, for the given operating mode and Thrust at LTO operating mode, n, (kN)
F_∞	Rated thrust
FAR_B	Fuel/air ratio in the combustor
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).
h_{vol}	Humidity of ambient air, vol water/vol dry air
h_{mass}	Ambient air humidity, kg water/kg dry air
h_d	Humidity of exhaust sample leaving "drier" or "cold trap", vol water/vol dry sample
HC	Unburned hydrocarbons
[HC] carbon	Mean concentration of exhaust hydrocarbons vol/vol, expressed as
m	Number of C atoms in characteristic fuel molecule
M_{AIR}	Molecular mass of dry air = 28.966 g or, where appropriate, = (32 R + 28.156 4 S + 44.011 T) g
M_{HC}	Molecular mass of exhaust hydrocarbons, taken as CH_4 = 16.043 g

M_{CO} Molecular mass of CO = 28.011 g

M_{NO2} 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

NO Nitric oxide

NO_2 Nitrogen dioxide

NO_x Oxides of nitrogen

$[NO_2]$ Mean concentration of NO_x vol/vol, wet = $[NO + NO_2]$

[NO] Mean concentration of NO in exhaust sample, vol/vol, wet

$[NO_x]_c$ Mean concentration of NO in exhaust sample after passing through the NO_2/NO converter, vol/vol, wet

n Number of H atoms in characteristic fuel molecule

P_B Combustor inlet pressure, measured

P_{ref} ISA sea level pressure

P_{Bref} Pressure at the combustor inlet of the engine tested (or the reference engine if the data is corrected to a reference engine) associated with TB under ISA sea level conditions.

P_T P1 + P2 + P3 + P4 + P5 + P6 + P7 + P8

R Concentration of O_2 in dry air, by volume = 0.209 5 normally

SN Smoke Number

S Concentration of N_2 + rare gases in dry air, by volume = 0.709 2 normally

T Concentration of CO_2 in dry air, by volume = 0.000 3 normally

T_B Combustor inlet temperature, measured

T_{ref} ISA sea level temperature

T_{Bref}	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
A,b,c,d	Specific constants which may vary for each pollutant and each engine type
x	Number of C atoms in characteristic exhaust hydrocarbon molecule
y	Number of H atoms in characteristic exhaust hydrocarbon molecule
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, n.
π_∞	Reference pressure ratio
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.
η	Efficiency of NO_2/NO converter

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